Syntactic Priming as a Window into the Representational and Experiential Basis of Syntactic Processing in Comprehension

Eunice Gomes Fernandes

Orientador(es): Prof. Doutora Maria Armanda Martins da Costa
                  Prof. Doutora Holly Parima Branigan
                  Prof. Doutor Moreno Ignazio Coco

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Júri:
Presidente: Doutor João Miguel Biscaia Valadas Branquinho
Vogais:
Doutor João Miguel Marques da Costa
Doutora Maria Pilar Pereira Barbosa
Doutora Ana Luísa Nunes Raposo
Doutora Maria Armanda Martins Costa

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ABSTRACT

This thesis investigates syntactic processing during comprehension in its representational and experiential components, i.e., the mental linguistic representations we access and the way we use them when we comprehend sentences. Our main claim is that syntactic priming is a behavioural tool that can give important insights into both syntactic knowledge and performance.

Syntactic priming, the tendency of speakers to repeat syntactic structure across otherwise unrelated utterances, was shown to be well suited to investigate the mental representation of verbs by Pickering and Branigan (1998), who showed that speakers repeated the previously processed variant of an alternation verb. They proposed the two possible argument structures had different representations at the syntactic level of its lexical entry, and that syntactic priming results from residual and transient activation of those representations.

Substantial research produced corroborating evidence of such effects, typically assessed within-trial, i.e., in adjacent sentences. More recently, however, intriguing results showed that the magnitude of the effects was also a function of how much the alternative syntactic structures were experienced, for example, during an experiment. Jaeger and Snider (2007, 2013) demonstrated that priming was stronger in two apparent contradictory circumstances: participants were more likely to repeat a structure the more they had experienced it (cumulativity) but also the less that structure was expected (surprisal). The results support implicit learning accounts of priming. Explanations of syntactic priming remain under debate.

In a series of experiments, we give new insights concerning both syntactic representations and the mechanisms associated with experiencing syntactic structures.

In two self-paced reading experiments (Chapter 3) we test sentences containing locative alternation verbs, for which linguistics has provided solid, but contrastive, theories of lexical representation. Contrastingly, to our knowledge, it has not been tested in more than one syntactic priming study (Chang, Bock, and Goldberg, 2003). We demonstrate that the two variants of this syntactic alternation do not elicit the same magnitude of priming. Our results provide supporting evidence for theories postulating different lexical representations of the variants (e.g., Rappaport & Levin, 1988), and seem to contradict theories of a unique and similar representation (e.g., Borer, 2005). They contrast with previous research findings (Chang et al., 2003) and suggest frequency issues must be considered when investigating representations through experimental tasks.
We test how the relative amount of experience with alternative syntactic structures affects syntactic priming in a visual-world paradigm task, where spoken sentences are understood situated in a visual context (Chapter 4). Here, we analyse anticipatory eye-movements to entities depicting possible arguments of a verb (e.g., Arai, van Gompel, & Scheepers, 2007), which index the comprehenders’ expectations about forthcoming linguistic input of the spoken sentence. We test how temporary ambiguity of relative clauses (RCs) (that can high- (HA) or low-attach (LA) to a complex NP, e.g., The father of the baby who will drink the beer / the baby bottle is tall) is resolved when participants are presented previously with sentences containing disambiguated HA or LA RCs. Our original manipulation is, however, of the amount of priming received within a trial: participants can be presented with one or two written primes before they receive the target. This design is intended to test the dynamics of priming at a short-term, departing from previous research that tested the dynamics of the effects along longer-term timeframes such as an experience. We report classical priming effects in the condition where participants are presented with a single prime. However, we find surprising effects of reversed priming when participants are exposed to two primes. That is, after experiencing two sentences with the same attachment type (e.g., LA), participants anticipate the alternative, non-primed type (HA). We speculate that one possible explanation of our findings is repetition suppression, the reduced neural activity upon stimuli repetition (Grill-Spector, Henson, & Martin, 2006). These results challenge the assumption of a positive and linear relationship between the amount of (short-term) experience and the strength of priming effects, and provide new evidence concerning short-term activation mechanisms underlying priming.

We further explore the cognitive complexity underneath RCs’ processing by examining (Chapter 5) the relation between reading, viewing and working memory (WM) in the data collected in Chapter 4 (restricted to the condition where participants were presented with two primes). Here, we investigate pronoun resolution as indexed by looks, while hearing the pronoun who in The father of the baby who will drink…, to the depicted possible pronoun antecedents (e.g., to the FATHER (S1) under a HA interpretation). We predict fixations to S1 as a function of: i) second-pass reading time observed during reading the NP1 region in the prime sentences (e.g., LA, The helpers in The helpers of the baker who will [SG]…), and ii) individual WM scores. We demonstrate that high-capacity individuals anticipate more the (non-primed) visual referent when they reread more the corresponding NP (e.g., anticipate the visual referent FATHER when reread more often NP1, the helpers). We suggest that WM capacity allows individuals to maintain alternative syntactic analyses of the sentences while reading, and evaluate them upon a subsequent visual context. These findings provide support to constraint-based models of sentence processing (e.g., Just & Carpenter, 1992), and provide, for the first time, linking
evidences of online measures during reading and online measures of subsequent image viewing (indexing the transfer of information from reading to viewing) and its mediation by working memory.

Overall, this thesis reunites the fundamental questions of linguistic competence and performance through syntactic priming research. It highlights the potential of this research tool by providing new evidence relevant for both the old theoretical puzzle of argument realization and the topic of the cognitive mechanisms involved in language processing, of broad and current interest.

Key-words

Syntactic priming, locative alternation, ambiguity resolution, lexical representations, sentence processing.
RESUMO

Esta dissertação investiga o processamento sintáctico nas suas componentes representacional e experiencial, i.e., quanto às representações linguísticas mentais a que acedemos e ao modo como usamos essas representações quando compreendemos frases. A nossa principal conclusão é de que o priming sintáctico é uma ferramenta que pode dar importante evidência empírica no que respeita ao conhecimento e à performance sintáctica.

O priming sintáctico é frequentemente descrito como a tendência dos falantes para repetir uma estrutura sintáctica entre enunciados que não são de outro modo relacionados. Naquele que é tido como o trabalho inaugural da investigação em priming sintáctico, Bock (1986) pediu aos participantes para descrever imagens (e.g., de uma mulher a ler um livro e um rapaz) depois de terem produzido determinadas frases. O principal resultado mostrou que os participantes descreviam a imagem (TARGET) usando a frase The woman reads a book to the boy com maior probabilidade quando tinham previamente produzido uma frase (PRIME) como The man gives a bone to the dog, em comparação com a produção prévia da alternativa sintáctica com o mesmo significado The man gives the dog a bone.

Pickering e Branigan (1998), que também testaram a alternância dativa em Inglês, propuseram que as duas subcategorizações possíveis de um verbo como give teriam representações diferentes, codificadas no nível sintáctico da entrada lexical do verbo. Por essa razão, o priming sintáctico mostrava-se adequado para investigar as representações mentais dos verbos. Os autores também avançaram uma explicação para o priming sintáctico como resultando de uma activação transiente e residual dessas representações.

Nos últimos trinta anos, um largo conjunto de estudos produziu evidência empírica de efeitos de priming sintáctico, que são, tipicamente, identificados within-trial, ou seja, dentro de cada item experimental, reflectindo a influência do processamento de uma frase no processamento da frase seguinte. Mais recentemente, contudo, esta área de investigação alargou o seu espectro em resultado da demonstração de efeitos surpreendentes que mostravam que a magnitude dos efeitos era também função do quanto as estruturas sintácticas testadas eram processadas, por exemplo, ao longo de uma experiência. Jaeger e Snider (2007, 2013), por exemplo, demonstraram que o priming sintáctico era mais forte em duas circunstâncias aparenmente contraditórias: os participantes produziam com maior probabilidade uma estrutura sintáctica quanto mais essa estrutura tinha sido experienciada (cumulativity) mas também quanto menos essa estrutura era expectável (surprisal). Os autores propuseram, com base na explicação do
priming sintáctico como um fenômeno de aprendizagem implícita (Chang, Dell, & Bock, 2006) que o processador da linguagem se adapta constantemente às estatísticas do ambiente sintáctico em que está inserido, adaptando as suas expectativas (expectation-adaptation). Vários estudos subsequentes focaram-se no tópico dos mecanismos cognitivos subjacentes ao priming sintáctico. Contudo, não há, neste momento, um modelo único capaz de dar conta de todo o padrão de resultados conhecidos.

Nesta dissertação, contribuímos com nova evidência empírica relevante quer para a questão das representações sintácticas, quer para a questão dos mecanismos associados à experiência das estruturas sintácticas. Focamo-nos na compreensão, uma modalidade de processamento que se considera elicitar efeitos de priming mais fracos.

Testamos primeiramente (Capítulo 3) frases com verbos de alternância locativa, para a qual a teoria linguística propôs teorias de representação lexical sólidas, mas contrastantes. Pelo contrário, tanto quanto sabemos, esta alternância foi testada apenas num estudo de priming sintáctico (Chang, Bock, & Goldberg, 2003). Demonstramos que as duas variantes da alternância locativa, Locativo-Tema (LT) e Tema-Locativo (TL) (e.g., carregar o tractor com o feno vs. o feno no tractor) não elicitam a mesma magnitude de priming. Designadamente, os participantes leem (leitura auto-monitorada) mais rapidamente (em comparação com um nível de referência) qualquer das variantes quando previamente leram uma frase LT, mas a leitura é mais lenta após frases TL. Estes resultados dão suporte a teorias que postulam uma representação da variante LT mais complexa que (e incluindo o significado de) a representação da variante TL (e.g., Rappaport & Levin, 1988). Da mesma maneira, a evidência é contrária a teorias que consideram uma única representação estrutural (e.g., Borer, 2005).

Contudo, também mostramos que verbos diferentes apresentam diferentes preferências por uma ou outra variante, e que questões de processamento devem ser consideradas. Concretamente, os resultados mostram que um tipo de prime que é menos expectável (porque foi menos experienciado do que o tipo alternativo, em cada momento da experiência) facilita mais um target to mesmo tipo. Assim, contribuímos com evidência que corrobora efeitos de surprisal previamente descritos. Significativamente, demonstramos que estes efeitos podem ser detectados no ambiente sintáctico de uma experiência em que a probabilidade geral relativa de ocorrência de cada variante é igual. Pelo contrário, estudos anteriores mostraram efeitos de surprisal em experiências que enviesavam a probabilidade de ocorrência das estruturas, favorecendo uma ou outra.

Investigamos mais em detalhe como experienciar as alternativas sintácticas afecta o priming sintáctico no Capítulo 4. Aqui, usamos o paradigma de visual-world, onde a compreensão de frases faladas é situada num contexto visual. Analisamos movimentos oculares antecipatórios para entidades visuais que correspondem aos argumentos possíveis de um verbo (e.g., Arai, van Gompel, & Scheepers, 2007), que são tidos como
indicadores das expectativas que o participante tem acerca do que vai ouvir, a cada momento em que a frase oral vai sendo apresentada. Testamos como a ambiguidade temporária de frases relativas (RCs) (que podem ser ligadas ao primeiro (high-attachment, HA) ou segundo (low-attachment, LA) NP dum NP complexo, e.g., O pai do bebé que vai beber a cerveja / o biberão é alto) é resolvida quando os participantes processam previamente frases que contêm RCs desambiguadas para HA ou LA (e.g., HA, O ajudante [SG] dos padeiros [PL] que vai [SG]…). O contexto visual, apresentando as entidades PAI, BEBÉ, CERVEJA e BIBERÃO, permite analisar predições, ao ouvir vai beber, dos argumentos (pragmaticamente) consistentes com uma interpretação HA ou LA (i.e., olhares para CERVEJA indicam HA e olhares para BIBERÃO indiciam LA).

A nossa manipulação experimental de interesse é, contudo, a quantidade de primes processados: os participantes podem ler uma ou duas frases escritas como primes, antes de lhes ser apresentado o target. Este desenho experimental pretende testar as dinâmicas de priming no curto prazo de um item experimental, quando os estudos anteriores, como mencionado, mostraram efeitos dinâmicos em espaços temporais mais alargados, como o de uma experiência. Para além disso, há indícios, na literatura de priming lexical, de que o priming pode resultar num efeito contrário, em que os participantes escolhem uma palavra não primada quando são expostos durante mais tempo a uma palavra prime.

Apresentamos efeitos de priming ‘clássicos’ na condição de uma frase prime (e.g., olhares para CERVEJA – uma interpretação HA – depois de ter lido uma frase HA). Contudo, encontramos efeitos surpreendentes de reversed priming quando os participantes foram expostos a dois primes. Ou seja, depois de experimentar duas frases com o mesmo tipo de ligação (e.g., LA), os participantes antecipam a ligação alternativa (HA). Sugerimos que uma possível explicação destes resultados faz referência ao fenómeno de repetition suppression, a redução de actividade neuronal observada quando há repetição de um estímulo (Grill-Spector, Henson, & Martin, 2006). Estes resultados são inovadores e importantes para a investigação sobre os mecanismos subjacentes ao priming sintáctico, já que mostram um efeito não reportado anteriormente. Para além disso, põem em questão o pressuposto geralmente aceite de uma relação positiva e linear entre a exposição (no curto-prazo) a um prime e a força dos efeitos de priming.

A complexidade do processamento de RCs é explorada ainda no Capítulo 5, onde investigamos a relação entre leitura, visualização de imagens e memória de trabalho (WM). Analisamos a condição da Experiência 3 (Capítulo 4) em que os participantes processavam dois primes antes to target. Neste caso, focamo-nos na resolução do pronomé, cujo indicador são os olhares, quando o participante ouve o pronome que em O pai do bebé que vai beber a cerveja / o biberão..., para os possíveis antecedentes presentes na imagem (i.e., para PAI (S1) numa interpretação HA e para BEBÉ (S2) numa interpretação LA). O nossa regressão linear prediz fixações em S1 e S2 em função de: i)
tempo de re-leitura nas regiões NP1 e NP2 das frases prime (e.g., LA, NP1, Os ajudantes em Os ajudantes do padeiro que vai…); e ii) valores individuais de memória de trabalho. Demonstamos que indivíduos com alta capacidade de memória antecipam mais o referente visual não-primado quando lêem mais o NP a ele associado (e.g., antecipam PAI quando lêem mais o NP1 Os ajudantes). Propomos que a capacidade de WM permite aos indivíduos construir e manter em memória análises sintáticas alternativas da frase lida, bem como considerar essas alternativas num contexto visual subsequente. Estes resultados dão suporte a teorias de processamento paralelo (e.g., Just & Carpenter, 1992), e revelam os mecanismos cognitivos partilhados que ligam leitura, visualização de imagens e memória. Realçamos, também, que este estudo oferece, pela primeira vez, evidência da relação entre medidas de leitura online e medidas do processamento incremental situado num contexto visual.

Em resumo, esta dissertação reúne as questões fundamentais da competência e performance linguísticas, através do priming sintático. Ela realça o potencial desta ferramenta de investigação ao oferecer novos e relevantes dados no que respeita quer ao puzzle teórico da realização argumental quer ao tópico dos mecanismos cognitivos envolvidos no processamento da linguagem.

**Palavras-chave**

Priming sintático, alternância locativa, resolução de ambiguidade, representação lexical, processamento de frases.
ACKNOWLEDGEMENT

Liberdade
- Liberdade, que estais no céu...
Rezava o padre-nosso que sabia,
A pedir-te, humildemente,
O pio de cada dia.
Mas a tua bondade omnipotente
Nem me ouvia.

- Liberdade, que estais na terra...
E a minha voz crescia
De emoção.
Mas um silêncio triste sepultava
A fé que ressuscitava
Da oração.

Até que um dia, corajosamente,
Olhei noutro sentido, e pude, deslumbrado,
Saborear, enfim,
O pão da minha fome.
- Liberdade, que estais em mim,
Santificado seja o vosso nome.

Miguel Torga, in Diário XII, Albufeira, 28 de Agosto de 1975

A liberdade é uma vocação do amor (Miguel Torga, in O Paraíso)

A minha profunda gratidão à Maria do Céu; o seu amor alimentou em mim a coragem que me trouxe até este lugar de liberdade.
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Introduction

Back in the late 50’s of the twentieth century, Chomsky’s linguistic theory outlined the questions that formed the basis of the generative grammar program: the study of language should investigate what constitutes the knowledge of language and how is that knowledge put to use (Chomsky, 1957, 1959; see also Chomsky & Lasnik, 1993). The program fitted well one foundational assumption of the emerging cognitive sciences: the mind/brain could be better understood in terms of an information processing system which operates over stored information-bearing symbolic units, the mental representations.

Chomskyan and other linguistic theories continued to set as a general goal of linguistics to describe both speakers’ stored knowledge (competence) and the processes by which that knowledge is used (performance). However, in spite of acknowledging that the psychological reality of theoretical constructs should be validated by behavioural evidence (Miller & Chomsky, 1963), the proposed theories have been shown to be difficult to test (e.g., Garnham, 1983). This made theoretical linguists to progressively distance from the growing body of psycholinguistics’ research.

Indeed, psycholinguistics as a science was developing, by that time, by engaging in research using experimental methods from cognitive psychology. It was also influenced by work on other areas such as artificial intelligence, which inspired models of processing and of linguistic representation, and acknowledged the importance of general cognitive principles in language, enlarging the scope of its research. Relying on empirical evidence gathered through tasks where language users’ performance can be assessed, it
has concentrated more on performance than on competence (with language processing theories being proposed since the 1980’s, e.g., Frazier, 1987). These aspects made the two disciplines develop in different directions (Garnham, Garrod, & Sanford, 2006).

We believe psycholinguistic research can inform both on the performance and the competence questions. Priming, in particular, is a suitable tool to investigate linguistic representations and processes. Priming refers to the facilitated processing of a stimulus following processing of another stimulus, and syntactic priming is the facilitated processing of a syntactic structure in a sentence resulting from the previous processing of a sentence with a similar structure. Since long, syntactic priming tasks were used to investigate linguistic representation, the rationale being that, if one structure influences processing of another structure, both shall be related in some relevant way (e.g., Branigan, Pickering, Liversedge, Stewart, & Urbach, 1995). It has, since then, been extensively investigated, and has inspired models of production and comprehension processes (e.g., Pickering & Garrod, 2004). Moreover, recent research has focused on the underlying cognitive mechanisms of the phenomenon (e.g., Chang, Dell, & Bock, 2006; Jaeger & Snider, 2013), making it a good place to look at the interaction between linguistic knowledge/processes and other relevant cognitive functions.

It is still a challenge for psycholinguistics today (and, more broadly, to cognitive science) the characterization of both linguistic knowledge and the way in which it is used (along with non-linguistic knowledge) in language processing. In this thesis, we show how syntactic priming remains a promising way to address these research questions. By investigating syntactic priming of structures for which theoretical linguists have proposed different representations, we show that priming can tap into linguistic knowledge itself and provide evidence in favour of particular theories; By exploring the dynamics of the effects and, in particular, its modulation by the number of primes preceding a target, we provide novel evidence concerning the experiential basis of syntactic processing, which are relevant to the debate on syntactic priming mechanisms; By testing the influence of working memory on a syntactic priming task, we shed new light on how it interacts with other functions of the cognitive system.
Overview of the thesis and contributions

In Chapter 1, we provide the relevant theoretical background motivating our experiments. We first present the key findings of syntactic priming research, which has been an important topic in psycholinguistics over the past thirty years.

Then, we focus on one particular syntactic alternation we will test and in the theoretical linguistics’ proposals of its lexical representation: we contrast Rappaport and Levin (1988)’s and Borer (2005)’s approaches to the locative alternation (e.g., The farmer loaded the hay onto the truck – locative variant, vs. The farmer loaded the truck with the hay – with variant). The first is a projectionist theory that postulates two lexical entries for the verb load. The second instantiates a constructional approach and takes both variants to have the same underlying structure, where lexemes are freely inserted. We also present the psycholinguistics evidence of verbs’ alternations processing in a syntactic priming paradigm. These are the topics concerning our study about linguistic representations, presented in Chapter 3.

In the remainder of Chapter 1, we look at syntactic priming as a language processing phenomenon. We review current models of syntactic priming and show how there is not, yet, a unifying account of the whole pattern of effects. We then focus on ambiguity resolution during comprehension, whereby we will investigate the experiential basis of syntactic processing, in Chapter 4. We end the Chapter by presenting the topic of working memory and how it may be involved in syntactic priming. This topic will be investigated in Chapter 5.
In Chapter 2, we present our methodology of investigation (moving-window self-paced reading, eye-tracking and visual world paradigm), as well as the used inferential analyses methods (LMEMs, length-residualized times, Growth-curve analyses).

In Chapter 3 (Experiments 1–2), we investigate syntactic priming during comprehension (self-paced reading) of sentences with locative alternation verbs. We demonstrate that participants read faster the Location-Theme variant sentences when they previously processed another Location-Theme variant sentence (compared to a baseline), and, conversely, read faster Theme-Location targets after Theme-Location primes. These results provide evidence of priming of non-ambiguous sentences in comprehension, in line with evidence of previous studies in production (Chang, Bock, & Goldberg, 2003). More importantly, our results suggest that, overall, the Location-Theme variant facilitates both types of subsequent targets, while the Theme-Location variant makes them more difficult. This result supports theoretical proposals for the representation of this alternation like Rappaport and Levin (1988)’s, which assume representations of different complexity for each of the variants. Through these findings, we demonstrate that such a syntactic priming task can be used to distinguish between existing theories about syntactic representations in the Lexicon. We note, however, that the relative amount of the variants experienced along the experiments modulates the effects. Accordingly, we argue that the experiential basis of syntactic processing shall be taken into consideration when investigating syntactic representations.

In Chapter 4 (Experiments 3–4), we investigate syntactic priming of temporary ambiguous relative clauses (RCs) such as The father of the baby who will drink the beer is tall. We are concerned, here, with how ambiguity resolution can be a function of previous processing in an experimental trial. There is evidence for priming of ambiguity resolution, whereby comprehenders tend to adopt the same interpretation they did in an immediately preceding sentence (prime). However, recent research using other syntactic constructions has reported apparent contradictory long-term priming effects, i.e., effects that occur along the experimental session. For example, Jaeger and Snider (2013) showed that accumulated presentation (along an experiment) of a particular structure produces stronger priming (cumulativity), but stronger priming was also found after primes that were less presented (surprisal). Our study differs from previous research in that we test how the amount of priming modulates the effects at a short-term, i.e., within a trial. By manipulating the number of prime sentences (1 vs. 2), we assess how the priming magnitude varies upon prime repetition. We employ a visual-world methodology, where sentence understanding occurs situated in a visual context, and incremental language processing is revealed by predictions of upcoming linguistic material, indexed by eye-movements to their respective depicted referents. We find that comprehenders make predictions congruent with the interpretation made at the prime, when they previously
processed one prime sentence. However, the reverse pattern occurs after two primes (i.e., participants make the alternative interpretation to the primed interpretation). This result is novel and surprising; building on evidence of similar effects in lexical priming, we hypothesize that repetition suppression (the reduced neural activity due to stimuli repetition) can underlie the effects. We discuss the relevance of the findings for current models of priming, and suggest that the hypothesis of short-term suppression of activation shall be further investigated. These experiments are reported in a paper to be submitted to the *Journal of Experimental Psychology: Learning, Memory and Cognition* (Fernandes, Coco, & Branigan, 2015).

In Chapter 5, we report analyses made on a subset of data of Experiment 3. We investigate how online reading measures at the prime RCs correlate with fixations in the subsequent visual context, and how both variables are modulated by individual scores of working memory (WM). We predict fixations upon hearing the RC pronoun (indexing pronoun resolution at targets) as a function of: (i) re-reading time on the pronoun antecedents at primes, and (ii) individual WM scores. We demonstrate that high-capacity individuals anticipate more the visual referent consistent with the non-primed (alternative) attachment interpretation when they reread more its associated antecedent NP. We suggest that WM allows individuals to maintain alternative syntactic analyses and evaluate them upon a subsequent visual context. These findings give support to parallel processing theories like the *constraint-capacity theory* (Just & Carpenter, 1992) and provide, for the first time, linking evidences between online reading measures of sentences and online measures of their incremental processing when situated in a visual context. This study was accepted in *EuroAsianPacific Joint Conference on Cognitive Science 2015* as an oral presentation and publication in full text in the Proceedings of the conference (Fernandes, Costa, & Coco, in press).

Finally, in Chapter 6, we present a summary of our findings, integrated in the current theories of language processing and structural priming, and suggest future research directions.
1. Background

1.1. Syntactic priming, mental representations and language processing modalities

Syntactic (or structural) priming is the tendency to reuse the syntactic structure of a previously experienced sentence. Bock (1986) found a tendency of speakers to describe a (target) picture using the type of sentence (e.g., active vs. passive) presented before (prime). Since her seminal work, many studies have investigated how that syntactic persistence could index the similarity of the stimuli at prime and target.

Pickering and Branigan (1998), for example, tested dative alternation verbs, i.e., ditransitive verbs that can select as their arguments either an NP_PP sequence (prepositional object (PO): e.g., give a bone to the dog) or an NP_NP sequence (double object (DO): e.g., give the dog a bone). In a written completion task, participants first completed prime fragments like (1a–b), where the post verbal noun phrase could induce either a PO (1a) or a DO (1b) completion. At the subsequent target (1c), participants could felicitously choose either a PO or DO construction. The verb in the prime fragments was manipulated so that it could be the same (e.g., showed) or differ from (e.g., gave) the verb in the target.

(1) (a) The racing driver gave/showed the torn overall . . .  PO inducing prime
(b) The racing driver gave/showed the helpful mechanic . . . DO inducing prime
(c) The patient showed . . . Target

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The results showed that participants produced more target sentences of the type of the sentence previously completed (prime) than of the alternative type. That is, the probability of using a DO structure at the target was higher after DO prime completions, compared to PO prime completions (and correspondingly, there was a tendency to repeat PO structures at targets following PO primes). The effects occurred even when there was no verb overlap between prime and target, although they were stronger if there was lexical repetition (a phenomenon termed *lexical boost*).

Pickering and Branigan proposed that, considering lexical entries are represented as nodes within a network, a verb’s lemma node is connected to other nodes encoding syntactic information about its possible combinations of arguments, its combinatorial nodes. For example, the verb *show* would be represented by a node identifying this particular lemma, and it would be linked to two combinatorial nodes representing its PO and DO possible argument structures. When processing a sentence with the verb *show* and a DO structure, the node DO would become activated. Assuming nodes retain residual activation following use, that node would be at an advantage to be selected when the processor further encounters the verb *show*, for which that construction is possible. Moreover, the combinatorial nodes are shared between different verbs that can occur with the same argument structure (e.g., *give* and *show*). Therefore, even when further encountering the verb *give*, the DO node to which it is linked would also have an activation advantage. The lexical boost would be explained by the additional activation of the node identifying the particular verb that is, in the first case, repeated (see 1.4.1 for details).

This and further studies suggested that verbs should have a mental representation where subcategorization information is encoded and, moreover, that this information is, at least in part, independent from the particular lemmas to which it is linked. As noted by Pickering and Ferreira (2008), evidence from such studies supports the claim that syntactic knowledge is representationally independent of lexical knowledge, although its use can arguably be influenced by ongoing lexical processing.

Further studies have continued to investigate structural priming in production tasks, aiming to better understand how we mentally represent syntactic structures. The basic assumption is that some cognitive mechanism underlies priming whereby syntactic representations generated at the prime trial are more easily accessed again later (either because they remained activated in memory or because their status relative to alternative constructions has been strengthened), making them a more probable choice for the processor (parser).

However, not many studies, until more recently, have investigated these effects in comprehension. This may be because production involves critical structural choices (e.g., should the speaker produce an active or a passive?) in the same way it involves choices
about which words to use (Pickering & Ferreira, 2008). This is not what happens when we comprehend a sentence, exception made for understanding structural ambiguities, which may well be the reason why most studies in comprehension used ambiguous sentences as stimuli. Branigan, Pickering, and McLean (2005), for example, tested the interpretation of prepositional phrases (PPs) such as with the gun in The policeman prodding the doctor with the gun, where the PP is ambiguous between high (to the policeman) and low (to the doctor) attachment. In a picture-expression matching task, participants first read a sentence followed by two pictures, only one of them corresponding to one of the possible interpretations, and the other to neither interpretation. That is, at prime trials, the prime expression was disambiguated by the pictures. Then, at target trials, they were presented with another ambiguous sentence (e.g., The waitress prodding the clown with the umbrella), this time followed by two pictures corresponding to the two possible interpretations. Therefore, by choosing one of the pictures to match with the sentence, participants would choose one of the possible interpretations. The results showed that participants tended to interpret the target PP in the same way they had interpreted the PP at the prime. This priming effect, however, was not found when the target sentences did not share the verb with the primes (e.g., prime: The policeman thumping the soldier with the gun; target: The waitress prodding the clown with the umbrella).

Further experiments found similar effects of priming for ambiguous sentences during comprehension only when the verb was repeated (Traxler & Tooley, 2008; Tooley, Traxler, & Swaab, 2009; though see Kim, Carbary, & Tanenhaus, 2014; Pickering, McLean, & Branigan, 2013). These results have been taken to reflect that language production and comprehension may rely on different cognitive mechanisms that can make syntactic priming in comprehension limited to cases where there is ambiguity (Pickering & Ferreira, 2008). Additionally, it seems that structural priming effects in both production and comprehension tend to have small effect sizes (Tooley & Traxler, 2010), and these may be harder to detect in online measures of processing like reading times. An alternative explanation for the divergent effects in the two modalities is that lexically dependent and independent syntactic priming effects may be caused by different underlying mechanisms, and that comprehension and production rely differently on each mechanism (Tooley & Traxler, 2010). We will return to this issue in section 1.3.2.

This brings us back to the link between representations of linguistic knowledge and processes whereby that knowledge is used, and it highlights that syntactic priming is a suitable paradigm to address it. Indeed, two aspects remain central in syntactic priming research: its lexical (in)dependency and its underlying cognitive mechanisms. The first is relevant for a better understanding of how syntax and the lexicon are represented; the second is increasingly providing relevant evidence of how syntax (and language) is
processed. In 2010, Tooley and Traxler suggested further research should test: i) syntactic structures other than the more commonly used; ii) the different mechanistic accounts; and iii) the time courses of both lexically dependent and independent effects. Recent work has followed this suggestion, but there is not, yet, the desired parsimonious model of syntactic priming.

1.2. Representational basis of syntactic processing

In the previous section, we saw how syntactic priming has been used to study the representation and the processing of language. Concerning representations, a relevant proposal is the one made by Pickering and Branigan (1998) for verbs: the node of a verb (e.g., give) is linked to nodes representing its combinatorial information, i.e., all possible sets of the number and type of arguments with which the verb can occur (say, NP_PP and NP_NP). The hypothesis of such representations is supported by syntactic priming evidence: if processing one sentence like John gave a bone to the dog (with an NP_PP structure) facilitates the processing of a syntactically similar (but lexically and semantically different) sentence, as Paul sent the letter to his brother, we can infer that the system recognizes the relation between the two, i.e., the structure NP_PP.

The representation of verbs’ combinatorial information in our mental lexicon has always been a topic in theoretical linguistics, as reflected in the old debate about argument realization, i.e., the study of the possible syntactic expressions of the arguments of a verb (Levin & Rappaport Hovav, 2005). In this section, we review the relevant linguistics’ literature, and focus on the particular case of the locative alternation. We do so because we have chosen to use this not usually tested syntactic structure in a syntactic priming task (Chapter 3). We present the major proposals that were made by theoretical linguists on the basis of nonbehavioural measures, which, we believe, can be tested experimentally. We also present (1.2.2) studies showing that syntactic processing of alternations, namely in priming tasks, can be modulated by the frequency of occurrence of the alternatives.

In Generative Grammar frameworks, the Standard Theory (Chomsky, 1965) predicted that a lexical entry specifies not only phonetic and semantic aspects (dictionary definition) but also the relevant properties for application of transformational rules and information about the positions in which the items can occur. Concerning the last one, verbs would be specified with strict subcategorization features, defining the number and syntactic category of sister constituents, and selectional features, determining the semantic properties of subcategorized constituents. The proposed selectional features (e.g., [± Animate], [± Human]) were not, however, sufficiently specific to avoid over-generation by the base component and transformational rules that had an over-
dimensioned descriptive power. That is to say, lexical specifications were too poor and grammatical rules were too rich to restrict the system output to grammatical sentences.

After Chomsky (1970)’s paper on nominalization, the descriptive power was somehow transferred from syntax to the lexicon. The so-called lexicalist hypothesis would remain as a main assumption in further work on generative grammar: the categorical component of the grammar was diminished and lexical structure assumed a more central role in syntactic description. The lexical entry for a predicator, for instance a verb, specifies the number and type of the arguments that predicator can take. The systematic linking between lexical representation and surface syntactic form is expressed in Chomsky (1981)’s Projection Principle, a central assumption of projectionist theories: representations at each syntactic level (i.e., logical form (LF), Deep (D-) and Surface (S-) structures) are projected from the lexicon, in that they observe the subcategorization properties of lexical items.

Within this government-binding (GB) framework, the predicate-argument structure of a verb is a list of (semantic or) thematic (θ)-roles borne by the NP arguments of that verb. The labels which identify the thematic roles are drawn from the lexical semantics literature, namely from Fillmore (1968)’s Case Grammar. They refer to the specific semantic role that arguments play in the event denoted by the verb, i.e., to the information about who did what to whom. Despite the lack of consensus concerning the appropriate set of θ-roles and the criteria determining what role a given argument bears, traditionally described semantic roles are the ones of the Agent (typically human and volitive entity which controls the action) and Theme or Patient (the entity that is affected or changes its state). The θ-Criterion (Chomsky, 1981) assures the one-to-one linking between θ-roles and arguments: Each argument bears one and only one θ-role, and each θ-role is assigned to one and only one argument.

Semantic notions have been recurrently used by generative theories of syntax to make different proposals of what should be a lexical representation. Those theories are termed by Levin and Rappaport Hovav (2005) meaning-driven theories. More recently, however, some linguists have been trying to explain the syntax-semantics interface in the opposite direction: semantic phenomena would be a result of syntactic operations. An example of these structure-driven approaches is Borer (2005)’s XS-approach (exo-skeletal approach), postulating a rich functional syntactic component and a correspondingly impoverished lexical component. These also called constructionist approaches claim that syntactic structure is independent from and previous to specific lexical items (listemes), and they oppose to the traditional projectionist theories of syntactic structures (see also Goldberg, 1995).

Syntactic alternations pose a challenge to projectionist theories of argument realization. According to the Projection Principle, the syntactic expression of a verb’s
arguments is determined by the lexical entry of that verb. Since alternating verbs can occur in different surface syntactic structures, and on the assumption that the lexicon must contain the information determining argument realization, a question arises whether there are two lexical entries to each of these verb’s argument structures or if we can assume just one lexical entry. In the latter case, we must explain how the information in this entry can be mapped onto different surface structures. While some lexicalist theories assume two entries, constructionist approaches answer the question postulating that syntactic structures are not projected from the lexicon, but rather exist independently at syntax, a level at which conceptual arrays drawn from the lexicon can enter freely (for a detailed review of the different approaches see Levin & Rappaport Hovav, 2005).

1.2.1. Linguistics’ approaches to lexical representations: the locative alternation

We now consider the locative alternation, illustrated in (2). Spray, a typical English verb of the also called spray-load alternation, can occur in two syntactic frames, giving rise to a pair of sentences that seem to describe the same event. In both paraphrases, the syntactic constituents order is [NP V NP PP], but each of the arguments bearing the semantic roles of Theme\(^1\) (paint; the substance coming at a particular location) and Location (the wall, the particular location) is either realized as the NP or the PP argument. Different theoretical proposals have been made for explaining this alternation, from projectionist to constructional ones, as discussed below.

(2) (a) Jack sprayed paint on the wall. Locative (Theme-Location) variant
      (b) Jack sprayed the wall with paint. With (Location-Theme) variant

1.2.1.1. Projectionist approaches

Initial accounts like Larson (1988, 1990)’s took the predicate-argument structure of a verb to be a list of (θ)-roles borne by the NP arguments of that verb. The variants would result from derivations from two different D-structures where the θ-roles determined by the verb were projected differently. However, the linking rules and thematic hierarchy proposed by Larson were not sufficiently specific to explain why the θ-roles would be projected in one or another way.

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\(^1\) Theme is mostly taken to be the same as Patient, the general label used for the typically affected entity realized as the direct object of a verb. Different authors propose different names for the same roles, or even different sets of roles. Rappaport and Levin (1988), for instance, term the roles for the locative alternation Locatum (Theme) and Goal (Location).
This motivated the introduction of aspectual notions in the debate, namely, of predicate decomposition proposals from Lexical Semantics. The central idea is that thematic roles are not sufficient to explain argument realization, and semantic properties of the events denoted by the verbs can explain the mapping between the lexicon and syntax. Lexical-semantic representations are taken by different authors to have the form of a predicate decomposition.

Rappaport and Levin (1988) argued that lexical representations for verbs based on thematic roles, such as (3) for the verb *paint*, do not exist. Instead, they proposed two different levels for that lexical representation: a syntactic level indicating the number of arguments a verb takes, with a variable corresponding to each argument (termed Predicate-Argument Structure: PAS); and a semantic level, which is the representation of the verb’s meaning, according to a predicate decomposition approach (termed Lexical Conceptual Structure: LCS). Significantly, PAS is predicted and derived from LCS via linking rules.

(3) **PAINT**: <Agent, Theme, Location>

With respect to locative alternation verbs, the variants in (4) are forms derived from two different lexical semantic representations, illustrated in (5).

(4) (a) *Jack sprayed paint on the wall.* Locative (Theme-Location) variant
    (b) *Jack sprayed the wall with paint.* With (Location-Theme) variant

(5) (a) Locative variant:
    SPRAY: [x cause [y to come to be at z]/ SPRAY]
(b) With variant
    SPRAY: [x cause [z to come to be in STATE]] BY MEANS OF [x cause [y to come to be at z]/ SPRAY]

The different representations are motivated by the observation of variation in meaning between the variants. In particular, the Location-Theme variant is claimed to entail the Theme-Location variant, but not vice versa, i.e., the first has a component of meaning that the second lacks, which results in the affected interpretation that can be ascribed to it (Rappaport & Levin, 1988, p. 26). That is, while (4a) describes an event of change of location, (4b) entails a change of state achieved by means of a change on location. The different lexical semantic representations are mapped to syntax by application of mapping algorithms determining the linking of each of the variables in the substructures (e.g., x in [x to come to be at LOCATION]) and the structural positions (e.g., direct object).

Another meaning-driven approach is proposed by Dowty (1991), who postulates a broader interpretation of the Theme θ-role, the Incremental Theme, which is the affected
entity of an event, and not only the entity that changes state. Accordingly, both the arguments of a locative alternation verb could be seen as Themes. Consider the example in (6). Both the hay and the truck can be seen as affected (i.e., loaded) by the act of loading. This would explain their possible alternation as a direct object in syntax.

(6) (a) Mary loaded the hay onto the truck.  
(b) Mary loaded the truck with the hay.

Dowty argues that role types are not discrete categories but rather are cluster concepts, and that only two types are needed to describe argument selection, the Proto-Agent and the Proto-Patient roles. Proto-Agent arguments have typical traits of their semantic relation in the event such as denoting volition, cause, and movement; Proto-Patient arguments can be seen as typically undergoing change, being incremental themes, affected and stationary entities. These coarse-grained categories are said to capture semantic generalizations and avoid having the enormous variety of semantic characteristics that somehow correlate with syntactic patterns diluting the thematic role notion beyond its usefulness. The principle and corollaries determining argument selection say that arguments with Proto-Agent properties will be lexicalized as the predicate’s subject, while the ones with Proto-Patient properties will be realized as the direct object.

Importantly, with a three-place predicate, if one of two non-subject arguments has more Proto-Patient properties, it is realized as direct object, but if the two are equally good Proto-Patients, either can be lexicalized as the object. The second hypothesis would explain the locative alternation.

Yet, Dowty recognizes there is a difference in meaning of the two variants. The meaning difference is seen as an aspcautal difference: in (6a) the event of loading the hay onto the truck is partially or completely done according to whether the hay is partly or completely on the truck, and in (6b) the event is partially or completely done according to whether the truck is partially or completely full of hay. This difference is instantiated through the Incremental Theme property of the Proto-Patient role. Incremental Theme is always an entailment of the actual direct object, no matter which NP appears in that position. That NP determines the telicity\(^2\) of the event in the extent that the event is complete only when all parts of its referent have been affected. Accordingly, he proposes that the two different subcategorizations for such a verb correspond to different meanings that are recorded as independent items in the lexicon (although possibly connected by

\(^2\)Telicity refers to the property of predicates which have an inherent temporal endpoint. Considering Vendler (1957)'s well-known aspcautal classes accomplishment, achievement, activity and state, the first two denote telic events (e.g., eat an apple, reach the summit), while the others are atelic events (e.g., play the piano, be in the garden).
lexical rules), although the exact terms of the representations for those entries are not made explicit.

Both Rappaport and Levin (1988) and Dowty (1991)’s proposals, therefore, postulate that the two locative alternation variants are the expression of two different meanings and, ultimately, of two different lexical entries. In particular, Rappaport and Levin (1988) propose that the Location-Theme variant has a more complex lexical representation which, importantly, contains as a subpart of it the lexical representation of the Theme-Location variant.

1.2.1.2. Constructionist approaches

As illustrated previously, aspectual questions gained relevance in argument realization approaches. On the one hand, in the largely accepted GB framework, syntagmatic and transformational rules became restricted to X-bar theory and Move-α, with all the rest being just a reflection of lexical specifications. On the other hand, Lexical Semantics was growing as an important branch of Linguistics by investigating the grammatically relevant aspects of meaning. Yet, the multiplication of concepts and theoretical proposals kept theories away from a unified approach of argument realization (Baker, 1997; Fodor, J. A., 1998).

Syntax was brought again to the heart of the argument realization puzzle by more recent theories. In a word, these theories propose that it is the syntactic expression of the arguments which determines different meanings, rather than differences in meaning which determine different argument realizations. Levin and Rappaport Hovav (2005) termed these theories the constructionist approach, after Goldberg’s (1995) famous title Constructions, which is taken to be the earliest comprehensive work within this framework.

While presenting a unified theory of language competence, Borer (2005; see also 1997, 2004) proposes that the lexical entry of a verb (and in fact of every content word) is a sound-meaning pair (a listeme) which has no information about arguments; these are contributed by the construction into which the listeme is inserted. The meaning of a simple sentence is compositionally derived from the meaning of the verb together with the meaning encoded in the syntactic structure. Crucially, structures are independent from specific lexical items’ properties.

Assuming a limited set of predefined structures on which every listeme may enter freely, i.e., without subcategorization restrictions, the language system will produce sentences such as (7). Yet, these are not ungrammatical; their oddity derives from our knowledge of the world associated with the meaning of the used concepts and can be overridden by the way other ungrammatical (e.g., from world knowledge) restrictions are
made on outputs, originating a coercion effect. Being necessary to appeal also to a conceptual system (extra-grammatical), the key idea is that this appeal, together with the proposed functional projections’ grammar, is sufficient to characterize verbs’ distributions. The two outputs from the grammar and the conceptual system will be checked at an independent cognitive place, the making sense component.

(7) (a) *Kim drank (up) the steak.*
(b) *Pat ate (up) the water.*

Borer’s fundamental premise is that argument structure is licensed by functional syntactic structure, and specifically, functional structure that is interpreted as (i.e., semantically translated into) event structure. Listemes are merged directly from a conceptual array and their interpretative properties with grammatical and syntactic relevance are derived from the functional structure they merge within. If we consider the conceptual array `<chase, skunk, cat>` and the arbitrary choice of *chase* as the L-head of the L-domain (i.e., the lexical domain where the first item is inserted), the construction of structure above the L-domain headed by *chase* must proceed from the following guidelines (Borer, 2005, p. 71):

(8) (a) A listeme inserted from the conceptual array may merge with some functional head to give rise to a specifier of a functional projection associated with both interpretational properties and categorial properties.

(b) A listeme may merge within the (original) L-domain if a semantically appropriate preposition or inherent case marker merges with it, and the resulting PP merges within the L-domain.

Considering (8a), each one of the non-head listemes *skunk* and *cat* can be merged as a specific functional specifier, possibly a case-assigning one. This operation would automatically categorize the merged element as an L-head of a nominal projection, as determined by the categorial properties of the relevant functional head. In particular, and because only nominal projections can receive case, if the relevant specifier position is a case-assignment position, it will categorize its head as nominal. That nominal projection would then become a DP, in order to be assigned case, since only DPs can receive case.

Telic events are taken to be quantities (or quantity structures), since they involve quantification over the subdivisions of the event, and atelic events are taken to be homogeneous (non-quantity) structures. The notion of quantification as a property of the arguments contributing to a telic interpretation of the event is here characterized as emerging from the DP structure. That is to say, the telicity-atelicity distinction is viewed

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Phrasal projections are assumed to have an $X^{\text{max}}$ and an $X^{\text{min}}$, and every phrasal projection has at most one specifier and at most one complement (binary branching).
as parallel to the semantic distinction between quantity and non-quantity nominal expressions. As an example, the listeme dog can be merged in a determinerless plural structure (a non-quantity DP structure: [DP <e>d [CL dogs [NP dog]]]), a quantity (indefinite) singular structure (a quantity structure: [DP <e>d [NP a <e>, [NP dog]]]) or a definite singular structure (a quantity structure: [DP the <e>d [NP the [CL the [NP dog]]]]). Functional heads are open values with a category label which are assigned range (i.e., valued) by functors. In the DP, D is headed by an open value <e>d, and it is the element in the position [Spec, DP] which assigns range to it. For example, in the definite singular structure (the dog), it is the the range assigner.

Figure 1.1 illustrates the functional projections of a verbal structure (indicating only the head labels). The (functional) position where the accusative case is, optionally, available, is the specifier of the projection AspQ (Q stands for quantity), and its maximum projection, AspQ max, is responsible for a telic interpretation. In AspQ max, the DP in the specifier position is interpreted as subject-of-quantity (s-o-q), i.e., the subject of structured change, and AspQ and its c-command domain are interpreted as a quantity predicate. If AspQ max is not projected (or if its specifier position is not associated with (accusative) case, as would be an unaccusative structure), a DP that needs case must be merged with T to become [Spec, TP] and be assigned nominative case. The other proposed functional projection is the EP (event phrase) node (i.e., the event structure corresponds to a syntactic functional structure). When the relevant predicate is AspQ, the event is interpreted as quantity event. Any element in [Spec, EP] not receiving by other way an interpretation is interpreted as originator of the event denoted by EP.

Figure 1.1: Schematic structure of the hierarchy of functional projections of verbal structure.

Now considering the locative alternation, Borer argues that the two variants are associated with the same telic structure, resulting from the insertion in a telic transitive structure of the same conceptual array. For the array <Kim, stuff, pillow, feathers>, for example, the structural representations of sentences (9) would be the ones in Figure 1.2.

(9) (a) *Kim stuffed the pillow with the feathers.*
   (b) *Kim stuffed the feathers into the pillow.*
Only two positions of structural case assignment are available ([Spec, TP] and [Spec, Asp₀], for nominative and accusative, respectively) so that, for the array \{(stuff), feather(s), pillow, Kim\} only two arguments can be structurally licensed and become direct arguments. Assuming the structure associated with the two arguments is the transitive telic one, with two arguments being interpreted as subject-of-quantity and originator, the third argument can only be interpreted through the attachment of an appropriate preposition. Therefore, at least two outputs are possible.

In the first one, the Location is the subject-of-quantity and the structured change is measured relative to it; the Theme in this case is licensed by a preposition and attached to L-head PP. This structural configuration is represented in Figure 1.2 (a) and reflects the reading typically assumed to imply the filling of the entire pillow but not necessarily the exhaustion of the feathers. In the second output (Figure 1.2 (b)), on the other hand, it is the Theme argument that is subject-of-quantity, so the change is measured relative to the feathers and the reading is that the feathers have been completely exhausted, although the pillow is not necessarily full.

Again, it should be noted that the system will generate sentences such as I stuffed the feathers with the pillow or I stuffed the feathers about the pillow. According to this proposal, these are not ungrammatical sentences. They are just odd, and that oddity can be reconciled with our knowledge of the world if we are willing to reconcile ourselves to give up of some traditional properties of these concepts.

To sum up, while some theories postulate two lexical entries underlying the variants of the locative alternation, others take these to reflect two possibilities whereby the same lexical items enter a same (independent) syntactic structure.
1.2.2. Verbs biases, frequency effects and structural priming

The linguistic theories discussed in the previous section focus on the representation of verbs and their possible syntactic realizations, making generalizations for groups such as locative alternation verbs. These theories are, for the most part, based on the authors’ grammaticality judgements of few particular sentences. However, as noted by Gruber and Gibson (2004), the investigation of the derivational complexity of different lexical structures can be contaminated by potential differences in plausibility between the real-world situations described by the particular sentences that are used to instantiate the structures.

This is so because comprehension may be affected not only by lexical frequency of words and the syntactic context in which they occur, but also by the plausibility of the situations described by sentences. Considering that comprehenders’ rating of whether the sentences sound ‘good’ or not may reflect both plausibility and lexical-syntactic complexity (i.e., complexity of linguistic derivation of the expression), Gruber and Gibson developed a new questionnaire method in which both of these factors are rated independently. In Experiment 1, they tested constructions known to be of different linguistic complexity: subject vs. object relative clauses like (10) and active vs. passive sentences like (11).

(10)  (a) The boy recited the limerick that appalled the priest.
       (b) The limerick that the boy recited appalled the priest.

(11)  (a) The architect built the house.
       (b) The house was built by the architect.

For each pair (16 pairs of each type were constructed), participants were asked to rate, on a scale of 1 (high) to 7 (low): i) the degree to which the two sentences described the same situation; ii) if sentences were rated in (i) as similar, the plausibility of the situation described by both sentences; iii) the complexity of the manner of expression of the situation for the first paraphrase (a), and iv) the complexity of the manner of expression of this situation for the second paraphrase (b). Participants rated sentences as having similar meanings and plausibility, but, importantly, one version (active and subject relative) as being simpler than the other, thereby showing that the questionnaire can detect complexity differences which are independent of plausibility differences.

There is also substantial psycholinguistics’ evidence of the influence of lexical specific information on comprehension. Trueswell, Tanenhaus, and Kello (1993), for instance, have investigated temporary ambiguities of noun phrases following verbs that more frequently occur with an NP (NP-biased) or a sentence complement (S-biased) such
as (12). Assuming verbs have lexically encoded subcategorization information and that processing a verb activates both the potential structures associated with that verb and its lexical co-occurrence patterns (i.e., the frequency with which it occurs with a particular word in a given structure), Trueswell et al. tested the hypothesis that readers would initially misinterpret the noun phrase the solution in sentence (12a) as the NP complement of forgot. Thus, reanalysis would be needed when encountering the following complement verb was, incongruent with that analysis. Conversely, in (12b), the subcategorization preference of hoped would rightly predict the following NP would be the subject of a sentence complement.

\begin{enumerate}
\item[(12)]
\begin{enumerate}
\item (a) The student forgot the solution was in the back of the book. \hspace{1cm} NP-biased
\item (b) The student hoped the solution was in the back of the book. \hspace{1cm} S-biased
\end{enumerate}
\end{enumerate}

The predicted pattern of results was found with self-paced reading (Experiment 2) and eye-tracking (Experiment 3) measures: reading times were higher for the NP-biased sentences at the preposition in (i.e., immediately after the disambiguating complement verb was). These results support the claim that both subcategory information and subtle patterns of lexical co-occurrence are used by the processing system and that the system takes into account preference for (i.e., frequency of) different possible argument realizations.

Specifically questioning the role individual verbs’ preferences play in priming, Gries (2005) investigated naturalistic corpus data. For the study of English dative alternation, all double object (DO: V NP NP, e.g., give the dog a bone) and prepositional object (PO: V NP PP, e.g., give a bone to the dog) constructions in the British component of the International Corpus of English were identified. Each sentence of the resulting 3003 prime-target pairs was coded as being of one or other type of construction and instantiating a particular verb, among other characteristics. Priming was assessed through the frequencies of occurrence of each structure in each of the four cells crossing Prime type and Target Type. An interaction between the two factors revealed a strong syntactic priming effect, whereby the frequencies were higher when prime and target sentences were of the same type. But the most interesting results concerned the verb-specific investigation. In particular, not all verbs showed the same pattern of priming. For example, for the verb give, the frequency of DO targets was higher when the prime was DO (compared to PO primes) but the frequency of PO targets was not significantly higher in the condition of a PO prime (compared to DO). The verb hand, however, showed the reverse pattern, with priming restricting to the PO variant, i.e., only PO targets’ frequency

\[4\] Verbs strongly biased towards one of the subcategorizations were selected based on a preliminary normative study evaluating participants’ preferences in a sentence completion task.
was higher following a similar PO prime, a pattern not found for pairs of DO prime – DO target.

Jaeger and Snider (2007) also found effects of verb bias for dative alternation verbs in corpora data but, contrary to Gries (2005), they found that the strength of a variant as prime was inversely correlated with the frequency of that variant for the particular verb used. They hypothesised that less expected primes should prime more because of a surprisal-sensitive persistence resulting from underlying mechanisms of priming such as implicit learning (cf. 1.3.1).

In their study, a database from the Switchboard corpus containing 1,108 pairs of prime and target sentences with dative alternation verbs was analysed. For each prime, surprisal was estimated as the probability of the prime structure given the verb: 

\[ \text{surprisal (X)} = \frac{1}{\text{probability (X)}} \]

where the probabilities were previously assessed as subcategorization frequencies in corpora. Because the effect of the prime’s surprisal could differ depending on its structure, two subsets of the database were created, one data set with PO (prepositional object: \([V \ NP \ PP]\)) primes and another with DO (double object: \([V \ NP \ NP]\)) primes, and separate analyses were conducted for each. For the PO prime dataset, the analysis showed that prime’s surprisal was a significant predictor of the PO structure probability at the target. That is, PO primes occurring with verbs that are biased towards the DO structure make it more likely that the target will be PO than PO primes occurring with PO-biased verbs. For the DO prime dataset, no effect of prime verb bias was found, which was taken to result from the overall higher frequency of DO structures in the corpus. In fact, more frequent alternatives should be less surprising and, therefore, worse primes. The surprisal hypothesis is, furthermore, compatible with previous evidence of so-called inverse frequency effects, whereby less frequent alternatives are better primes than frequent alternatives (e.g., Bock, 1986, where passive sentences prime more than active sentences; see also Kaschak, Kutta, & Jones, 2011).

In Chapter 3, we will test empirically the two theoretical proposals for locative alternation verbs’ representations, using a syntactic priming task. Although our results help to distinguish between proposals, we also show that a coarse-grained classification of these verbs as a single group may overlook differences that are relevant while processing these syntactic structures.

1.3. Experiential basis of syntactic processing

In this section we focus on empirical evidence of syntactic processing. We first review the main accounts of syntactic priming. While trying to explain why (and how) processing structures is also a function of the syntactic environment (e.g., of an experiment), these theories have called attention to the complexity of the experiential
basis of language processing. In section 1.3.2 we turn the spotlight on ambiguity resolution, a central aspect of language processing that we will investigate in Experiments 3 and 4.

1.3.1. Underlying mechanisms of syntactic priming

Syntactic priming has been mainly explained by two contrasting views: according to one, the effects result from the activation of representations made while producing or comprehending a structure, which persists for sufficient time for them to be used again on the next relevant opportunity; according to the other, syntactic persistence results from implicit learning, whereby processing a structure produces automatic and implicit learning of something about that structure and increases the probability of reusing it later on. Below we present both proposals and the relevant evidence supporting each one.

1.3.1.1. Residual activation vs. implicit learning: short- and long-term effects

Priming effects are taken to reveal similarities between mental representations of primes and targets. The priming phenomenon has been since long studied in respect to semantic relations between concepts, and has been explained in this domain as a consequence of the spreading of activation in semantic memory networks, as proposed, for example, by Collins and Quillian (1969). A semantic network consists of links and nodes which can be organized into a taxonomic hierarchy. Activation of a prime spreads through the network, thereby activating a connected node of a target, so when this target is presented its activation level is already sufficiently high to facilitate processing.

Concerning syntactic information, Roelofs (1992, 1993; see also Levelt, Roelofs, & Meyer, 1999) proposed a spreading-activation theory where the mental lexicon is conceived of as a network consisting of nodes representing not only meanings (concept nodes) and morphological/phonological aspects (word-form) but also syntactic information (lemma nodes). The lemma stratum (the level at which syntactic information is represented) contains nodes representing, for example, the syntactic category of an item (say, Noun), which are linked to different nodes representing different Noun items (say, dog, animal, chair, etc.).

Pickering and Branigan (1998) extended this model to accommodate subcategorization information of verbs (see also Branigan, Pickering, & Cleland, 1999, 2000; Cleland & Pickering, 2003, where a representation is proposed for nouns). For example, the activation of the verb give, when a speaker produces a sentence such as The man gives the dog a bone, will activate, in the lemma stratum (i.e., the layer codifying syntax, represented in Figure 1.3), the node give and other nodes linked directly to this...
one: the syntactic category node *verb*, the features nodes specifying *tense*, *aspect* and *number* of the particular use of the verb (singular, perfective, past) and the combinatorial node of the particular construction in which the verb is being used (NP_NP).

On the assumption that combinatorial nodes retain activation after use, the activated nodes are at an advantage in the production of a subsequent sentence, increasing the probability of the speaker further selecting the NP_NP structure when producing a sentence with the verb *give*. For example, if asked to describe an image depicting a woman giving a present to a boy, the speaker will more probably say *The woman gives the boy a present* than *The woman gives a present to the boy*. Because the combinatorial nodes are shared between verbs’ nodes, activating the node NP_NP in consequence of producing a DO sentence will be enough to prime the subsequent production of a sentence with this structure but a different verb, such as *The woman sends a friend a letter*.

This lexically independent priming is showed by the results of Pickering and Branigan’s Experiments 1 and 2 (with and without repeated verb), although lexical overlap between verbs in prime and target is shown to produce a stronger effect (*lexical boost*).

Crucially, in a spreading-activation account, activation of particular nodes (and links between them) rapidly decays, because activation must shift away from a current focus of processing to the next in order for additional information to be processed. Being so, these accounts predict that the priming effect will be relatively short-lived.

Figure 1.3: Representation of verbs’ syntactic information in Pickering and Branigan (1998)’s model.
As for implicit learning accounts, the assumption is that structural persistence in language could be a product of the same abstract learning shown in broader cognition domains. Considering a neural network, if activation is taken to correspond to the firing of network units, implicit learning is characterized as a change in the strength of the connections between those units.

Chang, Dell, and Bock (2006), for example, argued for implicit learning mechanisms underlying syntactic priming. They proposed to model it through error-based learning algorithms that use the difference between a predicted output and the correct target output to adjust the connection weights that were responsible for a prediction. More specifically, the implemented computational model was proposed to explain production learning: when listening, it predicts, one word at a time, the following output word, and learns by evaluating the deviations between its predictions and the actual occurring words. The resulting learning is then applied in subsequent production.

The model is based on Chang’s (2002) dual-path model, represented in Figure 1.4 (Chang et al., 2006). The meaning system maps an intended message to production of an utterance, while the sequencing system maps from each comprehended word (cword) to the next word in the sequence, through a simple recurrent network. It is the sequencing system that is responsible for learning: here, an expectation is compared to an output word. The sequencing system maps from cword units to a hidden layer. The hidden units copy their activation into a set of context units which, by their turn, pass their activation status as input to the hidden unit.

In between the lexical layers (cword and word) and the hidden units are compression layers (ccompress, compress), which help the sequencing network to create generalizations over words, rather than word-specific representations. In particular, the compression units keep the hidden layer from directly sequencing particular words, and instead force it to create word classes.
When the model’s output is not the predicted next word, its connection weights are altered in order to reduce this error in the future. Therefore, the model explains not only learning of syntactic representations that are purely structural but also representations that incorporate meaning. The recurrent network prefers to learn representations that just encode surface syntactic categories, and that accounts for the tendency to learn purely structural representations. However, because the model uses error-based learning, if purely structural representations are inadequate for predicting how a sentence should be produced, then the network will learn representations that allow it to distinguish the other relevant differences.

The learning assumptions of the model allowed it to replicate the documented priming effects involving thematic roles’ distinctions when both variants of the locative alternation have the same surface syntactic constituents’ order (Chang et al., 2003, cf. Chapter 3). Pickering and Branigan’s (1998) model assumed combinatorial nodes to roughly correspond to syntactic subcategorization frames that did not take into consideration semantic roles. Here, however, thematic roles distinctions are learned exactly because syntactic constituents’ order is not sufficient to distinguish the two variants.

A stronger argument and motivation for implicit learning accounts of priming is the evidence of long-lasting priming effects. Indeed, transient activation, as a short-term phenomenon, does not seem compatible with results showing persistence of priming over the processing of other stimuli. Bock and Griffin (2000), for example, found that separating the prime and target with up to 10 filler sentences did not disrupt the effects. In a picture description task, participants first heard and repeated aloud a prime sentence (active vs. passive or DO vs. PO), and then saw a picture that they had to describe (target). Between prime and target there was no filler sentence (Lag 0) in one third of the items, one filler (Lag 1) in another third, and two fillers (Lag 2) in the remaining third. Priming (higher production of targets with the same type of the prime) was found regardless of the Lag manipulation, thereby showing no evidence for decay of the effects. In a second experiment, the distance between prime and target varied between 0, 4 and 10 fillers. The results showed a priming effect when the target immediately followed the prime and when it occurred after 10 intervening sentences, but no effect when only 4 sentences intervened between prime and target.

Although there was no consistent decline in the magnitude of the effects, the results could not easily be accommodated by an activation account assuming activation to be transient. At least to some extent, priming is not subject to fast decay, so it was argued that implicit learning, and not transient activation, should be considered as a possible explanation for structural priming, since changes to connection weights are relatively
permanent, i.e., they can remain unaltered until the processor encounters a similar message with an alternative structure.

Contrasting evidence was given by Branigan, Pickering, and Cleland (1999), who argued activation of grammatical knowledge shall be considered. They tested persistence over intervening sentences in a written sentence completion task similar to Pickering and Branigan’s (1998): participants had to complete sentence fragments with ditransitive verbs (e.g., *The fan sent…*) after completing prime fragments inducing a PO or DO structure (PO: *The woman sent the insurance claim…*, DO: *The woman sent the insurance company…*). The lag between prime and target varied between 0, 1 and 4 intransitive fragments presented. Analyses on the proportions of PO and DO target completions following PO prime completions, and proportions of PO and DO target completions following DO prime completions showed an interaction of prime and target but also a three way interaction with distance: The priming effect was progressively weaker, as the lag increased. It is argued that these results are evidence of the activation within the mental lexicon. Still, other explanations would be possible, as acknowledged by the authors, like, for instance, the difference between a picture description and a sentence completion task. The later would emphasize conceptual-level processing, because participants have to generate the event they wish to communicate, while the former would emphasize other aspects of production, like syntactic encoding, because participants are given the event to describe.

The possibility that priming could decay rapidly in written but not spoken production was tested further by Branigan and colleagues (Branigan et al., 2000) in a spoken sentence completion task with three conditions: consecutive prime and target trials, one intervening fragment and a temporal gap (delay) intervening with no fragment presented (i.e., just a temporal delay). Similar priming effects were found in all three levels of the intervening fragments factor, making the authors suggest that the different effects could be associated with the modalities of production. In particular, written completion should take more time than spoken completion, leading to disruption of the effects.

Another difference between the presented studies is that, in the Branigan et al.’s (1999) one, the same verb appears in prime and targets, allowing for a possible explanation of the decreasing priming effect as being a decay of a *lexical boost*. This raises the question of the difference between lexically dependent/ independent effects. Implicit learning does not explain the enhanced priming effect of lexical overlap found by Pickering and Branigan (1998; repeated verbs) and Cleland and Pickering (2003; repeated nouns). Chang and colleagues recognize that this evidence is not easy to reconcile with a model that keeps its learning about structures separate from particular lexical items. They propose that, additionally to implicit learning and weight changes leading to long-lasting
structural priming, there may be an explicit memory mechanism for the wording of the prime. When planning the target, the repeated word will serve as a cue to the memory of the prime and will bias the speaker to repeat its structure. The explicit memory explanation is, nevertheless, recognized to be an *ad hoc* account.

If explicit memory is involved in priming, however, it is expected that the effects resulting from it shall be short-lived. Models like Roelofs (1992)’s assume a single decay parameter for all nodes in the network, with a large value compared to the one of the activation spreading parameter. Pickering and Branigan’s (1998) model, being an extension of Roelofs’ one, also predicts a relatively quick decay of activation, and therefore of the priming effects, and this is not consistent with evidence of the longevity of priming.

Hartsuiker, Bernolet, Schoonbaert, Speybroeck, and Vanderelst (2008) provided evidence of short- and long-term priming effects in Dutch, and they argued for a multifactorial account, combining features of residual activation and implicit learning models (see also Reitter, Keller, & Moore, 2011). Based on the fact that most studies showing short-term effects test pairs with lexical overlap between prime and target and long-lived effects seem to be associated with the absence of that repetition, Hartsuiker and colleagues tested the hypothesis that the lexical boost decays rapidly while a basic priming effects persists longer. They manipulated verb repetition (same verb vs. different verb between prime and target) and lag (0, 2 or 6 fillers between prime and target), and found stronger priming effects at shorter than longer lags, especially in the same verb condition. These results suggest that the lexical boost is short-lived but a basic priming effect maintains the same rough magnitude along different lags of the different-verbs conditions. The proposed working hypothesis is that there are multiple factors underlying syntactic priming, one of them being implicit learning, which operates on abstract, syntactic processes and has consequences for syntactic choices in the longer term, and the other which is lexical in nature and more short-lived, as explicit memory of the prime sentence’s surface structure. According to this dual mechanism account, lexically independent effects are due to an implicit learning mechanism, whereas the dependent effects would be better explained by a short-lived mechanism like the residual activation mechanism proposed by Pickering and Branigan (1998).

1.3.1.2. **Expectation-adaptation: priming as a dynamic phenomenon**

If implicit learning is associated with persistence of priming effects, whereby these do not decay when the distance between prime and target is increased, it is not surprising that it is also associated with cumulative effects, i.e., stronger effects as exposure to primes increases. Indeed, demonstrations of cumulative priming effects provide strong evidence
in favour of the long-term implicit learning account. Moreover, they have inspired researchers to investigate further the time-course of syntactic priming.

In a series of studies, Kaschak and colleagues provided evidence of cumulative priming effects of dative (PO and DO) constructions. Kaschak, Loney, and Borreggine (2006, Experiment 2), for example, tested participants who had to complete a target sentence like (13c) after completing a prime stem that could induce a DO (13a) or a PO (13b) construction.

(13)  
(a) Meghan gave her mother…  DO inducing prime
(b) Meghan gave the doll…  DO inducing prime
(c) The soldier gave…  Target

The experiment had two phases, a Recent experience phase where participants were biased towards one construction by only receiving primes (20 trials) that induced PO and DO structures in different proportions, and a Priming phase (6 trials) where they were presented with prime-target pairs for one type of construction (DO or PO). The pattern of experience with the DO and PO sentences in the recent experience phase was manipulated to create three conditions. In the Equal Exposure-Block (EE-B) condition participants produced an equal number of DO and PO constructions in the preliminary phase, but the tokens of each construction were blocked, so that one construction appeared entirely in the first half and the alternative construction appeared entirely in the second half of this phase. In the other two conditions, participants were unequally exposed (UE) to the alternatives: in one condition (UE-75), participants were exposed to 75% of primes with the alternative structure to the one that would be presented in the Priming phase trials (e.g., 15 DO primes before prime-target pairs with PO primes); in the other condition (UE-100), participants were biased towards one structure during the preliminary phase (e.g., 20 DO primes) and were then presented with prime-target pairs where the primes induced the alternative structure (PO).

A gradient of priming was found along the three conditions: participants in the EE-B condition produced more DO completions following DO primes than following PO primes (and more PO completions following PO primes than following DO primes), showing the expected priming effect. However, the tendency was progressively weaker as participants’ experience was skewed towards the alternative construction. Additional evidence of cumulative effects was given by further studies (e.g., Kaschak, 2007; Kaschak, Kutta, & Jones, 2011).

At the same time, research on syntactic priming was providing intriguing data suggesting that the effects might be more complex than they seemed. As noted before (section 1.2.2), when analysing a spontaneous speech database, Jaeger and Snider (2007) found effects of surprisal, whereby less frequent primes were more effective. In the voice alternation study, for example, a speaker was more likely to produce a passive sentence if
he had previously comprehended or produced a *passive* sentence. This effect was stronger than the corresponding effect with active sentences, which are clearly more frequent in the language. However, the priming effect was also stronger the more surprising the prime was, as measured by the number of occurrences of the particular verb in each structure, in the whole corpus. That is to say, the more the verb at the prime is found preferentially in the active voice, the more a passive sentence with that verb increases the likelihood of a subsequent production using the passive voice.

Interestingly, *cumulativity* was also found: the more one prime type (actives or passives) was comprehended or produced the more likely it was to be produced later. It may seem, at first sight, that these effects are somehow contradictory. After all, the more one type of stimulus is processed, the less surprising it becomes. In trying to reconcile surprisal and cumulative effects, Jaeger and Snider suggested that syntactic persistence can be *cumulative* and, nevertheless, the effect of an individual prime may depend on its surprisal given the distribution of recent preceding primes and depending on what cues speakers are sensitive to as to make a structure surprising.

In another study, Jaeger and Snider (2013) tested how the effects were modulated not only by *prior* (prior average language experience) but also by *recent* experience (within an experiment) with alternation structures. Study 1 analysed data from the dative alternation in spontaneous speech (comprising 1007 PO/DO target productions). Surprisal reflected the subcategorization bias of a verb as measured in a corpus and operationalized as $-\log_2 (p (\text{structure} / \text{verb}))$. The results showed that, the more surprising a prime structure was, the more likely the structure was to be repeated in the target.

Likewise, Study 2, where data from Kaschak (2007) and Kaschak & Borreggine (2008) were analysed, revealed again an effect of prime surprisal given by the prior experience in the language. Interestingly, in both studies, where the tested item were PO and DO dative structures, the effect of surprisal was significant only for PO primes. That is, the more surprising (less frequent for a verb) a PO prime is the more it appears as a target, but this effect was not significant when considering pairs of DO prime/ target. This may reflect an overall preference in the language for the DO construction, and again suggests an inverse frequency effect, whereby DO primes can exhibit only very weak priming effects to begin with.

Study 3 additionally investigated recent experience by manipulating the presentation of prime structures (Figure 1.5). These (DO/ PO constructions) could alternate throughout the experiment (e.g., PO-DO-PO-DO…) or be blocked so that all prime trials within the first half of the experiment used one prime structure and the prime trials in the remainder of the experiment used the other prime structure (e.g., PO-PO-…-PO-DO-DO-…-DO). Under the assumption that participants continuously adapt their syntactic expectations after each prime, participants’ expectations for a PO or DO prime
structure should depend, not only on prior experience, but also on how many PO and DO structures they have processed within the experiment prior to a prime trial (adapted surprisal). Adapted surprisal for PO and DO primes was based on the inverse logit of the proportion of PO and DO primes, respectively, in previous trials. Thus, for example, the higher the proportion of PO primes seen at some point in the experimental session, the smaller its surprisal value. Because in the block condition only one construction is presented in the first half of the experiment, this construction should become less surprising as the block proceeds so that when encountering the first prime of the second half of the experience adapted surprisal should rise and then again decrease along the remainder of the experiment. In the alternating condition, surprisal should be homogeneous, reflecting the distribution of primes. Figure 1.5 illustrates the distribution of estimated adapted prime surprisal by item order.

Prior surprisal was assessed through a preliminary norming experiment assessing subcategorization bias, and computed as in Study 1. A picture description paradigm was used, where participants had to describe 24 dative-eliciting pictures after having heard and repeated a prime sentence.

A logit regression was used to predict the occurrence, at targets, of PO over DO structures. A basic priming effect was observed in a significant main effect of Prime (PO primes made PO targets more likely) and a significant effect of Cumulativity (the higher the proportions of PO in preceding trials, the more likely they were produced as targets). Replicating Studies 1 and 2, there was also an interaction between Prior prime surprisal and PO prime, whereby the more surprising a PO structure was (according to its subcategorization bias) the more likely it was produced as target (non-significant for DO primes). But the key finding was the interaction between Adapted prime surprisal and Prime structure (again, simple effects are significant only for PO constructions): the more surprising a structure was because it had been presented less until a time point in the experiment, the more likely that structure was produced as a target.
These data strongly argue for the claim that priming is stronger the more surprising the prime is based both on prior and recent experience. The sensitivity to surprisal and the cumulativeness of syntactic persistence are unified by the proposed expectation-adaptation hypothesis, grounded on the implicit learning account of priming: syntactic priming results from comprehenders’ adaptation to the syntactic environment, in order to minimize future error. In other words, comprehenders use the prediction error (deviation between what is observed and expectations prior to the observation) to adjust their expectations for forthcoming syntactic structures.

1.3.2. Syntactic processing and ambiguity resolution

The accounts of priming referred in section 1.3.1 concern explicitly the production modality. This is not surprising, considering the large body of evidence of syntactic priming coming from production studies. As stated before, syntactic priming during comprehension seems more elusive, and evidence of such effects was given mostly by studies testing ambiguities, for example during reading or in sentence-picture matching tasks (see section 1.1). It has been suggested (Pickering & Ferreira, 2008) that this might reflect the similarity between ambiguity resolution and production, in that both cases involve critical structural choices. For example, in the same way a speaker has to choose if he will produce a sentence like (a) or (b) in (14), a comprehender has to integrate the constituent a mile, when encountering it, as either the direct object of jogs or the subject of the following clause.

(14) (a) Since Jay always jogs a mile this seems like a short distance to him.
(b) Since Jay always jogs a mile seems like a very short distance to him.

Ambiguity resolution has played a pivotal role in sentence processing theories. Frazier and Rayner (1982), for example, analysed eye-movements while participants read sentences with a temporary ambiguous post-verbal noun phrase, such as (14), and found readers were slower in reading (b) compared to (a). The garden-path model was proposed to explain that, in (b), a mile is initially interpreted as the direct object of the verb jogs (i.e., late closure principle): an incorrect interpretation that needs to be revised by reanalysing the ambiguous constituent a mile. The garden-path model is the best known of two-stage accounts of sentence processing, which predict that the initial parsing of a sentence is based exclusively on syntactic information and that other types of information (e.g., lexical and pragmatic information) would exert their influence only at a later stage. Interactive theories, on the other hand, predict that non-syntactic information can immediately influence sentence processing (e.g., Ford, Bresnan, & Kaplan, 1982; MacDonald, Pearlmutter, & Seidenberg, 1994).
Structural priming effects reflect the influence of parsing a sentence (prime) on the processing of a further processed sentence (target). This influence of previous experience is by itself contradictory with a narrow view of a two-stage account that would only consider parsing principles such as *Late Closure: When possible, attach incoming lexical items into the clause or phrase currently being processed (i.e., the lowest possible nonterminal node dominating the last item analysed)* (Frazier & Rayner, 1982, p. 180).

Consider the relative clauses modifying a complex NP in (15). These can be ambiguous regarding to what previous NP they refer to. In the famous example, *the servant of the actress who was on the balcony*, a high attachment (HA) reading implies that it is *the servant* who was on the balcony, while if the relative clause attaches to the lowest NP in the hierarchy of the sentence (low attachment: LA), it is *the actress* the antecedent of the relative pronoun.

(15)  
(a) Don mentioned the servant of the actress who was on the balcony.
(b) Don mentioned the servants of the actress who were on the balcony.
(c) Megan invited the friends of the girl who were on the beach to her dinner party.

If Late Closure would always apply: i) when comprehending a sentence like (15a), the parser would interpret the RC *who was on the balcony* as referring to the currently being processed NP *the actress*; ii) when comprehending (15b), the parser would find the LA attachment incongruent with the following information provided by the morphology of the verb *were*, which must agree with the plural of the NP *the servants*, so this garden-path would impose a reanalysis of the previous interpretation leading to a further high attachment interpretation; and iii) when comprehending (15c) after having comprehended (15b), the parser would still be lead into a garden-path and would make an initial syntactic commitment to a LA analysis, a misinterpretation that it would have to revise to an HA interpretation, in spite of having just previously processed a similar structure. In other words, (15b) would not prime (15c), i.e., comprehending (15b) would not facilitate the subsequent processing of (15c).

Even if we would consider some preference parameter in addition to a universal principle as Late Closure, that would have different values for different languages, this would not explain that (15b) would prime (15c) in a language with a LA preference. In short, if there is evidence of structural priming for both LA and HA attachments, previous exposure to similar constructions shall be considered to influence parsing of this type of sentence.

Note that this is not by itself evidence against the Late Closure principle. It could be that reading (15b) would involve the construction of some syntactic representation of a LA structure and also of a HA attachment (since LA interpretation had to be revised) and that the first interpretation (LA) was not discarded after being revised so that both representations of HA and LA structures would maintain some activation in memory that
would facilitate the activation of both structures again while comprehending (15c). But empirical evidence of priming effects and their modulation by the relative frequency of exposure to the alternative interpretations would be incompatible with the idea that only broad universal syntactic principles would be considered while comprehending (15c).

There is a large body of literature on relative clause attachment ambiguity resolution, and it is not the aim of this section to make an exhaustive review of it. Many factors have been shown to influence ambiguity resolution, such as the length of the relative clauses, the semantic characteristics of the noun phrases that are possible hosts and working memory capacity (cf. Chapter 5). The identification of possible confounds has resulted from the necessity of an explanation for why evidence was so contradictory, either across languages (as shown initially by the seminal work of Cuetos & Mitchell, 1988) or within languages (as shown by the differences between data of on-line and off-line measures and many more subtle differences from study to study). The main issue was at first the challenge of universal parsing principles such as Late Closure. Along the way, however, it turned out to be a question of determining the preferences for different languages. In the way, exposure-based models of parsing have contributed to the debate on RCs attachment.

Namely, Mitchell and colleagues (Mitchell & Cuetos, 1991; Cuetos, Mitchell, & Corley, 1996) have proposed the tuning hypothesis, according to which people resolve syntactic ambiguities in favour of the structural interpretation that they encountered most often in the past, i.e., on base of stored records of resolution of comparable ambiguities. Mitchell, Cuetos, Corley, and Brysbaert (1995) considered exposure-based phenomena like this and discussed the grain of record-keeping that should be appropriate in order that speakers, in face of a new ambiguity, can identify it with the stored records.

Wells, Christiansen, Race, Acheson, and MacDonald (2009) have also argued for statistical learning in relative clause comprehension, but in this case they contrasted the comprehension of subject (e.g., *the reporter that attacked the senator admitted the error*) and object (e.g., *the reporter that the senator attacked admitted the error*) relative clauses. The latter are known to be more difficult to process and less frequent in most languages, and the study showed that participants, after being trained (i.e., receiving experience) in equal proportions of subject and object relative clauses for a period, increased reading speeds for object relatives more than for subject relatives, in contrast with a control group.

More recently, Kamide (2012) showed that RC attachment to a complex NP can be primed; whereby syntactic ambiguity resolution within a given sentence is influenced by the way the same (or similar) ambiguity was interpreted in the previous sentences. The study employed a visual world-paradigm (see section 2.1.2) where displays with several objects like in Figure 1.7 were presented concurrently with auditory sentences like (16).
(16)  (a) The uncle of the girl who will ride the motorbike is from France.
(b) The uncle of the girl who will ride the carousel is from France.

In these sentences, application of real-world knowledge can resolve the ambiguity of the attachment of the relative clause who will ride the motorbike/ the carousel to the NP1 (the uncle) or the NP2 (the girl). However, in such a paradigm, comprehenders make predictions about upcoming linguistic material even before it is mentioned. That is, when hearing will ride while looking at a display like Figure 1.7, listeners make anticipatory looks to the depicted motorbike or carousel according to their online interpretation of the attachment (HA or LA, respectively).

In an early-training phase, the alternative attachments were associated with a talker identity (NP1 disambiguated sentences were spoken by male and NP2 disambiguated sentences by female talkers). After exposure to the voices, new ambiguous sentences uttered by those talkers were expected to be resolved according to the talker-specific attachment. The results showed that participants made looks to objects consistent with the attachment interpretation associated with each talker. That is, comprehenders looked more at (anticipated) the MOTORBIKE when the sentence was spoken by the male voice, and at the CAROUSEL when the sentence was spoken by the female voice.

In Chapter 4, we report two experiments investigating syntactic priming of RCs attachment in a VWP. Our main interest is, however, to investigate how syntactic processing in a priming task is a function of participants’ experience with the two types of attachment. In particular, we provide evidence on the dynamics of syntactic priming concerning short-term (within-trial) effects. By doing so, we contribute to the debate on the time-course and mechanisms of priming, as research has provided evidence restricted to long-term dynamics.

Figure 1.6: Example of a target picture from Kamide (2012).
1.4. Ambiguity resolution, working memory and priming

Working memory (WM) is the limited capacity system used for temporarily storing and manipulating information so as to support human thought processing (e.g., Baddeley, 2003).

WM constraints have since long been taken to influence sentence processing, by both two-stage accounts (which predict the initial parsing of a sentence is based exclusively on syntactic information, other types of information exerting their influence only at a later stage, e.g., Frazier & Rayner, 1982) and interactive theories (where non-syntactic information can immediately influence sentence processing, e.g., Ford, Bresnan, & Kaplan, 1982). For two-stage accounts, the assumption that the parser pursues only one interpretation is said to be an efficient response of the system to memory limitations (although, when re-analysis is needed, it imposes a greater cost to the parser, as the alternative interpretation is not available). For interactive theories, memory limitations determine the extent to which the parser, in every particular case (complexity of the linguistic material, individual differences in WM capacity, etc.) can maintain parallel computations. In this case, while it can be more demanding to construct multiple syntactic analyses, re-analysis is not necessary.

Structural priming effects reflect the influence of parsing a sentence (prime) on the processing of a further processed sentence (target). This influence of recent experience is by itself contradictory with a narrow view of an account that would only consider parsing principles such as Late Closure. As we mentioned in the previous section, empirical evidence of priming effects, whereby the processing of a high-attached sentence like (17a) can facilitate the subsequent processing of another HA sentence like (17b), seems incompatible with the idea that only broad universal syntactic principles would be considered while comprehending these sentences. Note, however, that additional parameters could be postulated along with this universal principle. It has been suggested that different languages can have different preferences as to how they parse RC attachment, and this preference could be set differently as a parameter for those languages.

(17)  (a) Don mentioned the servants of the actress who were on the balcony.
       (b) Megan invited the friends of the girl who were on the beach to her dinner party.

Parallel processing accounts also take into consideration WM limits arguing, for instance, that people with high memory capacity can take advantage of other constraints besides syntax because they can hold all relevant information. Just and Carpenter (1992), for instance, present a computer simulation that implements their theory of memory capacity constrained comprehension processes. Working memory is assumed to be the storage of items for later retrieval but also the storage of partial results in sequential
computation as it happens, namely, in language comprehension. In the theory, each representational element (e.g., a word, phrase, grammatical structure) has an associated activation level, and that level being above a minimum threshold (by virtue of being encoded from text, generated by computation or retrieved from long-term memory) makes it part of working memory. Because the system is limited, when the total amount of activation available is less than the required to perform further operations, some activation that is maintaining old elements will be deallocated, producing a kind of forgetting by displacement. The crucial assumption is that subjects differ in the maximum amount of activation that they have available, therefore differing in the degree to which they can process more demanding tasks (either because of storage or computational needs) without having to slow down processing or forget partial results of the computations being held.

Just and Carpenter propose their model based on previous studies where they assessed individual differences in working memory capacity for language using the Reading Span task of Daneman and Carpenter (1980), and showed there were differences of performance in comprehension tasks of high and low memory span individuals.

Concerning syntactic ambiguity, it is argued that comprehenders encountering an ambiguity may retain in memory more than one alternative interpretation (contra the garden-path assumption), the duration of that maintenance in memory depending on the working memory capacity of the comprehender. The claim was made based on results like the ones of MacDonald, Just, and Carpenter (1992), who tested comprehension of sentences like (18) where warned is temporary ambiguity between a main verb (MV, 18a) and a reduced relative (RR, with warned replacing who were warned, 18b).

(18)  
  (a) The soldiers warned about the dangers before the midnight raid.  
  (b) The soldiers warned about the dangers conducted the midnight raid.

The main verb interpretation is the most frequent resolution, and two-stage theories say comprehenders make only this interpretation, being therefore led to a garden-path when encountering a further verb like conducted, where the initial interpretation is found to be wrong. But a self-paced reading experiment revealed that high span readers took more time than low span readers on (18a), particularly at the last word of the sentence (raid). It is argued that all readers represent both interpretations in the ambiguous region (warned) but high span readers maintain it for longer periods and postpone some higher level processing. Having two parallel representations in working memory makes processing generally slower. In the region where disambiguation occurs, these readers take also more time because they still have two interpretations activated, while low span readers have only the most common interpretation activated.
In Just and Carpenter’s model, the amount of activation available determines whether the system maintains one or two interpretations in the ambiguous region of a syntactic ambiguity. Moreover, representations of each interpretation have an activation level proportional to their relative normative frequency, i.e., their frequency in the language.

However, the model does not provide details concerning how experience could influence processing. Moreover, the theory of capacity-constrained comprehension posits a linguistic working memory functionality separated from the representation of linguistic knowledge, stating that working memory capacity varies by itself from individual to individual (in terms of capacity and not of processing efficiency). An alternative considering that these differences emerge from biological factors but also from language experience is given by MacDonald and Christiansen (2002), who also claim that language-processing tasks and linguistic working memory tasks are simply different measures of language processing skills. Therefore, the correlations between WM measures and comprehension tasks emerge because both tasks are affected by similar factors, one of them being language processing experience. In this particular aspect, differences between different readers’ performance are taken to reflect different patterns of Frequency × Regularity interactions (i.e., low frequency and irregular material can approximate the same amounts of activations as frequent and regular materials for good readers) instead of variations in working memory capacity. Qualitative differences in the way high and low span readers approach ambiguity may also be the result of variations in sensitivity to probabilistic constraints that guide ambiguity resolution. Specifically, more experienced readers could compute more efficiently a considerable range of constraints, compared to less experienced readers, including the probability of occurrence of overall less frequent constructions in the language.

Therefore, individual differences in WM are expected to correlate with processing costs and strategies in ambiguity resolution, and can be instantiated by variations in comprehenders’ previous experience with particular constructions. However, and despite proposals like MacDonald and Christiansen (2002)’s bringing out the link between previous experience and current processing, WM has not been systematically studied as a component of syntactic priming. Priming effects are arguably dependent on memory, since the influence of a processed stimulus at time point \( t \) is seen at a following time point \( t+1 \) where there is retrieving of or access to an activated common representation or process. Thus, a priming paradigm can inform on how WM impacts not only processing isolated ambiguous sentences but also how the results of that processing are transferred and used in the subsequent processing of another ambiguous sentence.
In Chapter 5, we precisely investigate how WM modulates ambiguity resolution and how, in a task combining reading and situated language understanding (see 2.1.2), processing while reading relates with further processing in viewing.
2. Experimental Methodology and Analyses

Experimental methods used to study language comprehension try to track transitory events of that incremental processing. If we want to identify an effect associated with processing a particular word, for example, we need some technique that can do it with a millisecond resolution. Chronometric techniques used in Psycholinguistics can help researchers to better understand what mental representations we construct at each moment during language processing. In section 2.1, we present the methodologies we used in our experiments to tap into language processing during sentence reading and during spoken sentence understanding while viewing. The measures given by these methods are then used in inferential statistical analyses. In section 2.2, we first present linear mixed effects modelling as the more appropriate general approach to psycholinguistics’ data analysis. We then present particular approaches used to treat our data: Length-residualization of reaction times and Growth-curve analyses of eye-movement scan-paths.

2.1. Online processing methodologies

2.1.1. Self-paced reading and eye-tracking

One of the simplest online methods used by psycholinguists is self-paced reading (SPR), where the reader presses a button to see each successive word or segment in a sentence presented in a computer screen. This allows readers to control the exposure duration for each word or segment of the sentence they read. It is assumed that the latencies of the button presses
(reaction times) depend on the properties of the words being read and correlate with the time course of the cognitive processes during comprehension. Generally speaking, it is assumed that longer times reflect some difficulty in processing.

Just, Carpenter, and Woolley (1982) have shown that the moving-window version of the task produces data with many of the characteristics of naturally occurring eye-fixation data. In a moving-window task, parts of sentences (such as individual words or phrases) are revealed one-at-a-time, keeping the past and future parts of the sentence hidden. The whole sentence is first displayed as a series of dashes on the screen, with each dash representing a character in the sentence. When the participant makes the first button press, this causes the first word to appear, replacing the dashes that correspond to that word. Subsequent button presses make the previous word to be replaced by dashes while the current word is shown. Only one word is visible at any given time, thus creating the impression of a moving window of words on the screen. The words/segments appear in the same position that they would in normal text, and word-length information is available in peripheral vision. Figure 2.1 illustrates the time-course of the task for the sentence *John gave Mary a flower*.

Several studies have investigated structural priming using a self-paced reading task, assuming facilitated processing of a target following a structurally similar prime is reflected by shorter reading times. Frazier, Taft, Roeper, Clifton, and Ehrlich (1984), for example, found that reading times for the second clause of a conjoined sentence was faster when the clause was structurally similar to the first clause than when the clausal structures differed, which has been termed the *parallel structure effect*.

Figure 2.1: Illustration of the time-course of SPR for the sentence *John gave Mary a flower*. 
Frazier et al. tested the possibility that the mechanism for parallelism operates only in cases of temporary ambiguity, resulting, in this case, from the strategy of choosing between two equally applicable rules at a point of temporary ambiguity by repeating a recently successful choice. In order to do so, they tested temporarily ambiguous sentences like (19), where Tom’s stories and Jim’s stories can be temporarily interpreted as the direct object or a sentential complement of believed. If the interpretation of the first segment of a sentence (e.g., Jim believed all Tom’s stories) would prime the subsequent second fragment of the sentence (and Sue believed Jim’s stories), the second segment of sentences (a) and (b) should be facilitated, as the fragments have to be interpreted in the same way (i.e., with a direct object interpretation in (a) and a sentence complement interpretation in (b)). Sentences were presented in a word-by-word self-paced reading task, and participants were instructed to read each segment as rapidly as possible, while maintaining the ability to answer occasional questions, quickly and accurately. The results showed that the second segments were read faster when they were parallel in structure with the first fragment, compared to when they were not (19 c-d).

Longer reaction times in self-paced reading tasks have also been associated with semantic complexity, syntactic ambiguity or infrequency of lexical material. Still, this is not the most transparent and accurate method, and we should consider potential confounds like the so-called spill-over effects (i.e., the transfer of the processing cost of one word or segment to the following one), not easily controlled for when sentences are presented in segments. Moreover, the researcher can never be absolutely sure about where exactly are the participants looking at.

An influential method that can overcome these shortcomings is eye-tracking. In a reading paradigm, eye-trackers record with high temporal resolution the location, duration, and onset time of each fixation while people are reading presented text in a computer screen. Critical sentence regions are determined and gaze is measured and analysed considering aspects like the time spent in that region or the regressive movements for a previous region, which reflect processing costs of the presented linguistic material.

The paradigm relies on well known facts about the relation between reading and eye-movements. It is known, for example, that the mean fixation time in a word is 200–250 ms; that the average length of a saccade (movement between fixations) is about 7–9 letter spaces; that we extract parafoveal (peripheral) information; that content words (nouns, verbs, etc.) are fixated about 85% of the time, while the percentage is of 35% for
function words (determiners, prepositions, etc.); that long regressions (longer than 10 letters or more to previous lines) reflect processing difficulty; and that word frequency, predictability and length influence fixation probability and duration (Rayner, 1998).

Commonly used dependent measures in reading studies include first-pass time (the time spent in a region from first entering it until first leaving the region with a saccade in any direction), second-pass time (all the time spent in a region from re-entering that region, i.e., fixations beyond first-pass reading), total time (the sum of all fixations in a region, including re-reading) and probability of regression (the percentage of regressive (leftward) eye movements out of a region).

Strurt, Keller, and Dubey (2010) replicated the effects described in Frazier et al. (1984) and investigated further if parallelism effects could be seen in segments not linked by coordination, but by subordination. They found statistically equivalent effects in both cases and argued that these effects should be considered an instance of the general syntactic priming mechanism. In sentences like (20), where the segments are linked by subordination, eye-tracking reading times (total time and second pass measures) at the critical NP2 region (underlined) were reduced when NP1 had the same structure as NP2. For example, the adjective phrase a lazy worker was read faster when the reader had previously read the adjective phrase a demanding boss (20a) than when he had read previously the relative clause a boss who was demanding (20b).

(20)  
(a) NP1=Adjective Phrase (AdjP); NP2= Adjective Phrase (AdjP)  
A demanding boss said that a lazy worker did not do the job properly  
(b) NP1=Relative Clause (RelCl); NP2= Adjective Phrase (AdjP)  
A boss who was demanding said that a lazy worker did not do the job properly.  
(c) NP1=Adjective Phrase (AdjP); NP2= Relative Clause (RelCl)  
A demanding boss said that a worker who was lazy did not do the job properly.  
(d) NP1=Relative Clause (RelCl); NP2=Relative Clause (RelCl)  
A boss who was demanding said that a worker who was lazy did not do the job properly.

Strurt et al. conclude that the parallelism effect can be interpreted as syntactic priming. Moreover, since there was no lexical repetition between prime and target NPs in the tested sentences, this study provides evidence for the lexical independence of structural priming.

Strurt et al. ran the experiments in an eye-tracking paradigm, a more sensitive method than self-paced reading, since it registers exactly where in a word the eyes fixate, in a millisecond time basis. This is in fact a resolution advantage, considering that self-paced reading only measures total time for the words/ segments considered. Nevertheless, some authors argue that, although the self-paced method generally slows reading, this slowed down reading does not change the qualitative aspects of sentence processing in any important way (Mitchell, 2004).
Evidence of the sensitivity to priming effects of the self-paced reading method was given by Traxler and Tooley (2008), who tested temporarily ambiguous sentences containing reduced relative clauses, which are known to produce robust effects. In their experiments, the target sentence always contained a reduced relative, like (21c), and the prime sentence contained either a reduced relative (21a) or a main clause (21b).

(21)  
(a) *The defendant examined by the lawyer was unreliable.*  RR Prime  
(b) *The defendant examined the glove but was unreliable.*  MC Prime  
(c) *The engineer examined by the doctor had a large mole.*  RR Target

Target sentences like (21c) produced shorter eye-tracking measures (Experiment 1) and self-paced reading times (Experiment 4) at the disambiguating PP *by the doctor* if they were preceded by a sentence with the same structure like (21a) compared to when the prime had a main clause like (21b). These results indicate that self-paced reading is sensitive to the kinds of priming effects observed in the previous eye-tracking studies.

To sum up, self-paced reading has proven to be sensitive to syntactic priming effects, despite being a less powerful tool to investigate reading. Shortcomings of this method, like the impossibility of readers to re-inspect earlier parts of the sentence and spill-over effects, can be minimized by avoiding a word-by-word version and thereby presenting at a time a larger critical segment and measuring the total reading time at this region (Mitchell, 2004).

### 2.1.2. The Visual World paradigm

We already presented (section 1.3.2) some recent research that has investigated syntactic priming in comprehension using the visual world paradigm (VWP). This methodology builds on evidence of the almost simultaneous integration of visual and linguistic information (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). In the VWP, sentence comprehension is performed concurrently with a visual context. The main finding of VWP research is that eye movements on the visual context are conditioned by the linguistic stimuli processed and are, thus, an index of incremental language processing.

Indeed, it is well established that visual attention is directed towards depicted referents of entities mentioned in a spoken sentence and, moreover, that comprehenders can anticipate upcoming linguistic material. Thus, this method allows the investigation of participants’ anticipatory eye-movements to the visual referents depicted in the context, which index proactive predictions during comprehension (refer to Levy, 2008; Altmann & Mirković, 2009, for accounts of comprehension as a predictive process).
Concerning information conveyed by the verb, it has been shown that, when people hear sentences while seeing objects’ images in a screen, they tend to look to the depicted most probable verbs’ arguments that will be further mentioned even before they hear it. Altmann and Kamide (1999; see also Kamide, Altmann, & Haywood, 2003; Boland, 2005), for example, showed that, when participants hear the verb in the sentence The boy will eat the cake (eat condition) while looking at the picture in Figure 2.2, they look to the CAKE image more than they do it while hearing the verb of the sentence The boy will move the cake (move condition). It was also shown that, from the verb’s onset, the launch of the first saccadic movement to the target object was considerably shorter in the eat condition. These data are taken to reflect that syntactic and/or semantic subcategorization information of the verb is accessed rapidly and used to guide eye-movements in the visual context.

Likewise, anticipatory eye movements have been used to study ambiguity resolution, as they index the interpretation being pursued. Research on syntactic priming during comprehension has also taken advantage of this method by investigating whether comprehenders predict upcoming linguistic information consistent with the syntactic structure of a previously processed sentence.

Scheepers and Crocker (2004), for example, tested constituent order in German, which can be ambiguous. A sentence-initial feminine singular NP like Die Krankenschwester (The nurse [fem, sing]) can be interpreted as either subject (typically the agent) or object (typically the patient). In a VWP task, participants first read aloud an unambiguous prime sentence such as (22a) or (22b), i.e., a sentence with unambiguous constituent order SVO or OVS. Then, they were presented with a temporary ambiguous spoken target sentence such as (23a) or (23b) while viewing an image such as Figure 2.3.

The visual scene shows two transitive events at the same time and the case ambiguous first NP of the auditory sentence refers to the ambiguous character, the NURSE.
While hearing (23a), for example, participants could, initially, interpret the ambiguous NP *The nurse* either as the *agent* of blow-drying or the *patient* of pushing. It was expected that an interpretation of the ambiguous first-NP referent as either *agent* or *patient* would reveal itself in anticipatory looks to the forthcoming entity: the *patient* character (PRIEST), in the first case, and the *agent* character (SPORTSMAN), in the second. The rationale behind this hypothesis is that, once listeners commit to a role assignment of the first NP (assumed to happen very fast) they start to focus their attention on the entity that is likely to be the remaining argument. Accordingly, longer looks to the male *patient* (PRIEST) would indicate an interpretation of the first NP as *agent*, whereas longer looks to the male *agent* (SPORTSMAN) would signal an interpretation of *the nurse* as the *patient*. Therefore, syntactic priming would reveal itself in an *agent* interpretation of *the nurse* after SVO primes and a *patient* interpretation of it after OVS primes.

When analysing gaze duration (i.e., all consecutive fixations on an object before the eyes moved to another object) during the NP1 region (from sentence onset until the onset of the verb), an effect of prime was found according to the predictions: after SVO primes, gazes were longer to the *patient* than to the *agent*, and the reverse happened after OVS prime.
While tapping into predictions during comprehension, the VWP allows researchers to assess expectations for upcoming syntactic structures, thus assessing online syntactic processing. This predictive behaviour during sentence comprehension, as we have shown, can refer to syntactic choices, indexed by anticipatory eye movements, and thus more closely resembles the structural choices made in production. Therefore, the VWP is a method that arguably makes syntactic priming in comprehension easier to detect, and in fact it has proven to do it even when non-ambiguous stimuli are used, as we will later show (cf. 4.2).

In Chapter 3, we present two experiments that used the self-paced reading methodology, and in Chapter 4 two other experiments employing the visual-world paradigm. Finally, in Chapter 5 we present our work using eye-tracking reading data collected in Chapter 4’s experiments.

2.2. Inferential Analyses

2.2.1. Linear Mixed Effects Regression Models

Employing inferential statistics is the critical step allowing researchers to test their experimental hypotheses. The most used statistical technique in psychological research is analysis of variance (ANOVA), which compares the means of a dependent variable (DV) in different experimental conditions and provides a test statistic (F) indicating if we can safely reject the null hypothesis that the difference between those means is equal to zero. So, for example, in Traxler and Tooley (2008)’s study referred in section 2.1.1, the mean total time that participants spent in the disambiguating region by the doctor in targets like The engineer examined by the doctor had a large mole was of 709 ms when the target followed an RR prime (The defendant examined by the lawyer was unreliable) and of 766 ms when the prime was MC (The defendant examined the glove but was unreliable). The ANOVAs performed on these data showed that the difference was significant, so we can say the values are different because of the experimental manipulation and not because of any other random variance.

Traxler and Tooley employed two ANOVAs because, in psycholinguistics, not only participants, but also linguistic items, have to be taken as random effects, i.e., effects of variables that are not manipulated in the experiment and, therefore, can introduce variance we are not controlling for. Participants of an experiment, even when randomly chosen, are a sample of the population we want to generalize our data to. In the same way, the particular sentences we use as linguistic items are just a sample of the whole population of linguistic objects of the same type (e.g., the whole
population of RR sentences). Running two different ANOVAs with the observed data aggregated by participant (F1) and by item (F2) was the proposed way to deal with these two sources of random variance (Clark, 1973). However, this does not allow handling the two sources of variance simultaneously, and inflates a Type II error probability (chance of missing a real effect because the null hypothesis could not be rejected), as we have to reduce the limits of error making the result significant\(^5\).

Recently, new models were proposed to treat psycholinguistics data\(^6\). Linear Mixed Effects (LME) models (Baayen, Davidson, & Bates, 2008), in particular, have since then been adopted broadly in psycholinguistics. Such models, among other advantages, allow to specify crossed random factors such as participants and items in the same analysis, and are not restricted to factors with a fixed set of categorical levels but also allow tests of effects of continuous variables (covariates) and their interactions with categorical factors.

The formula of such a model specifies both fixed effects (of the explanatory variables) and random effects (e.g., of participants and items). Consider a general linear model like \( Y_{si} = \beta_0 + \beta_1 X_i + e_{si} \), where \( Y_{si} \) is the response for subject \( s \) and item \( i \). This response is a function of a baseline level via the fixed-effect \( \beta_0 \) (intercept) and a condition (X) effect via the fixed effect \( \beta_1 \) (slope). Because subjects can have different overall responses, but can also differ in their response to the different conditions, we need to account for how subject \( s \) deviates from both fixed effects \( \beta_0 \) and \( \beta_1 X_i \). The respective expanded model including random intercepts and random slopes is \( Y_{si} = \beta_0 + S_{0s} + (\beta_1 + S_{1s}) X_i + e_{si} \). The random intercepts and slopes allow subjects to vary around \( \beta_0 \) and \( \beta_1 \). Likewise, item variability is accounted for by random intercepts and slopes, with the mixed-effects model having the formula: \( Y_{si} = \beta_0 + S_{0s} + I_{0i} (\beta_1 + S_{1s} + I_{1i}) X_{si} + e_{si} \).

LME models allow, therefore, to account for both participants and items variance while quantifying the systematic variance contributed by the (manipulated) explanatory variables. We thus employ LME models in our inferential analyses. We use the implemented function \textit{lmer} of \textit{lme4} package in the R environment (R Core Team, 2013), and we fit maximal-random structures (Barr, Levy, Scheepers, & Tily, 2013), i.e., all possible main effects and interactions, as well as by-participant and by-item random intercepts and slopes for all explanatory variables. So, for example, if the independent variables (predictors) are \textit{Prime} and \textit{Target}, a maximal model includes the main effects of \textit{Prime} and \textit{Target}, their interaction \textit{Prime:Target} and the random effects, which include random intercepts for Participant and Item (e.g.,

\(^5\)F1 and F2 must both have \( p < .025 \) to get an overall \( p < .05 \).

\(^6\)Refer to the \textit{Journal of Memory and Language}’s Special Issue on \textit{Emerging Data Analysis} (vol. 59, issue 4) for a lengthy discussion on the traditional and new inferential statistics methods.
(1|Participant) + (1|Item)) and random slopes by Participant and Item for each fixed effect (((0+Prime|Participant) + (0+Prime|Item))...). The model will estimate regression coefficients for all main effects and interactions (just like an ANOVA) while taking into account all the variation specified in the maximal random structure.

### 2.2.2. Length-residualized reaction and reading times

In Chapter 3, we present two self-paced reading experiments, where our dependent measure is the time participants take at each of the windows presenting successive segments of sentences, i.e., from when they press the computer key that triggers the presentation of that segment until they again press the key, triggering the presentation of the following fragment. As this measure includes not only the time spent reading but also the time of key-pressing, it is more accurately called a reaction time (RT), instead of reading time. Nevertheless, it is a measure assumed to reflect reading processing, so that longer RTs are taken to index higher processing costs while reading.

It is known that, as intuitively expected, longer words or segments take longer to read than shorter ones. The simplest way to deal with this fact is, when analysing reading data, to divide the reading time on a word/segment by the number of characters of that word/segment. However, there is evidence of a non-linear relationship between word length and reading time, something that is problematic for analyses of these measures. Another solution to account for length effects, residualization, was first proposed by Ferreira and Clifton (1986). In their study, they examined (among others), sentences containing or not a reduced relative clause, such as (24) (a) and (b), respectively. In (24a), and according to the garden-path theory (cf. section 1.3.2), examined is first misinterpreted as a main verb, and further reanalysis takes place at the region by the lawyer, where longer reading indexes that additional processing load.

(24)  
(a) The defendant / examined / by the lawyer / turned out / to be unreliable.
(b) The defendant / that was/ examined / by the lawyer / turned out / to be unreliable.

In Experiments 1 and 2, participants’ eye-movements were tracked while reading the experimental sentences, and length corrected first-pass and second-pass reading times on the critical region were computed dividing the values (in ms) by the number of characters in the region. As predicted, participants were slower in reading the temporary ambiguous condition of the reduced relative clause.

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7 We assume random slopes on main effects (Prime, Target) to be independent (0+...), as the different explanatory variables are unrelated and therefore have different randomness. The examples use R lme4 code.
Experiment 3 aimed at replicating the effects with a self-paced reading methodology, but here a problem arose: the division ms/character was inappropriate, as the transformation assumes a value of zero for character length of zero, but this is a wrong assumption when pressing the key in the task sets a lower bound on the zero intercept of such function. In order to overcome this shortcoming, expected reading times for regions of different lengths were estimated by a linear regression of the times onto the lengths. Then, the resulting expected reading times were subtracted from the observed reading times, and the differences were the outcome variable analysed as a function of the independent variables.

In a study that repeated Ferreira and Clifton’s Experiment 1, Trueswell, Tanenhaus, and Garnsey (1994) discussed the ms/character transformation of the eye-tracking reading data. They showed how the assumption of a linear relation between reading and number of characters is not correct when its y intercept is not zero (i.e., a hypothetical region of 0 characters has 0 ms reading time), which is shown to be the case in their data. In this case, the transformation does not remove all variance due to string length and, moreover, a non-linearity arises, especially for shorter length regions. The residual correction proposed by Ferreira and Clifton is, therefore, recommended to adjust reading times (unless string length is tightly controlled across items), also in eye-tracking data. The residualization shall be done for each subject separately, as there is substantial by-subject variation in the best fit of reading time to region length.

In analysing both self-paced reading RTs (Chapter 3) and eye-tracking reading data (Chapter 5), we will adopt residualization to length-correct our measures.

2.2.3. Growth-curve analysis

In Chapter 4, we present Experiments 3 and 4, employing an eye-tracking visual-world paradigm to investigate syntactic priming of relative clauses attachment. As we mentioned before, anticipatory eye-movements in the VWP reflect ongoing linguistic processing. In a syntactic priming task, written prime sentences are presented on the screen, after which the presentation of the visual-world stimulus, combining listening of a spoken target sentence with viewing a visual context, occurs. The measure of interest is eye gaze in the visual context, which indexes syntactic processing that is consistent with the syntactic interpretation made at the written primes.

Traditional analysed measures are the probability of gazes to a target picture to which participants are expected to look at, as compared to a competitor picture. Gaze probabilities have been traditionally analysed using ANOVAs, but in the last years new approaches have been proposed to overcome some shortcomings of those analyses. As
noted by Barr (2008), the dependent variable here is typically the region to which a participant directs his or her gaze at a given moment in time, a variable that is inherently categorical. This means that, contrary to other paradigms where the dependent measure is a continuous variable (e.g., RTs) modelled as function of some categorical variable (e.g., design factors), in this case we want to assess the effects of a continuous variable (time) on a categorical variable (gaze location).

Data can be transformed in order to suit canonical statistical techniques such as ANOVA and *t*-test. For example, time can be transformed into a categorical variable by aggregation into series of analysis windows, and fixation regions can be transformed into a continuous variable by calculating proportions aggregated over time and trials. However, there are still shortcomings of these approaches. While aggregating time into windows of interest such as the time-window corresponding to an NP, for example (e.g., the NP1 region (with mean 1005ms) in Scheepers & Crocker (2004)’s study; see 2.1.2), the analysis of variance is applied to a greatly compressed representation of the data and cannot estimate the fine-grained time-course of fixations\(^8\). Aggregation into several smaller windows (e.g., 300ms) where ANOVAs are run separately is also common approach. Yet, here too, the analysis taps not into the trajectory of change over time but instead on the changes of patterns between a few windows.

Parametric (or growth) curves, traditionally used in longitudinal studies (e.g., Singer & Willet, 2003), is an alternative way to assess changes in a dependent variable over time. Mirman, Dixon, and Magnuson (2008) propose analysing data on a proportional scale and fitting curves using orthogonal polynomials. That is, the relationship between fixation proportions and time is represented through curvilinear models resulting from the term of Time being raised to a particular power (e.g., Time\(^2\)).

Building on this approach, we will fit LME models to proportion of fixations (DV), where Time (represented as an orthogonal polynomial of order 2) and the independent variables are introduced as fixed effects. The linear and quadratic terms of the polynomial (Time\(^1\) and Time\(^2\)) represent the rate and direction of change of the DV along time.

\(^8\) Aggregation serves also the purpose of avoiding the ANOVA assumption of independence between observations, as fixations at time \(t\) are not independent from that at time \(t+1\).
3. Priming the Locative Alternation: investigating syntactic representations

3.1. Introduction

As we mentioned in Chapter 1, syntactic priming studies can provide evidence of the similarity between syntactic representations instantiated by prime and target sentences, whereby, if the processing of a particular target is facilitated following the processing a particular prime, we can infer that prime and target share relevant representational properties. Accordingly, accounts of syntactic priming such as residual activation (Pickering & Branigan, 1998) have postulated abstract representations of syntactic structures within the Lexicon. For the well-studied English dative alternation, for example, it was assumed that a verb would be linked to two representations of the respective possible argument realizations, DO (double object: NP_NP, e.g., give someone something) and PO (prepositional object: NP_PP, e.g., give something to someone). These postulated representations were fine-grained enough to explain the pervasive behavioural evidence of the tendency to produce the same sentence type (DO or PO) of a previously processed, otherwise unrelated, sentence. Therefore, psycholinguistics studies did not seem to need considering more complex theoretical linguistics proposals of such linguistic objects (concerning the English dative alternation, see, e.g., Larson, 1988).

However, syntactic priming, we believe, can provide important empirical evidence for such linguistic theories and, likewise, linguistic theories can help psycholinguists by providing them theoretical constructs that may help to explain what has been shown to be a complex pattern of results, especially when considering the syntactic priming literature.
of the past 15 years. For example, there is evidence of inverse frequency effects (see sections 1.2.2 and 1.3.1.2), whereby a less frequent alternative produces stronger priming than a more frequent one. While this and other effects have been explained by assuming underlying mechanisms involved in priming, such as implicit learning, it is possible that the difference in magnitude of priming effects for the two variants of an alternation indexes a difference in the complexity of those variants’ representations.

In this Chapter, we precisely focus on this hypothesis. In particular, we build on the two contrasting theoretical proposals for how the variants of the locative alternation are represented in our lexicon (section 1.2.1). Our main goal is to provide empirical evidence than can distinguish those theories, by investigating if the two variants behave differently in a priming task and, if so, how could the proposed representations account for the differences. In order to do so, we conduct two self-paced reading experiments testing syntactic priming with sentences containing locative alternation verbs. In Experiment 1, our stimuli are constructed based on eight different Portuguese locative alternation verbs; the prime type contrasts the two variants with a baseline level, and we find a main effect of prime that indicates the alternatives have a different effect on the targets, regardless the target type. This result provides support to theories proposing representations of different complexity for the two alternatives. We also show that the effects are modulated by the relative amount of experience with the two alternatives along the experimental session, in line with implicit learning accounts of syntactic priming. In Experiment 2, we select only five verbs that, according to a pre-test, show a preference for what seems to be the more complex of the variants. We replicate Experiment 1’s priming effects and further show that they are a function of prime surprisal, in consonance with the expectation-adaptation hypothesis (refer to section 1.3.1.2).

3.2. Background

Linguists have drawn substantial attention to verbs’ argument realization, i.e., to how verbs encode the number and type of arguments with which they can occur. In Section 1.2.1 we presented two contrasting views of how the argument realization of locative alternation (also called spray-load alternation) verbs would be encoded in our mental lexicon. These verbs can occur with two different surface argument structures where, while both are constituted by a sequence NP_PP, the semantic roles of Theme and Location are differently attributed to the two NP and PP constituents.

On one hand, projectionist theories like Rappaport and Levin (1998)’s say the variants in (25) derive from two different lexical entries consisting of the two different predicate-decomposition representations in (26). The theoretical implication of this
account is to consider the Location-Theme (LT) variant to be more complex and entailing the Theme-Location (TL) variant.

(25) (a) Jack sprayed \([\text{paint}]_{\text{NP}}^{\text{Theme}} [\text{on the wall}]_{\text{PP}}^{\text{Location}}\) Theme-Location variant
(b) Jack sprayed \([\text{the wall}]_{\text{NP}}^{\text{Location}} [\text{with paint}]_{\text{PP}}^{\text{Theme}}\) Location-Theme variant

(26) (a) Theme-Location variant:
SPRAY: \([x \text{ cause } [y \text{ to come to be at } z] / \text{SPRAY}]\)
(b) Location-Theme variant
SPRAY: \([x \text{ cause } [z \text{ to come to be in STATE}] \text{ BY MEANS OF } [x \text{ cause } [y \text{ to come to be at } z] / \text{SPRAY}]\]

Contrastingly, constructionist proposals (e.g., Borer, 2005) postulate a unique transitive structure, where lexical roots are inserted. Depending on the functional projection where they are inserted, these roots receive different interpretations regarding their semantic role in the described event. Therefore, a unique syntactic representation is assumed, the differences in meaning resulting from the order of insertion of words in that structure.

In a word, while the first theory takes the variants to be of different inherent complexity, the second does not distinguish them in this respect.

These theoretical proposals have not been tested empirically. However, syntactic priming can provide evidence that helps distinguishing them. Assuming that the facilitation of a target sentence following a prime sentence is an index of the similarity between representations of both sentences, we contrast two competing hypothesis:

i) If Location-Theme (LT) structures have a more complex representation than Theme-Location (TL) structures, and the first entails the second, we may expect that LT prime sentences will facilitate both TL and LT target sentences;

ii) If TL and LT sentences have the same syntactic structure, we may expect that both TL and LT primes will facilitate equally TL and LT targets.

It is important to note that we are overlooking complexities that arguably are involved in processing such structures. In particular, our second hypothesis narrows the view of processing these structures, by not taking into account that, even if having the same syntactic structure (i.e., linear surface order of syntactic constituents), the two variants differ at least in the linear order of the semantic roles. This difference shall be relevant in processing these sentences and, even in Borer’s theory, they can have an impact, for example, in the conceptual system. That is, something must distinguish, ultimately, the two variants.

That the difference is semantic and not syntactic is the rationale motivating Chang, Bock, and Goldberg (2003)’s study investigating the sensitivity of structural priming to variations in thematic roles within messages. To the best of our knowledge, this is also the only study using the locative alternation as stimuli in a syntactic priming
task. Crucially, our work differs from this previous work by assessing the effects during comprehension and, more importantly, by testing the two above mentioned competing hypotheses, i.e., by assessing how differently the two variants may behave as primes.

Chang et al. (2003: Experiment 1) tested items of the locative alternation in a sentence recall task to look for priming effects in production of target sentences such as (28) when preceded by prime sentences containing a different verb such as (27).

(27) (a) *The farmer heaped straw onto the wagon.*
    TL prime
(b) *The farmer heaped the wagon with straw.*
    LT prime

(28) (a) *The maid rubbed polish onto the table.*
    TL target
(b) *The maid rubbed the table with polish.*
    LT target

This particular alternation is well suited, they argued, for isolating the part that thematic roles play, since the order of the roles varies while the syntactic structure NP [V NP [P NP]PP]VP remains the same, and both critical arguments are typically inanimate, thereby avoiding the possible confound of the influence of animacy features. Therefore, if the order of semantic roles can be primed, TL sentences should prime TL sentences more than LT sentences do, and vice-versa (the *roles* hypothesis).

A sentence recall task (e.g. Potter & Lombardi, 1998) was used, where participants silently read sentences presented word-by-word at a fast rate and, after an intervening task, were asked to repeat the sentence aloud. Because the fast rate of presentation and the distractor task make recalling more difficult, participants sometimes change the syntactic structure of the sentences when repeating them. Using this task to access priming effects, the authors expected that, after a prime trial (including silent reading, distractor task and recalling (speaking) prime sentences), the production (recalling) of the target trial (including silent reading, distractor task and recalling target sentences) would be affected by the prime trial, so that participants would for the most part correctly recall the content of the target, but sometimes would wrongly recall its structure, using the structure of the previously recalled sentence (prime).

The design manipulated prime type (TL vs. LT) and target type (TL vs. LT). Recalled target sentences were recorded, transcribed and coded as TL, LT or *other*. ANOVA’s (by-participant and by-item) performed on the arc-sine transformed proportions of LT responses out of all TL and LT responses showed that participants were significantly more likely to produce LT sentences after LT primes (0.515) than after TL primes (0.473)\(^9\). In addition, a target type effect was found, as expected, indicating that participants tend repeat the target sentence using the correct form of it. Table 3.1 shows

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\(^9\) We note that the corresponding analysis for proportions of TL responses is not given, although the figures in Table 3 show a similar trend (higher production of TL sentences after TL primes).
the raw counts and proportions of LT (third column) and TL (fourth column) sentences produced for each Prime and Target form.

Table 3.1: Chang et al. 2003 (Experiment 1): proportions and counts of LT and TL versions of the locative alternation produced for each prime and target forms.

<table>
<thead>
<tr>
<th>Prime form</th>
<th>Target form</th>
<th>Location-Theme</th>
<th>Theme-Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location-Theme</td>
<td>Location-Theme</td>
<td>0.977 (129)</td>
<td>0.023 (3)</td>
</tr>
<tr>
<td>Theme-Location</td>
<td>Location-Theme</td>
<td>0.917 (121)</td>
<td>0.083 (11)</td>
</tr>
<tr>
<td>Location-Theme</td>
<td>Theme-Location</td>
<td>0.053 (7)</td>
<td>0.947 (125)</td>
</tr>
<tr>
<td>Theme-Location</td>
<td>Theme-Location</td>
<td>0.008 (1)</td>
<td>0.992 (125)</td>
</tr>
</tbody>
</table>

3.3. Experiment 1: priming the locative alternation using Self-paced Reading

The Chang et al. (2003) study is said to provide evidence for priming of thematic roles which are taken to have some independent representation from the representation coding for the linear order of syntactic constituents. However, the data do not allow inferring about the possible difference between the two variants: on one hand, the reported analyses respect only to the subset of data of LT productions; on the other, obtained measures are not distinguished from a baseline level where the Prime trial would have an unrelated form. Therefore, it remains an open question whether the two variants behave differently in a priming paradigm.

In our Experiment 1, we are concerned with how the locative alternation variants may differ in their priming capacity. We assess these differences by comparing the two types of prime with a baseline level, and by investigating the dynamics of the effects (i.e., concerning the particular syntactic environment of the experimental session) for each variant. We use a self-paced reading methodology, where priming effects reveal themselves by shorter reaction (reading) times at targets of the same type of the previously processed prime. Since we are testing two types of sentences that vary in the order of their verb’s two arguments, we will focus on reading times of the verb’s arguments, in each target sentence.

3.3.1. Participants

Forty eight native European Portuguese speakers from the University of Lisbon participated voluntarily in the experiment. All subjects had normal or corrected-to-normal vision.
3.3.2. Design and Materials

Eight Portuguese locative alternation verbs were used to create 48 critical prime-target pairs (provided in Appendix A): *carregar* (load), *imprimir* (print), *borrifar* (spray/splinkle), *pintar* (paint/draw), *gravar* (record/engrave), *plantar* (plant), *semeiar* (sow) and *esfregar* (rub). The prime sentence could have a Theme-Location (TL) structure, a Location-Theme (LT) structure, or be an unrelated sentence (i.e., Baseline: BL), as illustrated in (29a–c). The target sentence could occur in the two possible structures TL or LT, like in (27a–b).

(29) (a) No armazém | o empregado | carregou | a mercadoria vendida | na carrinha comercial | para entregar | ao cliente.

In the warehouse | the employee | loaded | the sold merchandise | onto the commercial van | to deliver | to the client.

(b) No armazém | o empregado | carregou | a carrinha comercial | com a mercadoria vendida | para entregar | ao cliente.

In the warehouse | the employee | loaded | he commercial van | with the sold merchandise | to deliver | to the client.

(c) À hora do almoço | os trabalhadores navais | reuniram-se todos | junto ao ministério da economia | para iniciar a manifestação.

At lunch time | naval workers | met all | close to the ministry | of economics | to start | the public demonstration.

(30) (a) No multibanco | a rapariga | carregou | o dinheiro necessário | no cartão telefónico | e ligou logo | ao namorado.

At the cash machine | the girl | loaded | the necessary money | onto the phone card | and soon called | her boyfriend.

(b) No multibanco | a rapariga | carregou | o cartão telefónico | com o dinheiro necessário | e ligou logo | ao namorado.

At the cash machine | the girl | loaded | the phone card | with the necessary money | and soon called | her boyfriend.

Thus, we have a 3 (prime type: BL, TL, LT) × 2 (target type: TL, LT) design, crossing two within-participants (i.e., the same research participants participate in all experimental conditions) independent variables, creating the six conditions illustrated in Table 3.2.

Table 3.2: The six condition cells of Experiment 1, crossing Prime and Target.
The 48 experimental pairs (8 verbs in 6 conditions each, 96 sentences) occurred in six different lists. Conditions were distributed through sentence pairs 1–48 across the lists according to a Latin Square design. In order to control for order effects of lexical material, items’ order was a function of random selection in each list.

For all lists, prime-target pairs were separated by 1 randomly selected set of 2 or 3 filler sentences (120 sentences). Half of the 48 filler sets are a pair of sentences and half are a set of three sentences. For half of each of the two subsets of filler sentences, two sentences are a pair of sentences with the same causative alternation verb found in its transitive variant. This procedure was intended to cancel the possible strategic value of the repeated verb as a cue to assume the target as having a 50% chance of being either variant of the locative alternation, and also to make experimental pairs not readily discriminable from the filler sentences. For the other half, sentences had different verbs and constructions than causative and locative alternations. In each list, 40% of the filler sentences were followed by a comprehension question. Filler sentences were selected randomly from a list, although guaranteeing that sentences were grouped in pairs/triplets, as stated above.

3.3.3. Pre-tests

The 48 experimental pairs of prime and targets were pretested using the Gruber and Gibson (2004) questionnaire (see section 1.2.2). For each of the 96 sentences, the two TL and LT versions were presented (e.g., In the warehouse the employee loaded the sold merchandise onto the commercial van (the commercial van with the sold merchandise) to deliver to the client) and participants were asked to rate, on a scale of 1 (high) to 7 (low): i) the degree to which the two sentences described the same situation; ii) if sentences were rated in (i) as similar, the plausibility of the situation described by both sentences; iii) the complexity of the manner of expression of the situation for the first paraphrase (e.g., TL); and iv) the complexity of the manner of expression of this situation for the second paraphrase (e.g., LT).

Participants were provided with one example (active vs. passive) before the 96 test items. To control for ordering effects, there were two lists, one with the sequence 1-96 and the other beginning with item 96 and ending with item 1. Also to control for order effects, the order between Theme-Location and Location-Theme versions for each pair was counterbalanced (ABBA technique). The pre-test was administered online to 36 participants who were other students from the University of Lisbon that were not tested in the main experiment.

Overall, participants rated each pair of sentences (i.e., the TL and LT versions of an item) as describing the same situation (mean = 2.17, SD = 1.52) and the described
event as being plausible (mean = 1.75, SD = 1.21). Interestingly, they scored LT versions to be more complex (mean = 2.44, SD = 1.67) compared to TL versions (mean = 2.01, SD = 1.39), a difference that was found significant when applying a Wilcoxon Signed-Ranks Test (Z = 7.58, p < 0.01).

3.3.4. Procedure

The 48 participants were randomly assigned to the 6 lists. Participants were tested in a moving-window noncumulative self-paced reading task (refer to section 2.1.1). The experiment began with the presentation of the instructions on the screen. Participants were instructed to silently read each segment as rapidly as possible while maintaining the ability to answer occasional comprehension questions accurately. After participants finished reading the instructions they had a practice block of five sentences to test if they had understood the task, and then the experiment began, starting with 4 filler sentences that preceded the first experimental trial.

After some sentences (40% of the fillers) participants saw a screen with a yes-no question about the last presented sentence, and had to answer it pressing the green (for yes) or red (for no) keys on the keyboard. After that, a new sentence began.

Sentences were presented in segments as indicated by the slashes (|) in (29) and (30). Reading of each sentence began with a 200 ms fixation prompt, a horizontal array of five asterisks in the centre of the screen. The participant then read a sentence, segment by segment, with the display initially filled with dashes replacing the non-space characters of the entire sentence. When subjects pressed the space bar for the first time, the first segment appeared replacing the dashes corresponding to it. When the bar was pressed again, the previous segment was replaced by dashes, and the next segment was uncovered. Participants proceeded like this until the last segment was presented. Thus, only one sentence segment was visible on the screen at any time. After this, the next sentence was presented, beginning again with the 200 ms fixation prompt, and participants proceeded the same way until all sentences of the list were presented.

Participants were tested individually, seated in front of a computer terminal. Experimental trials were controlled by a PC Pentium (R) 4 CPU 3.00 GHz with a monitor ASUS A9250 running E-Prime software (Schneider, Eschman, & Zuccolotto, 2002 a, b). A Refresh Clock Test was previously run to guarantee measurements had millisecond accuracy. Reaction times (the time between each press of the space bar) for the critical segments (underlined in 30) were recorded.
3.3.5. Results

All 48 participants answered correctly to more than 85% of the questions, so all their data were analysed.

For a target sentence like (31), we considered the reaction times (RTs) at the first and second segments after the verb, i.e., the first (NP: the necessary money) and second (PP: onto the phone card) arguments of the verb. This allows us to have a unique measure that can capture the effects in any of the segments, and still assess any difference between the NP and PP phrases by including in our analysis a predictor coding for phrase (NP vs. PP).

(31) No multibanco | a rapariga | carregou | o dinheiro necessário | no cartão telefónico | e ligou logo | ao namorado.

At the cash machine | the girl | loaded | the necessary money | onto the phone card | and soon called | her boyfriend.

We first proceeded to length-residualization of RTs, to account for the effects of word length and variability in reading speed between subjects (refer to section 2.2.2 for details). The length-residualized RTs were then screened for outliers, using a cut-off at 2.5 standard deviations from each subject’s mean in a procedure that affected 1.56% of the data. We then analysed the residualized RTs using linear-mixed effects modelling (LME, refer to section 2.2.1), where we included all possible main effects and interactions and a maximal-random structure (i.e., by-participant and by-item random intercepts and slopes for all explanatory variables; cf. Barr, Levy, Scheepers, & Tily, 2013). The resulting model is a maximal linear mixed-effects model (MLMEM).

Our main variables of interest are Prime (BL, TL, LT), Target (TL, LT) and Phrase (NP, PP). However, and in order to assess how priming effects are modelled by the relative amount of LT and TL sentences processed at each point during the experimental session, we included in our model another predictor, which we called cumulLT. This was computed as the ratio between the number of previously processed LT sentences and the number of previously processed TL sentences, for each participant and experimental item. This ratio was empirical logit transformed so that it assumes the value of zero when the amount of LT and TL sentences previously processed is equal, and positive and negative values when there were processed more and less (respectively) LT sentences, compared to TL sentences.

Outliers are observation values that, being too distant from the other observations, are taken to be generated by processes that are not under study (e.g., participant’s inattention) and shall, therefore, be eliminated (see Ratcliff, 1993). We followed Wells et al. (2009) in choosing the cut-off value of 2.5 SD and the replacement of outliers by the values at the cut-off thresholds.

For each participant and item, cumulLT is computed by the formula log2((count LT + .5) / (count TL + .5)), where count LT and count TL are the number of previously processed LT and TL sentences.
Figure 3.1 shows the mean residualized RTs in the six conditions crossing *Prime* and *Target*. We observe that, relative to the baseline (first panel), while after LT primes (second panel), RTs are shorter (especially for LT targets), in the condition of Prime TL (third panel) RTs are higher (regardless of the Target type). This means that participants spent less time reading target sentences when they had previously processed an LT prime, and more time when the target follows a TL prime. In addition, when considering the interaction between *Prime* and *Target*, we observe that, after LT primes (second panel), LT targets (grey) are more facilitated (i.e., shorter RTs) than TL targets (red), and that after TL primes (third panel), TL targets also have shorter RTs compared to LT targets.

These effects are revealed in the main effect of TL prime and in the interactions *TL:target* and *LT:target* found significant in our regression model, presented in Table 3.3. In the model, the predictors (i.e., independent variables) entered as fixed effects are *Prime* (with three levels, in which the BL condition was the intercept against which LT and TL were contrasted), *Target* (LT, −0.5 vs. TL, 0.5), *Phrase* (NP, −0.5, PP, 0.5) and *cumulLT* (continuous, ranging from −3.16 to 3.7). The random effects are Participant (48) and Item (48), entered as intercept, as well as uncorrelated slopes of the fixed predictors.

![Figure 3.1: Experiment 1: mean residualized RTs for LT (grey) and TL (red) targets when following BL primes (first panel), LT primes (second panel) and TL primes (third panel), for the NP and PP regions collapsed.](image-url)
Table 3.3: Experiment 1; MLMEM of the residualized RTs at NP and PP. Predictors are Prime (BL, TL, LT; BL is the reference level, and the coefficients for LT, TL are relative to it), Target (LT, −0.5, TL, 0.5), Phrase (NP, −0.5, PP, 0.5) and cumulLT (continuous). The table presents the estimated model coefficients, the standard error, t-value and derived p-value.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>S.E.</th>
<th>t-value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-8.1248</td>
<td>6.6416</td>
<td>-1.2233</td>
<td>0.2210</td>
</tr>
<tr>
<td>TL</td>
<td>31.0740</td>
<td>13.8588</td>
<td>2.2422</td>
<td>0.0250</td>
</tr>
<tr>
<td>LT</td>
<td>-18.6681</td>
<td>14.3161</td>
<td>-1.3040</td>
<td>0.1920</td>
</tr>
<tr>
<td>cumulLT</td>
<td>-2.4409</td>
<td>11.0599</td>
<td>-0.2207</td>
<td>0.8250</td>
</tr>
<tr>
<td>target</td>
<td>1.1401</td>
<td>9.8239</td>
<td>0.1161</td>
<td>0.9080</td>
</tr>
<tr>
<td>phrase</td>
<td>7.4631</td>
<td>18.9481</td>
<td>0.3939</td>
<td>0.6940</td>
</tr>
<tr>
<td>TL:phrase</td>
<td>-8.8659</td>
<td>23.8376</td>
<td>-0.3719</td>
<td>0.7100</td>
</tr>
<tr>
<td>LT:phrase</td>
<td>1.3995</td>
<td>23.8204</td>
<td>0.0588</td>
<td>0.9530</td>
</tr>
<tr>
<td>target:phrase</td>
<td>17.7078</td>
<td>16.8884</td>
<td>1.0485</td>
<td>0.2940</td>
</tr>
<tr>
<td>cumulLT:target</td>
<td>-69.9621</td>
<td>16.3406</td>
<td>-4.2815</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>cumulLT:phrase</td>
<td>21.2195</td>
<td>16.4939</td>
<td>1.2865</td>
<td>0.1980</td>
</tr>
<tr>
<td>TL:cumulLT</td>
<td>-3.1032</td>
<td>24.3269</td>
<td>-0.1276</td>
<td>0.8980</td>
</tr>
<tr>
<td>TL:target</td>
<td>-45.6701</td>
<td>24.0509</td>
<td>-1.8989</td>
<td>0.0580</td>
</tr>
<tr>
<td>LT:cumulLT</td>
<td>9.7844</td>
<td>23.5402</td>
<td>0.4156</td>
<td>0.6780</td>
</tr>
<tr>
<td>LT:target</td>
<td>49.9948</td>
<td>24.1601</td>
<td>2.0693</td>
<td>0.0390</td>
</tr>
<tr>
<td>TL:cumulLT:target</td>
<td>-60.2938</td>
<td>45.7022</td>
<td>-1.3193</td>
<td>0.1870</td>
</tr>
<tr>
<td>LT:cumulLT:target</td>
<td>43.1607</td>
<td>44.0627</td>
<td>0.9795</td>
<td>0.3270</td>
</tr>
<tr>
<td>LT:target:phrase</td>
<td>41.1056</td>
<td>47.6166</td>
<td>0.8633</td>
<td>0.3880</td>
</tr>
<tr>
<td>TL:target:phrase</td>
<td>-15.6689</td>
<td>47.3444</td>
<td>-0.3310</td>
<td>0.7410</td>
</tr>
<tr>
<td>TL:cumulLT:phrase</td>
<td>10.5165</td>
<td>41.9786</td>
<td>0.2505</td>
<td>0.8020</td>
</tr>
<tr>
<td>LT:cumulLT:phrase</td>
<td>5.7702</td>
<td>40.0666</td>
<td>0.1440</td>
<td>0.8850</td>
</tr>
</tbody>
</table>

The coefficient of TL (β = 31.07) is interpreted as an increase of 31 ms in RTs, relative to BL, when the prime is TL. The interactions reveal priming effects whereby, after TL primes, TL targets have shorter RTs (β = −45.67×0.5), while LT targets have longer RTs (β = −45.67×−0.5). Likewise, after LT primes, participants are faster at LT targets, compared to TL targets (β = 49.99×−0.5; β = 49.99×0.5).

We do not find any effect of Phrase. We find, however, an interesting effect of cumulLT revealing that, the higher this ratio (reflecting participants’ higher exposure to LT sentences relatively to TL sentences) the faster participants process TL targets (and, conversely, the slower they process LT targets). We illustrate this effect in Figure 3.2, where we plot RTs as a function of Target.

3.3.6. Discussion

Our results show that the locative alternation can be primed in a comprehension task. In particular, after reading a type of prime, participants are faster to read a target of the same type, compared to a target of the alternative type. We thus replicate previous findings of priming with the locative alternation (Chang et al., 2003).
More interestingly, we found a main effect of Primer whereby, relative to a baseline condition where targets are preceded by an unrelated sentence, TL primes make targets more difficult. The converse effect (i.e., that LT primes facilitate any type of target) is not significant, but has the expected direction. In fact, when running an additional analysis on only the subset of data including LT and TL primes (i.e., excluding the BL condition), we find a main effect of Prime ($\beta = -25.04$, $p < 0.05$) indicating that participants read the targets faster after LT primes and slower after TL primes. That is, these results indicate that the two variants do not elicit equally structural priming and suggest that LT sentences facilitate both targets. We take this evidence as supporting the first of our competing hypotheses, i.e., that LT structures have a more complex representation that entails the TL representation, making them a good prime for both types of target.

As for the cumulLT effect, we believe that it reflects what are known effects of the experiential basis of syntactic processing in a syntactic priming paradigm. Indeed, the effect of facilitation of TL targets (and more difficult processing of LT targets) the more LT sentences are processed (relative to the processing of TL sentences) is consistent with reported surprisal (section 1.3.1.2) effects, through which the more one variant is processed, the less surprising it is and, therefore, the worse it is as a prime. For example, Fine, Jaeger, Farmer, and Qian (2013) showed that a given structure yielded successively weaker priming effects within the experiment as participants experienced proportionally
more exemplars of that structure (and proportionally fewer exemplars of the alternative) as the session progressed. As these authors noted, such long-term effects (i.e., along the experimental session) are consistent with an error-based mechanism, in which the deviation between expectation and outcome determines weight changes and hence ultimately levels of activation: The more unexpected a structure, the greater the subsequent weight change and hence the higher the activation level for that structure. Conversely, the less unexpected a structure (because of repeated exposure), the smaller the weight changes, and hence the lower is the activation of that structure.

Studies on the dynamics of priming (refer to section 1.3.1.2) have taken into account not only frequency in the syntactic environment of an experiment, but also frequency in the language. In our experiment, we only considered the relative amount of the two structures processed at any given point in the experiment. However, our sentences’ pre-test also revealed that the LT variant was rated, overall, as a more complex structure than TL. While this could be seen as evidence supporting theoretical proposals of a more complex representation for the LT variant, there is also substantial evidence of subcategorization biases, whereby different verbs occur more frequently with one or the other possible argument realization (see section 1.2.2).

It is possible, thus, that the rated complexity of variants in our pre-test is also a function of the individual verbs used in our sentences. In order to investigate if this was the case, we analysed further our pre-test data. Table 3.4 shows the mean complexity ratings for each variant and each of the eight verbs. Interestingly, we see that five of the verbs (engrave, print, paint, plant and sow) have higher ratings for the LT alternative, contrary to the remaining three verbs (spray, load, rub).

<table>
<thead>
<tr>
<th>Mean complexity rating (from 1: low, to 7:high)</th>
</tr>
</thead>
<tbody>
<tr>
<td>spray</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>LT</td>
</tr>
<tr>
<td>TL</td>
</tr>
</tbody>
</table>

We divided the pre-test data in two subsets, one containing the sentences with the five mentioned verbs and the other containing the sentences with the three verbs. Crucially, in the first case, the LT variant was rated as significantly more complex (mean = 2.43, SD = 1.67) compared to the TL variant (mean = 2.01, SD = 1.39), as revealed by a Wilcoxon Signed-Ranks Test (Z = 7.58, p < 0.001). The opposite pattern was found for the verbs spray, load and rub, where TL was rated as significantly more
complex (mean = 2.3, SD = 1.49) than LT (mean = 1.83, SD = 1.24), as revealed by a Wilcoxon Signed-Ranks Test ($Z = -6.58$, $p < 0.001$).\footnote{As noted by Bresnan and Nikitina (2009, p. 10), frequency effects may also affect grammaticality judgments: \textit{grammaticality judgments of the contrasting pairs of examples are (...) systematically biased by the probability of similar descriptions of the event types depicted by the examples}. The distinction we found between the two groups of verbs indeed emerges from an informal consultation to the Reference Corpus of Contemporary Portuguese (CRPC: http://alfclul.clul.ul.pt). Whether the distinction between groups of locative alternation verbs relies on events semantics remains an open question, but we stress that this grouping seems to follow a distinction between locative alternation verbs of fixation and locative alternation verbs of dispersion (Duarte, 2003; see Levin, 1993 for English verbs examples).}

In order to disentangle what can be the effects driven by subcategorization biases and the ones resulting from the experiential basis of processing (i.e., from the syntactic environment of the experiment), we ran a second experiment restricting our stimuli to sentences containing the verbs for which LT was rated as a more complex variant (\textit{engrave, print, paint, plant} and \textit{sow}).

### 3.4. Experiment 2: priming locative alternation verbs with a Theme-Location preference

We have suggested that LT constructions might be an effective prime for both locative alternation variants due to their hypothesized higher complexity of lexical encoding, which would embed a lexical representation for the TL construction (Rappaport & Levin, 1988), somehow activating a syntactic representation that would prime both structures. We also saw, however, that the different verbs we used seem to have different subcategorization biases and, moreover, that the relative proportion of LT and TL sentences processed along the experiment modulated priming.

In Experiment 2, we use sentences with verbs that apparently have a TL preference. Therefore, we shall assume the LT variant is, in these cases, less preferred and expected. If dynamic effects like surprisal-sensitivity (whereby a less expected prime elicits more priming than a more expected prime, see section 1.2.2) are mostly due to subcategorization biases, we might expect that in Experiment 2, more than in Experiment 1, a main effect of prime is found, indicating that the less preferred variant is a better prime. If these effects reflect, instead, the proportionality of each variant in the syntactic environment of the experiment, we might expect priming to be a function of how surprising each prime is at a particular trial. We operationalize surprisal for each trial, considering the type of prime (say, LT), as the ratio of the number of previously processed sentences of the alternative structure (TL) and the number of previously processed sentences with the same structure (LT)\footnote{For an LT prime, prime surprisal ($\text{primeSurp}$) is $-\log2 \left( \frac{\text{count } LT + .5}{\text{count } TL / .5} \right)$, where \text{count } LT and \text{count } TL are the number of previously processed LT and TL sentences, while for a TL prime it is $-\log2 \left( \frac{\text{count } TL + .5}{\text{count } LT / .5} \right)$.}. That is, while in Experiment 1 we...
used a measure that assessed the relative amount of the alternative structures at each trial, but ignoring the specific type of prime of that trial, we now estimate precisely how surprising the specific prime type in that particular trial is. By doing so, we tap into the effects of surprisal that are not a function of the subcategorization bias of verbs, but only of the experiential basis of the structures during the experiment. Thus, if indeed adapted surprisal (i.e., along the experiment, cf. Jaeger & Snider, 2013) modulates priming, a main effect of Prime Surprisal is expected.

### 3.4.1. Participants

Forty native European Portuguese speakers from the University of Lisbon participated voluntarily in the experiment. All subjects had normal or corrected-to-normal vision.

### 3.4.2. Design and Materials

Five locative alternation verbs with a TL preference (*engrave, print, paint, plant* and *sow*) were used to create 40 critical prime-target pairs (provided in Appendix A). In order to have a clearer contrast of the levels of prime, we did not include a baseline. The design, thus, crossed *Prime* and *Target*, as illustrated in Table 3.5. The forty experimental pairs occurred in 4 different lists according to a Latin Square design. For all lists, prime-target pairs were separated by 2 to 3 randomly selected filler sentences, like in Experiment 1. Items’ order was a function of random selection in each list. In each list, 50% of the filler sentences were followed by a comprehension question.

**Table 3.5:** The four condition cells of Experiment 2, crossing Prime and Target.

<table>
<thead>
<tr>
<th>‘Prime Type’</th>
<th>TL</th>
<th>LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Target Type’</td>
<td>TL→TL</td>
<td>LT→TL</td>
</tr>
<tr>
<td>LT→LT</td>
<td>LT→LT</td>
<td></td>
</tr>
</tbody>
</table>

### 3.4.3. Pre-tests

We pretested the experimental sentences (40 items, each in both TL and LT versions) using the same questionnaire as in Experiment 1, adapted from Gruber and Gibson

\[((\text{count TL} + .5)/(\text{count LT} / .5))\]. We follow Jaeger and Snider (2013) in this operationalization of surprisal.
(2004). Participants (N = 22) rated the two variants of each item as describing fundamentally the same situation (mean = 2.10), and as a plausible situation (mean = 2.05). As expected, LT sentences were rated as a more difficult, complex or unnatural way of expressing that situation (mean = 2.626, SD = 0.983) compared to TL variants (mean = 1.753, SD = 0.489). A paired samples T-Test revealed the difference between TL and LT ratings was significant (t (21) = 4.751, p < 0.001).

### 3.4.4. Procedure

The procedure was identical to the one of Experiment 1.

### 3.4.5. Results

All 40 participants answered correctly to more than 85% of the questions, so all their data were analysed. Like in Experiment 1, RTs were length-residualized and outliers were removed using a cut-off of 2.5 SD (affecting 1.25% of the data). We analysed, as before, RTs at the NP and PP regions using MLME with a maximal-random structure. The predictors entered in the model are Prime (LT, −0.5 vs. TL, 0.5), Target (LT, −0.5 vs. TL, 0.5), Phrase (NP, −0.5, PP, 0.5) and Prime Surprisal (primeSurp, continuous, ranging from −3.16 to 1.87). The random effects are Participant (40) and Item (40), entered as intercept, as well as uncorrelated slopes of the fixed predictors.

Figure 3.3 shows the mean RTs for the four conditions crossing Prime and Target, at the NP (two leftmost panels) and PP (two rightmost panels) regions. We present the two regions’ RTs because, this time, we found a significant effect of Phrase.

The fixed predictors entered in the MLME are Prime (LT, −0.5 vs. TL, 0.5), Target (LT, −0.5 vs. TL, 0.5), Phrase (NP, −0.5, PP, 0.5) and primeSurp (continuous, ranging from −3.16 to 3.7). The random effects are Participant (40) and Item (40), entered as intercept, as well as uncorrelated slopes of the fixed predictors. Table 3.6 summarizes the fitted model.

We observe, like in Experiment 1, that participants read faster both types of target when they are primed with LT. However, Prime has not a significant main effect. We observe significant main effects of PrimeSurprisal and Phrase, indicating participants are faster reading targets when the sentence immediately before (prime) was more surprising, as well as at the NP region.

The interaction Prime:Target, indexing priming with both variants, is only significant when interacting with PrimeSurprisal, i.e., priming is a function of prime surprisal.
Furthermore, we observe a four-way interaction of Prime, Target, PrimeSurprisal and Phrase, indicating that the priming effect is especially seen at the NP region.

Table 3.6: Experiment 2; MLMEM of residualized RTs at NP and PP. Predictors are Prime (LT, −0.5, TL, 0.5), Target (LT, −0.5, TL, 0.5), Phrase (NP, −0.5, PP, 0.5) and primeSurp (continuous). The table presents the estimated model coefficients, SE, t-value and derived p-value.
To illustrate this effect Figure 3.3 plots the RTs as a function of Prime Surprisal at the NP region. The plot shows a clear decrease in RTs when a target is preceded by a similar prime (TL-TL, LT-LT) along the increasing value of prime surprisal.

### 3.4.6. Discussion

In Experiment 2, we aimed at distinguishing effects driven by subcategorization biases and by the relative amount of experience with the variants along the session. We tested five verbs that, being biased towards TL, have in LT a less frequent or preferred argument realization.

We did not replicate the main effect of Prime found in Experiment 1, whereby LT sentences prime both LT and TL targets (although there is a similar trend, as illustrated in Figure 3.3). Moreover, the interaction of Prime and Target is not significant unless the Surprisal of the prime is entered in the model. That is to say, participants read faster a type of target (e.g., LT) when it follows a prime of the same type (LT) and that type was less experienced in the session (i.e., participants were more exposed to TL).

These results suggest that, when Surprisal of a prime sentence is considered, its effects override what can be effects driven by subcategorization biases.
3.4.7. General Discussion

Experiments 1 and 2 tested sentences containing locative alternation verbs. We aimed at providing empirical evidence supporting linguistic theories of the lexical representation of those verbs.

In Experiment 1, we showed that the variants of this alternation, characterized by a different surface order of the arguments of the verb associated with the Theme and Location semantic roles (Theme-Location; TL and Location-Theme, LT), do not elicit priming in the same extent. In particular, our data show that sentences of the LT variant facilitate both LT and TL targets. That is to say, participants read faster any of the variants when they previously processed an LT sentence. We believe this result supports Rappaport and Levin (1998)’s approach to this alternation, where the LT variant is postulated to have a more complex representation that entails the representation of the TL variant.

In addition, we replicated previous findings of priming with this alternation for both variants, by which a type of sentence is facilitated when preceded by another sentence of the same type (compared to a prime with the alternative structure). Moreover, these results are found in a comprehension task, in contrast with previous studies (Chang et al., 2003). Since syntactic priming seems more elusive in comprehension than in production, and the difference between the modalities’ sensitivity to the effects remains under debate (refer to Chapter 1 and Chapter 4 for references), our study provides novel and relevant evidence corroborating the similarity of the processing modalities.

We also assessed the effects related with the experiential basis of syntactic processing. In particular, we showed that the syntactic environment a comprehender is faced with influences the way he processes syntactic structures in that experiencing one of the structures more makes the alternative to that structure easier to process.

In Experiment 2, we provided further evidence of how priming effects are a function of the characteristics of the distribution of alternative structures along an experimental session. The priming effects indexed by shorter reading times of target sentences of the same type of the prime sentence were found only significant when considering how much the prime type was expected, given the previously processed sentences at a given point in the experiment. In consonance with recent proposals of syntactic priming as an implicit-learning, expectation-adaptation mechanism (Jaeger & Snider, 2007, 2013), we showed that a less expected prime is a better prime than a more expected one. Importantly, we provide evidence of Surprisal effects during comprehension, and in a task where the overall probability of the alternatives (TL or LT) was equally 0.5. Previous research (Fine et al., 2013) has, in fact, reported such effects during comprehension, but in studies where the design of the experiments strongly biased the experience of the structures towards one of the alternatives.
3.4.8. Conclusions

In Chapter 3, we reported two experiments that used syntactic priming to investigate the mental representation of the locative alternation structures. We demonstrated how relevant empirical evidence can be to linguistic theory, by helping to distinguish contrasting views of theorists whose proposed constructs are not usually experimentally tested. Of course, the psycholinguistics data are not easy to interpret and usually do not provide strongly conclusive results, as it is very difficult to control for all variables influencing language processing. Ultimately, we cannot claim such data definitely support one theory and reject the other. In the particular case of lexical representations, for example, we could always make further assumptions of how other components of the language system (and indeed other cognitive components) could be considered to account for the data. As we noted before, the proposal of a same structural representation for the locative alternation, as proposed, e.g., by Borer (2005) could be accommodated by postulating differences in another component such as the making sense component of the system. That said, however, we believe our data, showing that the two variants of the locative alternation behave differently in a syntactic priming paradigm, support Rappaport and Levin (1998)’s predicate decomposition approach to the representation of this alternation.

Another relevant issue that is not commonly considered by these theories is the variation between items like verbs, languages or individual differences. Psycholinguistics attempts, precisely, to make generalizations while taking into account such variability. Nevertheless, we are always being faced with the difficulty of such enterprise and with evidence of multiple factors intervening in such a complex cognitive function as language processing. The last decade was particular fruitful in findings suggesting syntactic priming is more complex than it might look at first. It is now clear that the statistics of the syntactic environment, either in a language, for an individual, or in the design of an experiment, modulate effects that have been for long assumed as a straightforward relationship between activation of mental representations and their subsequent facilitated access. We gave corroborating evidence of the sensitivity of priming to Surprisal during an experiment. Moreover, we observed different effects for the two variants that can index not only differences in mental representations but also differences in the frequency of the variants for particular items or in the whole language. Therefore, our study raises the question of if, and how, could frequency and representation complexity be related. For instance, it is possible to question whether LT is an overall less frequent alternative, in different languages. If that was the case, this could be seen as a way of our language system to avoid using structures that impose greater processing load. On the other hand, assuming it is the lower frequency of occurrence that makes one structure more ‘complex’ (in that a non-expected linguistic item may be more demanding cognitively,
e.g., because it captures more attentional resources), one can question where, in the language or cognitive system, is that information stored. Implicit learning accounts of syntactic priming (see section 1.3.1.1) have proposed layers in the system where activation of linguistic representations varies according to the system’s experiences. However, many questions remain to be answered, as research constantly updates its findings and there is, today, a truly complex pattern of syntactic priming results, which are not easily accommodated in a parsimonious model.

To sum up, this Chapter showed syntactic priming can be used to test linguistic theories about representations and also to investigate how syntactic processing is modulated by how comprehenders experience structures during an experiment.

In the next Chapter, we go one step further in unravelling the experiential basis of syntactic processing in a syntactic priming task.
4. Priming RCs’ attachment disambiguation: investigating the experiential basis of syntactic processing

4.1. Introduction

As we saw in section 1.3, the underlying mechanisms of syntactic priming have been a central topic of this research area, especially in the past fifteen years. A renewed interest in the topic was driven by studies suggesting that the phenomenon is more complex than traditional studies have assumed. Indeed, while most studies have investigated syntactic priming through experiments where a typical design crossed prime and target types within a trial where one target followed one prime, and accepted transient activation as explaining the effects, more recent research has broaden the scope of research by investigating the time-course of the effects both within-trial and along an experiment. As we saw in section 1.3.1.1, studies manipulating the lag between prime and target (e.g., Bock & Griffin, 2000) motivated a new explanation of syntactic priming as an implicit learning phenomenon. Moreover, a series of studies (refer to section 1.3.1.2) focused on how the experience with the tested syntactic structures, both in a language and along an experiment, modelled the effects. Jaeger and colleagues, in particular (Jaeger & Snider, 2007, 2013; Fine & Jaeger, 2013; Fine et al., 2013), provided strong evidence of how syntactic processing is a function of the pattern of experience with syntactic structures. The expectation-adaptation hypothesis, postulating that comprehenders constantly update their expectations for syntactic structures according to the statistics of the syntactic environment, was proposed to account for the apparent contradictory effects of surprisal
and cumulativity. While the first is reflected in stronger priming the more surprising (i.e., less expected) a prime is, the second reveals itself in stronger priming following cumulative presentation of primes.

The dynamics of syntactic priming remain largely under debate, and this is a key issue for syntactic priming, as it has implications for what are assumed to be the underlying cognitive mechanisms involved. While expectation-adaptation (building on implicit learning accounts) is an appealing theory, questions remain open, and more research is needed for a computational model like Chang et al. (2006)’s to account for the complex pattern of found results.

In section 1.3.1.2, we referred an important study conducted by Jaeger and Snider (2013, Study 3), where the experience with dative structures (DO/PO) was manipulated by having the two alternatives alternating during the experiment or blocked, so that participants only experienced one type of structure in the first half, and the alternative structure in the other half of the experiment. Both effects of surprisal and cumulativity were found, when analysing the responses across all items. However, we should note, because a finer-grained analysis is not provided, we cannot safely say at which point in the experiment surprisal or cumulativity are more relevant. It is possible, for example, that cumulative effects arise after repeated presentation of one structure in the first part of the blocked condition, where participants are only presented with one type of sentence. Likewise, surprisal might be an effect with greater significance at the initial trials of the second half of the experiment, where a new type of structure is presented, after accumulated presentation of the alternative sentence type.

More importantly, this, as well as other studies (refer to section 1.3.1.2) manipulated the amount of exposure to each structure along the experiment, i.e., at a long-term. It remains, therefore, to be seen how the amount of experience within a trial might modulate the magnitude of priming. In this Chapter, we precisely investigate how prime repetition within a trial influences priming. As we shall see, although it has been (at least tacitly) assumed that this repetition should increase priming effects, this might not be the case necessarily. In this Chapter, we report two experiments addressing this question, and we demonstrate that indeed this is not the case, at least for the materials and task we used. We suggest that additional mechanisms shall be considered to account for the experiential basis of syntactic processing.

### 4.2. Background

As we mentioned before, syntactic priming in comprehension seems to be more elusive than in comprehension. In reading, the effects of experiencing a single prime appear to be relatively weak. For example, Traxler (2008) found that when participants read sentences
with an ambiguous prepositional phrase (e.g., *The vendor tossed the peanuts in the box into the crowd during the game*), they were faster to read the disambiguating region (*into the crowd*) when they had previously read a prime involving the same analysis (e.g., *The girl tossed the blanket on the bed into the laundry this morning*) than a prime involving the alternative analysis (e.g. *The girl tossed the blanket into the laundry this morning*), but only when the verb was repeated. (see also Branigan, Pickering, & McLean, 2005; Traxler & Tooley, 2008; Tooley, Traxler, & Swaab, 2009; though see Kim, Carbary, & Tanenhaus, 2014; Pickering, McLean, & Branigan, 2013).

Other studies suggest stronger priming effects occur following exposure to multiple primes. Noppeney and Price (2004) found facilitation without verb repetition when participants read blocks of five ambiguous sentences with the same structure (e.g., reduced relatives like *The child left by his parents played table football*) compared to sentences with different structures (e.g., sentences containing reduced relatives and sentences with a main clause interpretation like *The artist left his sculptures to the British Museum*), and reported corroborating decreased activity in the left anterior temporal region (associated with semantic and syntactic processing) in the repeated-structure condition (see Mehler & Carey, 1967, 1968; Carey, Mehler, & Bever, 1970 for additional evidence of priming with multiple primes). Participants also showed a reduction in reading times for locally ambiguous sentences that persisted over an experimental session (Fine et al., 2013) and even several days or weeks (Wells et al., 2009) after they had been repeatedly exposed to the same structure. This pattern of results is consistent with stronger activation of a syntactic representation following exposure to more than one exemplar of a structure (i.e., prime) than following exposure to a single exemplar.

All these studies measured facilitation through reading times on words that were consistent or inconsistent with a particular structure, and thus examined whether prior exposure to syntactic structure affected how easily incoming material could be reactively integrated with the current parse. More recent research has used a visual world paradigm to investigate whether it also affects comprehenders’ predictions about upcoming structure prior to encountering disambiguating material. In the VWP, as we showed in section 2.1.2, sentence comprehension is performed concurrently with a visual context. Participants’ linguistic predictions (and their time-course) can be investigated by tracking anticipatory eye-movements to visual referents depicted in the context as participants hear the sentence unfold.

Importantly, two VWP studies have shown that comprehenders’ structural expectations are affected by immediately prior structural experience, i.e., syntactic priming (Arai, van Gompel, & Scheepers, 2007; Thothathiri & Snedeker, 2008).
In Arai et al.’s study, participants first read aloud a prime sentence with either a double object (DO) or a prepositional object (PO) structure (e.g., *The assassin will send the dictator the parcel/to the dictator*). They then heard an auditory target sentence (DO or PO, e.g., *The pirate will send the princess the necklace/to the princess*) while concurrently viewing a picture depicting the corresponding agent (PIRATE), recipient (PRINCESS), and theme (NECKLACE) objects, like Figure 4.1. Upon hearing the verb *send* (and before the onset of the following NP), participants were more likely to anticipate the object congruent with the primed sentence: after a DO prime there were more looks at the recipient object, and conversely, after reading a PO prime there were more looks at the theme object. However, this priming effect only occurred when the verb was repeated. There was no priming when the prime involved a different verb (e.g., *The assassin will give the dictator the parcel/to the dictator*).

Thothathiri and Snedeker (Experiment 3)\(^\text{14}\) also studied comprehension of PO/DO sentences, but using an act-out spoken comprehension task in which participants were exposed to two primes. Participants first heard two auditory DO or PO primes embedded in a context story (e.g., DO: *...a nice bookstore clerk sold the secretary a book. That night, John read his daughter a story*; PO: *...a nice bookstore clerk sold a book to the secretary. That night, John read a story to his daughter*). Then, they heard a target DO or PO dative sentence containing a different verb (e.g., DO/PO: *Now you can give the leopard the sock/give the letter to the bird*) while their eye-movements to objects (LEOPARD, LETTER, SOCK, BIRD) on a podium were recorded. After hearing two DO primes, participants made more looks to the recipient (LEOPARD) compared to the

\(^{14}\) Thothathiri and Snedeker carried out two further experiments in which they found priming effects. However, both experiments involved a between-participants design that may have induced deliberate strategies, because participants could have realized that the prime and target sentences always had the same structure and adjusted their expectations accordingly, as Thothathiri and Snedeker noted.
theme (LETTER) objects, consistent with a DO analysis, during a time-window of 400 ms from the onset of the noun in the NP following the verb (leopard/letter). As Thothathiri and Snedeker observed, this window may have included disambiguating material, and hence did not necessarily tap into purely predictive processing (a possibility also reinforced by the fact that they found an effect of target structure in this window). These results are consistent with syntactic priming (that was not dependent on repetition of the verb), but it is not clear whether priming affected comprehenders’ anticipatory structural predictions, or the integration of material following disambiguation.

In sum, prior exposure to syntactic structures has been shown to affect subsequent comprehension, and evidence from a VWP suggests such effects can manifest themselves as anticipatory prediction of the primed structure. Whereas syntactic priming without verb repetition has been consistently found following multiple primes, it has been much less consistently found following a single prime. These results suggest that levels of activation for the primed structure are different during processing of the target sentence after experiencing a single prime versus multiple primes.

We already mentioned the main models of syntactic priming that have been put forward (section 1.3.1.1). Each of them appeals to a different type of mechanism: transient residual activation or implicit learning. The first was put forward to account for short-term effects (across adjacent sentences), while the second was motivated by evidence of long-lasting priming (across many sentences). Both of these models were proposed to account for syntactic priming in production, but have also been applied to comprehension. In activation accounts, activation does not decay immediately, so that a previously processed structural representation retains residual activation that makes it a better candidate for subsequent selection than an unprimed alternative. In implicit learning accounts, the primed structure has higher activation during processing of the target because of changes in the connection weights in the system supporting syntactic processing. Exposure to a structure leads to adjustments of the relative weight of its representation (and of alternative structures). Processing one structure makes the weights associated with that structure (and hence its activation) greater, relative to an unprimed alternative, and the system maintains these relative weights until new evidence imposes changes to them.

Neither model can explain the full spectrum of syntactic priming results, with residual activation accounting for short-term priming and the lexical boost to priming when verbs are repeated, but not for long-lasting effects, and implicit learning accounting for long-lasting effects but not the lexical boost. Accordingly, it has been argued that both mechanisms are relevant. A transient activation component might relate to short-term effects, whereas implicit learning could underlie longer-term effects. If this were the case, then activation levels for the primed structure might be determined by different
mechanisms over different timeframes: Priming over short timeframes might be primarily determined by transient activation, whereas priming over longer timeframes might be determined by long-lasting changes in weights associated with different structures.

In this Chapter, our main concern is how priming is affected by exposure to one or more primes. We have seen that there is some evidence that priming in comprehension may be stronger following multiple primes, and in fact some studies have repeated prime structures on the (implicit) assumption of a straightforward linear relationship between number of exposures and magnitude of priming (e.g., Thothathiri & Snedeker, 2008; see Pickering & Branigan, 1998, for production).

However, recent research suggested that the activation level of the primed structure is not simply additive with increasing exposure, as we showed in section 1.3.1.2. In fact, the magnitude of priming appears to be modulated by our prior expectation of the primed structure, at many levels of granularity. This includes previous experience of a particular structure with respect to an experiment and to the language as a whole, as well as the frequency of the structure in conjunction with relevant verbs (e.g., Fine & Jaeger, 2013, Fine et al., 2013; see also Bernolet & Hartsuiker, 2010; Jaeger & Snider, 2013, for related evidence from production). For example, Fine and Jaeger (2013) reanalysed Thothathiri and Snedeker (2008)'s data, and showed that the reported main effect of prime structure remained only marginally significant when prime surprisal (computed as the probability of the structure for each particular verb and context story) and the prime structure-prime surprisal interactions were included in the model. These data suggest that the effect of prime may be driven by the high-surprisal primes, and, therefore, that the assumption of a linear additive relationship does not hold for a long-term component of syntactic priming.

But what about immediate priming based on transient residual activation? It is possible that sequential exposure to more than one prime might increase activation levels in a straightforwardly additive manner, so that priming would be stronger after experiencing two prime sentences than after experiencing one prime sentence. However, this need not be the case. Most obviously, activation levels might be subject to ceiling effects, so that exposure to more than one prime would not raise activation levels beyond exposure to a single prime. In that case, any priming based on residual activation would be equally strong after one prime as after more than one prime.

Perhaps more interestingly, evidence from a range of cognitive domains (e.g., social cognition, visual cognition) suggests that activation of representations is sometimes reduced rather than enhanced following repeated or prolonged exposure (e.g., Laing & Chow, 2002; Lombardi, Higgins, & Bargh, 1987). With respect to language, models of lexical processing in production assume that representations are deactivated immediately following use, in order to avoid interference in subsequent processing (e.g., perseveration
errors; Dell, Burger, & Svec, 1997). Similarly, there is evidence for suppression in lexical processing in comprehension, whereby an activated representation is inhibited after some period of exposure. Huber, Shiffrin, Lyle, and Ruys (2001; see also Huber, Shiffrin, Quach, & Lyle, 2002) found that participants showed facilitation for the unprimed word (relative to the primed word) in a word-selection task after prolonged exposure to the prime, although they showed the usual facilitation for the primed word when exposed to the prime for a short duration. They interpreted their results in terms of an accommodation mechanism, whereby an initial increase in the activation of primed information would be ‘discounted’ (by lowering its activation level) after prolonged exposure, to allow unobstructed subsequent processing. These results suggest that cognitive, and specifically linguistic, representations are not always facilitated following short term activation, but may instead be subject to temporary suppression under certain circumstances.

Although substantial recent research on syntactic priming has focused on how variations in exposure to particular structures can affect processing of those structures over the long-term, very few studies have addressed whether, and if so how, variations in exposure to particular structures might modulate immediate processing of those structures, i.e., immediate priming. In this Chapter, we therefore examine whether participants’ anticipatory syntactic processing during comprehension can be affected by prior exposure to one or more than one prime sentence with a particular syntactic structure. Our particular concern is whether exposure to more than one prime would result in stronger immediate priming than exposure to a single prime, as has often been tacitly (and in at least some cases, explicitly) assumed, or whether immediate priming might not be straightforwardly additive with repeated exposure, in the same way as long-term priming.

To address this issue, we conducted two VWP experiments in Portuguese. Participants read aloud one or two relative clause (RC) prime sentences (Activation 1 and Activation 2), in which ambiguity was morphologically disambiguated on the auxiliary verb to one or the other attachment (HA or LA reading; e.g., HA: *O ajudanteSING dos padeirosPL que vaiSING distribuir o pão chegou* , ‘The helper of the bakers who will deliver the bread has arrived’; see Table 4.1). They then listened to a RC target sentence (e.g., *O paiSING do bebéSING que vaiSING beber a cerveja é alto*, ‘The father of the baby who will drink the beer is tall’), in which the RC was temporarily ambiguous between a high-attachment (to the first noun phrase, NP1) and a low-attachment (to the second noun phrase, NP2): Either the father or the baby could be the antecedent of the pronoun *who* (see Table 4.1). Disambiguation occurred at the NP following the verb, and was based on pragmatic knowledge (here, that it is more likely for the father to drink the beer than the
baby bottle, and conversely that it is more likely for the baby to drink the baby bottle than the beer; Knoeferle, Crocker, Scheepers, & Pickering, 2005).

Target sentences were presented concurrently with visual contexts depicting the referents mentioned in the sentence (here, the FATHER, the BABY, the BEER and the BABY BOTTLE). Building upon previous work (e.g., Altmann & Kamide, 1999), we expected participants’ eye movements to reflect their predictions about as-yet unencountered information in the unfolding sentence. As in Arai et al. (2007), we interpreted such anticipatory eye-movements as an index of syntactic priming. For example, when participants heard who will drink and before they heard the disambiguating NP (the beer vs. the baby bottle), looks to the BEER (Object 1: O1) would reflect a prediction that the relative clause would be high-attached (to NP1; the father), whereas looks to the BABY BOTTLE (Object 2: O2) would reflect a prediction that the relative clause would be low-attached (to NP2; the baby). Our measure was therefore proportions of looks to O1 versus O2 in the time-window prior to disambiguation.

If repeated exposure to a structure linearly strengthens its activation (as largely assumed in previous work), participants should display stronger priming (e.g., more looks to O1 following HA primes) after two primes than after one prime (i.e., Activation 1 < Activation 2). If however short-term activation is subject to ceiling effects, then exposure to a second prime might not enhance priming beyond that yielded by exposure to a single prime (i.e., Activation 1 = Activation 2). Finally, if short-term activation of syntactic information does not increase linearly with repeated exposure, but is instead susceptible to temporary inhibition, we might find that priming would be reduced, or possibly even absent, following two primes compared to following a single prime15 (i.e., Activation 1 > Activation 2).

Our main interest is in how prior exposure affects prediction of syntactic structure before encountering any disambiguating material. We therefore measured eye movements from the onset of will until the onset of the direct object. However, for consistency with previous research that focused on the disambiguating window (Thothathiri & Snedeker, 2008), we also investigated a late disambiguation window from the onset of the direct object. By investigating both an early anticipatory window and a late disambiguation window, we were better able to elucidate the time-course dynamics of syntactic priming during situated language understanding.

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15 The pattern of a smaller priming effect following two primes than following a single prime would also be accounted by an error-based learning mechanism that makes the second prime less unexpected and, therefore, a worse prime; see Fine & Jaeger, 2013.
4.3. Experiment 3: short-term syntactic priming during comprehension

Experiment 3 investigated whether participants’ anticipation of syntactic structure during comprehension of sentences involving relative clauses with ambiguous attachment was affected by immediate prior exposure to one or two sentences involving one of the possible attachments.

4.3.1. Participants

Twenty-four students at the University of Lisbon who were native speakers of European Portuguese participated voluntarily in the experiment. All subjects had normal or corrected-to-normal vision.

4.3.2. Design and Materials

We constructed 48 experimental items (see Appendices for a full list of materials), each consisting of three stimuli, as illustrated in Table 4.1. In each trial, two written sentences served as primes, which appeared in written trials, and a spoken sentence combined with a picture served as the target, which appeared in visual world trials.

Table 4.1: Example of stimuli in Experiment 3.

<table>
<thead>
<tr>
<th>(1)</th>
<th>Written primes in Activation 1 condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Filler</td>
</tr>
<tr>
<td></td>
<td>A turista francesa vai passear por Portugal durante duas semanas.</td>
</tr>
<tr>
<td></td>
<td><em>The French tourist will visit Portugal for two weeks.</em></td>
</tr>
<tr>
<td>(b)</td>
<td>High attachment: to NP1 (Low attachment: to NP2)</td>
</tr>
<tr>
<td></td>
<td>O ajudante (ajudantes) dos padeiros (do padeiro) que vai distribuir o pão chegou (chegaram).</td>
</tr>
<tr>
<td></td>
<td><em>The helper (helpers) of the bakers (baker) who will [sg] deliver the bread has (have) arrived.</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(2)</th>
<th>Written primes in Activation 2 condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>High attachment: to NP1 (Low attachment: to NP2)</td>
</tr>
<tr>
<td></td>
<td>O irmão (irmãos) dos herdeiros (do herdeiro) que vai ler o testament é (são) de França.</td>
</tr>
<tr>
<td></td>
<td><em>The brother (brothers) of the heirs (heir) who will [sg] read the will is (are) from France.</em></td>
</tr>
<tr>
<td>(b)</td>
<td>High attachment: to NP1 (Low attachment: to NP2)</td>
</tr>
<tr>
<td></td>
<td>O ajudante (ajudantes) dos padeiros (do padeiro) que vai distribuir o pão chegou (chegaram).</td>
</tr>
<tr>
<td></td>
<td><em>The helper (helpers) of the bakers (baker) who will [sg] deliver the bread has (have) arrived.</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(3)</th>
<th>Visual-World Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High attachment: to NP1 (Low attachment: to NP2)</td>
</tr>
<tr>
<td></td>
<td>O pai do bebé que vai beber a cerveja (o biberão) é alto.</td>
</tr>
<tr>
<td></td>
<td><em>The father of the baby who will [sg] drink the beer (the baby bottle) is tall.</em></td>
</tr>
</tbody>
</table>
Primes consisted of either a filler sentence (1a) followed by an RC sentence morphologically disambiguated to an HA or LA interpretation (1b; Activation 1) or two RC sentences morphologically disambiguated to an HA or LA interpretation (2a–b; Activation 2). The target sentence was pragmatically disambiguated to an HA or LA interpretation (Target: HA vs. LA). This resulted into a $2 \times 2 \times 2$ (Prime: HA vs. LA × Target: HA vs. LA × Activation: Activation1 vs. Activation2) repeated-measures design.

In addition to the experimental items, we constructed 96 filler sentences that did not contain relative clauses (48 sentences with ditransitive verbs and 48 sentences with conjoined constructions). Of these, 64 were spoken sentences associated with a visual scene (visual world trials) and 32 were written sentences to be read aloud (written trials). Thus, the proportion of written and visual world trials was reversed in fillers (1:2), compared to experimental items (2:1). The filler sentences (between 1 and 3) separated experimental triplet trials. Participants therefore encountered written-written-spoken sequences of experimental items interspersed with different number and types of written and spoken fillers. This way the experimental manipulation was not transparent to participants, controlling for possible learning strategies.

Eight lists were constructed, each comprising six experimental items from each condition, with exactly one version of each item appearing in each list, according to a Latin Square design, together with the 96 filler sentences; participants were randomly assigned to each list of 240 sentences. The experiment lasted for about 45 minutes. Items were presented in an individually randomized order, subject to the constraint that at least one filler intervened between each critical experimental item.

Figure 4.2: Schematic representation of an experimental trial with a visual context depicting the entities mentioned in the spoken target sentence *The father of the baby who will drink the beer/the baby bottle is tall*: the pronoun antecedents (S1: FATHER and S2: BABY) and verb’s objects (O1: BEER and O2: BABY BOTTLE), a central object (VACUUM CLEANER) and a distractor object (STOOL).
Target sentences were recorded on a digital Marantz PMD 670 tape recorder with a DPA 4060 microphone (inserted on a headset), inside a semi-anechoic chamber, by a female native speaker of European Portuguese instructed to use a neutral intonation. The mono recordings were registered at 44100 Hz, saved as wave-files and edited: For each item, the onsets of the auxiliary verb *vai* (will), the main verb and the determiner of the post verbal NP were hand-coded in milliseconds (means: 2309 ms (SD = 297 ms), 2683 ms (SD = 306 ms) and 3259 ms (SD = 357 ms), respectively).

Each target sentence was paired with a visual context array where target objects were pasted in images using GIMP (32-bit PNG files at 1024×768 pixels resolution). They were resized to fit the eye-tracker screen resolution of 1440×900 pixels, subtending 27 × 18 degrees. Each picture (see Figure 4.2) contained six target objects, corresponding to the two possible agents of the main action to which the relative pronoun referred (FATHER and BABY in (3)), two possible arguments of the main verb (drink; BEER and the BABY BOTTLE), and two other objects: a distractor and a central object (to account for the central fixation bias: see, Tatler, 2007).

The target objects were arranged in the array around an imaginary circle so that the distance between every two depicted objects was never smaller than 300 pixels. Given the distance of 75 cm separating participants from the screen, this meant that objects were separated by more than 6 degrees of visual angle. This is about three times the distance of 2 degrees of visual angle at which object recognition deteriorates sharply (Findlay & Gilchrist, 2003, p. 138; Nelson & Loftus, 1980); we can therefore assume that fixations on one object reveal processing only of that specific object, and that a saccade must be made if another object is intended to be fixated.

To keep participants’ attention focused, we asked a comprehension question about the agent carrying out the action after each experimental item (e.g., *who will drink the beer?*), as well as in half of the fillers (16 visual trials and 32 written sentences). This question enabled us to restrict the analysis of fixation data on the experimental items where the attachment (LA vs. HA) at target sentences was correctly understood by the participants.

### 4.3.3. Pre-tests

Target sentences (e.g., *The father of the baby who will drink the beer is tall*) were pretested by asking participants who was the agent of the action (i.e., *the father or the baby*, thus choosing an attachment of the RC), and to score both their confidence on the attachment answer and the acceptability of the sentence (on a Likert scale from 1 [not at all confident/acceptable] to 7 [completely confident/acceptable]). The 96 sentences (48 sentences in either the HA or LA Target conditions) were presented in two random orders.
to fifteen participants. Each participant rated all 96 sentences so that the two conditions of an item were scored by the same participant.

Although target sentences were pragmatically disambiguated, both attachments were grammatical and hence participants could low-attach an HA target, and vice versa (e.g., interpreting *the baby* as the agent of *drink the beer*). Consistent with previous research demonstrating a LA preference in Portuguese (Maia, Fernández, Costa & Lourenço-Gomes, 2007), accuracy was higher for LA attachment (mean = 0.95, SD = 0.21) compared to HA attachment (mean 0.58, SD = 0.49). However, participants were equally confident when responding to both Target types, with mean ratings of LA (5.8) not significantly higher than HA (5.4), as indicated by a Wilcoxon Signed-Ranks Test (Z = −0.68, p = 0.51). Similarly, acceptability ratings of the sentences were not significantly higher in the LA (5.1) compared to the HA (4.4) condition (Z = −1.24, p = 0.22).

### 4.3.4. Procedure

Participants’ eye-movements were recorded using an SMI IVIEW X™ HI-SPEED eye-tracker at a sampling rate of 1250 Hz on a 21” screen (1024 × 768 pixels image resolution). Viewing was binocular but only the participant’s dominant eye was tracked. Connected to the participant’s PC was a satellite speaker and subwoofer system for auditory presentation. The experiment began with a nine-point calibration procedure. A 5-point calibration was repeated every 4 critical trials (20 sentences) or whenever the experimenter found it necessary. We accepted calibration when the degree angle deviation was smaller than 0.5 for x and 1 for y. In an initial screen, we instructed participants to read aloud the written sentences and listen carefully to auditory sentences while paying attention the visual context in preparation for comprehension questions. Eight practice trials (six written sentences and two visual world trials) were initially presented.

A reading stimulus always started with a fixation cross in the centre of the screen that the participant had to fixate to trigger the presentation of the written sentence. After reading the sentence aloud, the experimenter pressed a response button to trigger the presentation of the next sentence. Visual-world stimulus also started with a fixation cross which triggered, upon fixation, the presentation of the visual context (previewed for one second) and then the sentence was played. The visual context remained on the screen for one second after the spoken sentence terminated, and then a new trial started. Critical trials were composed of two written stimuli and a visual world stimulus (see below and Figure 4.2).
4.3.5. Analyses

Visual targets were annotated using Be Gaze (SMI) by drawing six areas of interest (AOI), and labelling them as: the antecedents of the pronoun (S1 and S2, reflecting a high/low attachment, respectively), the possible objects of the verb (O1 and O2), the Central and the Distractor visual objects (see Figure 4.2). Fixation data was then mapped onto these areas. A fixation on the AOI was counted from the onset of the saccade leading into it, i.e., saccades are included in fixations.

In line with previous VWP research on syntactic priming, we focused our analyses on the object NPs, O1 and O2 (Arai et al., 2007; Thothathiri & Snedeker, 2008). We assumed that fixations to the objects prior to the disambiguating post-verbal NP indicated a preference for either an LA or an HA resolution (e.g., the BEER visual object over the BABY BOTTLE visual object reflects a HA preference for the sentence The father of the baby who will drink…). Trial-by-trial, fixation data on O1 and O2 (a binomial 0, 1) unfolded over a time-course in windows of 1 ms each (roughly corresponding to the sampling rate of data acquisition, i.e., 1250 Hz).

We first considered fixation data from the onset of the (auditory) will linguistic region of interest (with 200ms added to account for eye-movement programming/execution), till 950ms after it, which corresponds to the mean onset of the NP following the verb (duration = 949±135 ms), i.e., the object of the verb action that pragmatically disambiguates the sentence. In this window, we examined anticipatory eye-movements as indicators of attachment ambiguity resolution.

In order to directly compare our results with previous research (Thothathiri & Snedeker, 2008), we also considered a second post-verbal window by aligning fixation data to the onset of the post-verbal NP (the beer/the baby bottle) till 550 ms after it\(^\text{16}\). This window therefore included the linguistic information that pragmatically disambiguates the relative clause as HA or LA.

As the onset of linguistic regions varied across sentences, we aligned fixations on an item-by-item basis. We first calculated proportion of fixations to O1 \((p(O1))\) and proportion of fixations to O2 \((p(O2))\) relative to all six AOIs in windows of 50 ms (to reduce correlation between consecutive time-points). We then computed the ratio between those proportions: \(\text{ratio} = p(O1)/p(O2)\)\(^\text{17}\), and standardized it (i.e., z-scored), such that our dependent measure was centred around zero and expressed in units of variance. This measure makes it possible to directly assess how these two objects

\(^{16}\) Because the nouns had an initial phonological ambiguity (leopard vs. letter), Thothathiri and Snedeker analysed a 400 ms window from NP onset. In our study, neither the nouns nor the determiner were ambiguous (the determiner is marked for gender in Portuguese). We therefore analysed a window beginning at the determiner (the) and ending 550 ms later, in order to have as similar a region to theirs as possible.

\(^{17}\) We added .5 both at the nominator and denominator of the ratio to avoid indeterminate forms.
competed for attention. Positive z-scores indicate a preference to look to O1; negative scores represent a preference to look to O2. We considered only those trials in which participants correctly understood the intended attachment (81% of data, 910 out of 1127 trials).

We analysed the time-course of fixation ratio using linear-mixed effect modelling and fitted full models with a maximal-random structure (refer to section 2.2.1 for details). As fixation data almost never distribute linearly over the time-course, we captured such non-linear changes by modelling our Time predictor as an orthogonal polynomial of order 2, i.e., a spline (Growth Curve Analysis, cf. section 2.2.3). The linear term of the polynomial (Time$^1$) has exactly the same interpretation as a linear regression of fixations over time. The quadratic term (Time$^2$) can be used to identify sudden changes in the linear trend, e.g., a decrease followed by an increase. The experimental predictors entered in the model as fixed effects were: Prime (HA, −0.5 vs. LA, 0.5) and Activation (Activation 1, −0.5 vs. Activation 2, 0.5), which were centered to reduce collinearity. When analysing the post-verbal window, we added another predictor capturing the structure of the Target sentence (HA, −0.5 vs. LA, 0.5). The random effects were Participant (24) and Item (48), entered as intercept, as well as uncorrelated slopes of the fixed predictors. In the tables, we report the coefficient estimates of the model predictors, their standard error, the t-value, and derive the p-value from it. We visualize observed data as shaded bands, representing the standard error from the mean, and overlay the fit of the MLME model.

Our analyses focused on two time windows. Our critical analyses examined predictive priming effects (i.e., participants’ syntactic expectations about upcoming material) based on the critical verb region (prior to the disambiguating noun), but we also examined participants’ eye movements in the post-verbal region (including the disambiguating noun), in order to allow direct comparison with previous findings.

### 4.3.6. Results

#### 4.3.6.1. Anticipatory window

Figure 4.3 plots the standardized fixation ratio $p(O1)/p(O2)$ from the onset of will until the onset of the post-verbal NP. There was a significant effect of Time$^1$ whereby participants developed an attentional preference to O1 (see Table 4.2). This preference to O1 was especially prominent for Activation 1, as indicated by the significant two-way interaction Activation:Time$^1$. 

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Figure 4.3: Experiment 3; Time-course of the Standardized Fixation Ratio $p(O1)/p(O2)$ from the onset of will. The Prime condition is visualized as lines (HA, solid; LA, dashed) while Activation is organized by panel (Activation 1, left; Activation 2, right). Lines represent the model fit and the shaded bands are the SEs around the observed mean. The vertical lines indicate the mean onset of the verb (374ms).

Importantly, we found a significant interaction of Activation and Prime. There was a clear preference of looks to O1 following a single HA prime, and a converse preference for O2 following a single LA prime (i.e., Activation 1; see left panel of Figure 4.3). However, this pattern reversed following two primes: Participants made anticipatory looks to the object congruent with the non-primed resolution (O1 for LA primes; O2 for

Table 4.2 Experiment 3; MLMEM of the Standardized Fixation Ratio $p(O1)/p(O2)$ along 950ms (19 bins). Predictors are Time (Linear, $Time^1$, Quadratic, $Time^2$), Activation (Activation 1, −0.5, Activation 2, 0.5) and Prime (HA, −0.5, LA, 0.5).

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>S.E.</th>
<th>t-value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>0.003</td>
<td>0.059</td>
<td>0.054</td>
<td>0.957</td>
</tr>
<tr>
<td>activation</td>
<td>0.006</td>
<td>0.063</td>
<td>0.099</td>
<td>0.921</td>
</tr>
<tr>
<td>prime</td>
<td>-0.039</td>
<td>0.060</td>
<td>-0.651</td>
<td>0.515</td>
</tr>
<tr>
<td>$Time^1$</td>
<td>0.097</td>
<td>0.032</td>
<td>3.048</td>
<td>0.002</td>
</tr>
<tr>
<td>$Time^2$</td>
<td>0.011</td>
<td>0.032</td>
<td>0.330</td>
<td>0.741</td>
</tr>
<tr>
<td>activation:prime</td>
<td>0.155</td>
<td>0.030</td>
<td>5.175</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>activation: $Time^1$</td>
<td>-0.189</td>
<td>0.064</td>
<td>-2.960</td>
<td>0.003</td>
</tr>
<tr>
<td>prime:$Time^1$</td>
<td>0.091</td>
<td>0.064</td>
<td>1.420</td>
<td>0.156</td>
</tr>
<tr>
<td>activation:$Time^2$</td>
<td>-0.093</td>
<td>0.064</td>
<td>-1.455</td>
<td>0.146</td>
</tr>
<tr>
<td>prime:$Time^2$</td>
<td>-0.058</td>
<td>0.064</td>
<td>-0.908</td>
<td>0.364</td>
</tr>
<tr>
<td>activation:prime:$Time^1$</td>
<td>-0.185</td>
<td>0.127</td>
<td>-1.455</td>
<td>0.146</td>
</tr>
<tr>
<td>activation:prime:$Time^2$</td>
<td>-0.130</td>
<td>0.127</td>
<td>-1.018</td>
<td>0.309</td>
</tr>
</tbody>
</table>
HA primes), although the effects of priming are substantially weaker in this case (see right panel of Figure 4.3).

4.3.6.2. **Disambiguating window**

Figure 4.4 plots the time-course of standardized fixation ratio from 100 ms prior the onset of the post-verbal NP till 150 ms after its offset\(^\text{18}\) across the conditions of *Prime* (HA, LA) and *Target* (HA, LA), in *Activation 1* (left panel) and *Activation 2* (right panel).

We found a significant interaction of *Prime* and *Activation* (see Table 4.3), now with a negative sign: There was a preference for O1 when participants were primed with HA (circles) in the Activation 2 condition. This was especially the case for LA targets, as reflected in the marginally significant three-way interaction *prime:target:activation* (unfilled circles). Additionally, *Target* was a significant predictor of fixations: Upon hearing HA targets (solid shapes) and regardless of the Activation condition, O1 was preferred over O2 (two-way interaction *target:Time\(^1\)*) and this attentional preference displayed an upward bowing trend (target:Time\(^2\)). The opposite was observed for LA targets, i.e., a preference for O2 (unfilled shapes).

\[\text{Figure 4.4: Experiment 3; Time-course of the Standardized Fixation Ratio } p(O1)/p(O2) \text{ in the disambiguating window. The conditions crossing Prime and Target are visualized through different shapes (e.g., Prime HA } \times \text{ Target HA, solid circles) while Activation is organized by panel (Activation 1, left; Activation 2, right). Points represent the observed means and the shaded bands are the SEs around them. Vertical lines indicate the limits of the analysed region.}\]

\[\text{18 Our analysis window starts at NP onset till 550 ms after it, as marked in Figure 3 by vertical lines. We plot a larger time-window to visualize how fixations distribute around the critical time-window.}\]
Table 4.3: Experiment 3; MLMEM of the standardized fixation ratio \( p(O1)/p(O2) \) along 550ms (11 bins) from NP onset. Predictors are \( Time \) (Linear, \( Time^1 \), Quadratic, \( Time^2 \)), \( Activation \) (Activation 1, -0.5, Activation 2, 0.5), \( Prime \) (HA, -0.5, LA, 0.5) and \( Target \) (HA, -0.5, LA, 0.5).

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>S.E.</th>
<th>t-value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-0.028</td>
<td>0.054</td>
<td>-0.524</td>
<td>0.601</td>
</tr>
<tr>
<td>prime</td>
<td>-0.006</td>
<td>0.060</td>
<td>-0.101</td>
<td>0.920</td>
</tr>
<tr>
<td>target</td>
<td>-0.122</td>
<td>0.086</td>
<td>-1.424</td>
<td>0.154</td>
</tr>
<tr>
<td>activation</td>
<td>-0.035</td>
<td>0.071</td>
<td>-0.501</td>
<td>0.616</td>
</tr>
<tr>
<td>( Time^1 )</td>
<td>-0.001</td>
<td>0.028</td>
<td>-0.014</td>
<td>0.989</td>
</tr>
<tr>
<td>( Time^2 )</td>
<td>-0.016</td>
<td>0.028</td>
<td>-0.553</td>
<td>0.580</td>
</tr>
<tr>
<td>prime:target</td>
<td>-0.071</td>
<td>0.039</td>
<td>-1.831</td>
<td>0.067</td>
</tr>
<tr>
<td>prime:activation</td>
<td>(-0.188)</td>
<td>0.036</td>
<td>(-5.252)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>target:activation</td>
<td>0.044</td>
<td>0.039</td>
<td>1.142</td>
<td>0.253</td>
</tr>
<tr>
<td>activation:Time^1</td>
<td>0.079</td>
<td>0.057</td>
<td>1.399</td>
<td>0.162</td>
</tr>
<tr>
<td>activation:Time^2</td>
<td>-0.044</td>
<td>0.057</td>
<td>-0.785</td>
<td>0.433</td>
</tr>
<tr>
<td>prime:Time^1</td>
<td>-0.013</td>
<td>0.057</td>
<td>-0.231</td>
<td>0.817</td>
</tr>
<tr>
<td>prime:Time^2</td>
<td>0.023</td>
<td>0.057</td>
<td>0.408</td>
<td>0.684</td>
</tr>
<tr>
<td>target:Time^1</td>
<td>(-0.465)</td>
<td>0.057</td>
<td>(-8.112)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>target:Time^2</td>
<td>(-0.204)</td>
<td>0.057</td>
<td>(-3.558)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>prime:target:activation</td>
<td>(-0.140)</td>
<td>0.073</td>
<td>(-1.910)</td>
<td>0.056</td>
</tr>
<tr>
<td>prime:activation:Time^1</td>
<td>-0.028</td>
<td>0.113</td>
<td>-0.247</td>
<td>0.805</td>
</tr>
<tr>
<td>prime:activation:Time^2</td>
<td>0.132</td>
<td>0.113</td>
<td>1.167</td>
<td>0.243</td>
</tr>
<tr>
<td>target:activation:Time^1</td>
<td>-0.001</td>
<td>0.115</td>
<td>-0.008</td>
<td>0.994</td>
</tr>
<tr>
<td>target:activation:Time^2</td>
<td>-0.022</td>
<td>0.115</td>
<td>-0.196</td>
<td>0.844</td>
</tr>
<tr>
<td>prime:target:Time^1</td>
<td>0.189</td>
<td>0.115</td>
<td>1.646</td>
<td>0.100</td>
</tr>
<tr>
<td>prime:target:Time^2</td>
<td>-0.084</td>
<td>0.115</td>
<td>-0.729</td>
<td>0.466</td>
</tr>
</tbody>
</table>

4.3.7. Discussion

Experiment 3 examined whether immediate syntactic priming effects were modulated by the number of primes (1 vs. 2). It showed that participants who had read aloud a single prime sentence predicted the primed structure as they processed the target verb of an auditory target, as indexed by anticipatory looks to the object congruent with that structure. This pattern is consistent with previous research showing that structural priming serves to facilitate predictive processes of language understanding (e.g., Arai et al., 2007).

However, when participants had read aloud two consecutive prime sentences disambiguated to the same structure, they instead predicted the alternative, non-primed structure during the same linguistic region of interest (i.e., an LA resolution following two HA primes), as indexed by anticipatory looks to the object that was congruent with that structure.

During a later time window that included the disambiguating word, however, participants’ eye movements were influenced by the structure of both the prime(s) and the target. The effect of target type is consistent with previous literature (Arai et al., 2007; in a window between 300 and 600 ms after NP onset; and Thothathiri & Snedeker, 2008;
400 ms after NP onset, although for a different syntactic structure), and confirms that participants, as expected, reactively look at the object mentioned in the spoken sentence.

The effect of priming in the Activation 2 condition, whereby participants look more to the object congruent with the primed attachment, is consistent with Thothathiri and Snedeker’s (2008) findings in a similar (disambiguating) time window. It is an opposite pattern to the one we found in the anticipatory window, which could be interpreted as a delayed priming effect when two primes instead of one are presented. However, we also found a three-way interaction prime:target:activation indicating that priming is further modulated by the target type. For example, there is a preference for O1 when two HA primes are presented in the LA target condition (unfilled circles), compared to the HA target condition (solid circles). We return to this issue in the Discussion of Experiment 4.

These results suggest that immediate syntactic priming effects manifested as prediction of the primed structure varied with differences in the number of primes to which participants were exposed. As such, they suggest that activation levels for alternative structures during processing of the target did vary as a function of short-term repetition of structure — but not in a straightforwardly additive manner. Indeed, exposure to more than one prime reduced the likelihood of anticipatory looks congruent with the primed structure, relative to conditions involving a single prime. This suggests that activation levels for the primed structure were lower following two primes than following one prime. However, because Experiment 3 compared fixations following HA vs. LA primes (i.e., participants had always previously experienced one or other structure) , it is not possible to tell whether this pattern reflected decreased expectation (i.e., reduced activation) for the primed structure, increased expectation (i.e., increased activation) for the non-primed structure, or both.

Experiment 4 addressed this question by comparing anticipatory fixations following two HA or LA primes with anticipatory fixations following two unrelated baseline sentences that should prime neither attachment (and hence should reflect the resting level of activation for HA and LA representations). We therefore sought to replicate Experiment 3’s finding of a preference for the non-primed structure following two primes, and to identify whether such a preference reflected inhibition of the primed structure, facilitation of the non-primed structure, or both.

4.4. Experiment 4: investigating reversed priming

Experiment 4 replicated the Activation 2 conditions of Experiment 3, and examined how exposure to two primes affected activation of the primed alternative relative to an unrelated baseline. This allowed us to determine whether repetition of a prime affected
the activation of both the primed and the alternative attachment of the RC, compared to a resting level (that reflected overall preferences for one or other structure within the language).

### 4.4.1. Participants

Twenty-four further participants from the same population as Experiment 3 were tested. All subjects had normal or corrected-to-normal vision.

### 4.4.2. Design, Materials and Procedure

We used the same materials as in Experiment 3, except that we created sixteen new filler sentences for the Baseline (BL) condition (see Appendix A).

There were always two written primes presented before the visual-world target (i.e., we used only the Activation2 conditions from Experiment 3, in addition to the BL condition). Prime sentences comprised two HA sentences, two LA sentences or two fillers (BL), as illustrated in (1), (2) and (3), respectively, in Table 4.4. The visual-world targets were spoken sentences such as (4).

**Table 4.4:** Example of stimuli in Experiment 4.

<table>
<thead>
<tr>
<th></th>
<th>Written primes in HA condition</th>
<th></th>
<th>Written primes in LA condition</th>
<th></th>
<th>Written primes in BL condition</th>
<th></th>
<th>Visual-World Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a) O irmão dos herdeiros que vai ler o testamento é de França. The brother of the heirs who will [sg] read the will is from France.</td>
<td>(a) Os irmãos do herdeiro que vai ler o testamento são de França. The brothers of the heir who will [sg] read the will are from France.</td>
<td>(a) A turista francesa vai passear por Portugal durante duas semanas. The French tourist will visit Portugal for two weeks.</td>
<td>(b) O médico vai apresentar no hospital a nova técnica cirúrgica. The doctor will present the new cirurgical technique in the hospital.</td>
<td>(a) O pai do bebê que vai beber a cerveja (o biberão) é alto. The father of the baby who will [sg] drink the beer (the baby bottle) is tall.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(b) O ajudante dos padeiros que vai distribuir o pão chegou. The helper of the bakers who will [sg] deliver the bread has arrived.</td>
<td>(b) Os ajudantes do padeiro que vai distribuir o pão chegaram. The helpers of the baker who will [sg] deliver the bread have arrived.</td>
<td>(b) O médico vai apresentar no hospital a nova técnica cirúrgica. The doctor will present the new cirurgical technique in the hospital.</td>
<td>(b) O médico vai apresentar no hospital a nova técnica cirúrgica. The doctor will present the new cirurgical technique in the hospital.</td>
<td>(b) O pai do bebê que vai beber a cerveja (o biberão) é alto. The father of the baby who will [sg] drink the beer (the baby bottle) is tall.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
This manipulation resulted in a 3 (Prime: HA vs. LA vs. BL) × 2 (Target: HA vs. LA) repeated-measures design. Six lists were constructed, each comprising eight items from each condition with exactly one version of each item appearing in each list, according to a Latin Square design, and participants were randomly assigned to each list.

We used the same methodology and procedure as in Experiment 3.

### 4.4.3. Analyses and Results

As in Experiment 3, we ran time-course analyses on the standardized ratio between proportion of fixations on O1 and proportion of fixations on O2, i.e., z-score \((p(O1)/p(O2))\). We fitted full maximal-random mixed effect models to the ratios as a function of Time, as represented by an orthogonal polynomial of order 2 (i.e., linear and quadratic terms, \(Time^1\) and \(Time^2\), reflecting rate and direction of change). We analysed data in a time windows aligned to the verbal region (from onset of \(will\) until mean NP onset). We treated Prime as a predictor with three levels, in which the BL condition was the intercept against which we contrasted the HA and LA prime conditions (i.e., BL is the reference level, and the coefficients for HA, LA are relative to it). The random effects were Participants (24) and Item (48). As in Experiment 3, we report analyses restricted to trials where participants answered the attachment question correctly (758 out of 1129 trials, 67% of the data).

#### 4.4.3.1. Anticipatory window

Figure 4.5 shows the observed (shaded bands) and estimated (lines) mean ratios between proportions of fixations to O1 and O2 for the BL, HA and LA conditions, from onset of \(will\), spanning a period of 950 ms.

There was a significant effect of \(Time^1\) (see Table 4.5), whereby O1 received more looks over time compared to O2. Relative to the baseline, we found significant priming only in interaction with Time. In particular, after reading aloud two primes with the same structure, participants made anticipatory looks to the object congruent with the non-primed attachment resolution (more looks to O1 following LA primes; more looks to O2 following HA primes), relative to when they had read two unrelated sentences that primed neither structure. For LA primes, there was also an interaction with \(Time^2\), indicating an upward bowing trend (i.e., a fall in likelihood of fixation followed by a rise).
Figure 4.5: Experiment 4: Time-course of the Standardized Fixation Ratio \( p(O1)/p(O2) \) from the onset of *will*. The Prime condition is visualized as lines (HA, solid; LA, dashed; BL, dotted). Lines represent the model fit and the shaded bands are the SEs around the observed mean. The vertical line indicates the mean onset of the verb (374 ms).

**Table 4.5**: Experiment 4; MLMEM of the Standardized Fixation Ratio \( p(O1)/p(O2) \) along 950 ms from *will* onset. Predictors are Time (Linear, \( Time^1 \), Quadratic, \( Time^2 \)), and Prime (HA, LA, contrasted to BL)

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>S.E.</th>
<th>t-value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>0.0016</td>
<td>0.0441</td>
<td>0.0365</td>
<td>0.9709</td>
</tr>
<tr>
<td>HA</td>
<td>-0.0766</td>
<td>0.1023</td>
<td>-0.7490</td>
<td>0.4538</td>
</tr>
<tr>
<td>LA</td>
<td>0.0778</td>
<td>0.1156</td>
<td>0.6727</td>
<td>0.5012</td>
</tr>
<tr>
<td>( Time^1 )</td>
<td>0.1645</td>
<td>0.0354</td>
<td>4.6474</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>( Time^2 )</td>
<td>-0.0069</td>
<td>0.0354</td>
<td>-0.1953</td>
<td>0.8452</td>
</tr>
<tr>
<td>HA: ( Time^1 )</td>
<td>-0.2721</td>
<td>0.1001</td>
<td>-2.7180</td>
<td>0.0066</td>
</tr>
<tr>
<td>HA: ( Time^2 )</td>
<td>-0.1288</td>
<td>0.1001</td>
<td>-1.2860</td>
<td>0.1984</td>
</tr>
<tr>
<td>LA: ( Time^1 )</td>
<td>0.4403</td>
<td>0.1006</td>
<td>4.3783</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>LA: ( Time^2 )</td>
<td>0.2724</td>
<td>0.1006</td>
<td>2.7083</td>
<td>0.0068</td>
</tr>
</tbody>
</table>

### 4.4.3.2. Disambiguating window

We analysed fixations 550 ms after NP onset for a subset of our data excluding the BL condition, so to draw direct comparisons with previous literature on the topic. Figure 4.6 plots the observed means of the ratio \( p(O1)/p(O2) \) in these conditions, and Table 6 presents the summary of the MLMEM fitted to the data.
We confirm the interaction of Target and Time. The HA target conditions show a sharp increasing preference for O1, while the LA target conditions show a decline in that preference. The interaction of Target with Time reflects the upward and downward bowing trends of the first (HA target) and second (LA target) respectively. This result suggests that, like in Experiment 1, participants’ eye movements were reactive to the content of the target noun as they heard it.

The plot shows how, at NP onset, there was still a preference for an HA reading (O1) when participants were primed with LA sentences (triangles). This preference for the non-primed structure was however no longer significant (prime effect). Instead, the HA prime conditions (circles) showed a momentary increased preference for O1 (prime:Time), replicating the priming effect found in the same time window in Experiment 1.

Importantly, we also replicate Experiment 3’s interaction of Prime and Target, whereby with LA primes there are more looks to O1 when the target is HA compared to LA target. Furthermore, the three-way interaction prime:target:Time reveals that the effect of priming, as reflected in an increasing HA (O1) preference with HA primes, is more prominent when the target has the same attachment resolution (HA).

Figure 4.6: Experiment 4; MLMEM of the standardized fixation ratio p(O1)/p(O2) along 550 ms (11 bins) from NP onset. The conditions crossing Prime and Target are visualized through different shapes (e.g., Prime HA × Target HA, solid circles) Predictors are Time (Linear, Time, Quadratic, Time^2), Prime (HA, −0.5, LA, 0.5) and Target (HA, −0.5, LA, 0.5).
Table 4.6: Experiment 4; MLMEM of the standardized fixation ratio \( p(O1)/p(O2) \) along 550 ms from NP onset. Predictors are Time (Linear, \( Time^1 \), Quadratic, \( Time^2 \)), prime (HA, −0.5 vs. LA, 0.5) and target (HA, −0.5 vs. LA, 0.5).

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>S.E.</th>
<th>t-value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>0.001</td>
<td>0.061</td>
<td>0.019</td>
<td>0.985</td>
</tr>
<tr>
<td>prime</td>
<td>0.133</td>
<td>0.107</td>
<td>1.236</td>
<td>0.217</td>
</tr>
<tr>
<td>target</td>
<td>-0.177</td>
<td>0.133</td>
<td>-1.336</td>
<td>0.181</td>
</tr>
<tr>
<td>( Time^1 )</td>
<td>0.056</td>
<td>0.040</td>
<td>1.403</td>
<td>0.161</td>
</tr>
<tr>
<td>( Time^2 )</td>
<td>-0.025</td>
<td>0.040</td>
<td>-0.627</td>
<td>0.530</td>
</tr>
<tr>
<td>prime:target</td>
<td>-0.138</td>
<td>0.067</td>
<td>-2.062</td>
<td>0.039</td>
</tr>
<tr>
<td>prime: ( Time^1 )</td>
<td>-0.243</td>
<td>0.080</td>
<td>-3.026</td>
<td>0.002</td>
</tr>
<tr>
<td>prime: ( Time^2 )</td>
<td>-0.070</td>
<td>0.080</td>
<td>-0.867</td>
<td>0.386</td>
</tr>
<tr>
<td>target: ( Time^1 )</td>
<td>-0.296</td>
<td>0.081</td>
<td>-3.655</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>target: ( Time^2 )</td>
<td>-0.175</td>
<td>0.081</td>
<td>-2.158</td>
<td>0.031</td>
</tr>
<tr>
<td>prime:target: ( Time^1 )</td>
<td>0.165</td>
<td>0.162</td>
<td>1.022</td>
<td>0.307</td>
</tr>
<tr>
<td>prime:target: ( Time^2 )</td>
<td>0.372</td>
<td>0.162</td>
<td>2.296</td>
<td>0.022</td>
</tr>
</tbody>
</table>

4.4.4. Discussion

In Experiment 4, we contrasted priming following two sentences that primed one of the two possible target structures (HA or LA) with a non-primed baseline condition that primed neither possible target structure. We fully replicated Experiment 3: When they heard the verb, participants launched more anticipatory eye movements to the object that was congruent with the non-primed structure after reading aloud two primes than after reading two unrelated sentences. The pattern of results suggests that exposure to two primes facilitated the non-primed and inhibited the primed structure during an anticipatory processing window.

4.5. Comparison of Experiments 3 and 4

To determine whether the tendency found in Experiments 3 and 4 to fixate objects congruent with the non-primed structure following two consecutive primes was consistent and equally strong across experiments, we conducted analyses of their combined data for the same anticipatory and disambiguating time windows as our main analyses. The analyses focused on the HA and LA prime conditions, so as to include Experiment (3 vs. 4) as a fixed effect (between-participants and within-items).

Figure 4.7 plots the fitted model means of the standardized ratio \( p(O1)/p(O2) \), from will onset. A significant effect of \( Time^1 \) again shows increasing preference for O1 compared to O2, more prominent in Experiment 4 (\( Time^1:exp \); refer to Table 4.7 for the model estimates). We also confirm the two-way interaction of Prime with \( Time^1 \), whereby participants show growing preference for the object congruent with the non-primed attachment resolution (e.g., more looks to O1 with LA primes). This effect is shown to be
stronger in Experiment 4 (three-way interaction $\text{prime} \times \text{Time}^1 \times \text{exp}$), and to have an upward trend for prime LA and a converse downward trend for HA prime ($\text{prime} \times \text{Time}^2 \times \text{exp}$).

Table 4.7: Combined data of Experiments 3 and 4; MLMEM of the standardized fixation ratio $p(O1)/p(O2)$ along 950 ms (19 bins) from will onset. Predictors are Time (Linear, $\text{Time}^1$, Quadratic, $\text{Time}^2$), Prime (HA, −0.5, LA, 0.5) and Experiment (3, −0.5, 4, 0.5).

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>S.E.</th>
<th>t-value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
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<td>0.037</td>
<td>0.091</td>
<td>0.927</td>
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<tr>
<td>prime</td>
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<td>0.069</td>
<td>1.016</td>
<td>0.310</td>
</tr>
<tr>
<td>$\text{Time}^1$</td>
<td><strong>0.105</strong></td>
<td><strong>0.031</strong></td>
<td><strong>3.334</strong></td>
<td><strong>0.001</strong></td>
</tr>
<tr>
<td>$\text{Time}^2$</td>
<td>-0.004</td>
<td>0.031</td>
<td>-0.128</td>
<td>0.898</td>
</tr>
<tr>
<td>exp</td>
<td>-0.008</td>
<td>0.075</td>
<td>-0.110</td>
<td>0.912</td>
</tr>
<tr>
<td>$\text{Time}^1 \times \text{exp}$</td>
<td><strong>0.202</strong></td>
<td><strong>0.063</strong></td>
<td><strong>3.205</strong></td>
<td><strong>0.001</strong></td>
</tr>
<tr>
<td>$\text{Time}^2 \times \text{exp}$</td>
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<td>0.063</td>
<td>1.012</td>
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<tr>
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<td>0.413</td>
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<td><strong>2.879</strong></td>
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<td>prime:$\text{Time}^2$</td>
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<td>0.063</td>
<td>0.680</td>
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</tr>
<tr>
<td>prime:$\text{Time}^1 \times \text{exp}$</td>
<td><strong>0.360</strong></td>
<td><strong>0.126</strong></td>
<td><strong>2.859</strong></td>
<td><strong>0.004</strong></td>
</tr>
<tr>
<td>prime:$\text{Time}^2 \times \text{exp}$</td>
<td>0.324</td>
<td>0.126</td>
<td>2.577</td>
<td>0.010</td>
</tr>
</tbody>
</table>

Figure 4.7: Experiment 4; MLME of the standardized fixation ratio $p(O1)/p(O2)$ along 550ms (11 bins) from Combined data of Experiments 3 and 4; Time-course of the Standardized Fixation Ratio $p(O1)/p(O2)$ from the onset of will. The Prime condition is visualized as lines (HA, solid; LA, dashed). Lines represent the model fit and the shaded bands are the SEs around the observed mean. The vertical line indicates the mean onset of the verb (374 ms).
Figure 4.8 plots the means of $PO1/PO2$ (collapsed across Experiments 3 and 4) in the conditions crossing Prime and Target, during the post-verbal time window. We observe (refer to Table 4.8), like in Experiment 4, two-way interactions of both Prime and Target with Time$^1$, the first reflecting the priming effect whereby participants look increasingly at the object congruent with the attachment interpretation of the prime and the second showing growing looks to the object that is mentioned in the target sentence. Target additionally interacts with Time$^2$, indicating the upward and downward trend of the ratio for targets HA and LA, respectively.

As illustrated in Figure 4.8, the preference for O1 rises in the condition crossing prime LA and target HA (solid triangles) and falls in the condition crossing prime LA and target LA (unfilled triangles). Finally, a significant main effect of Target, which was not present in the individual analyses, corroborates the importance of the presence of disambiguating linguistic information in this time-window: participants, as expected, look more to the actually mentioned object.
Table 4.8: Combined data of Experiments 3 and 4; MLMEM of the Standardized Fixation Ratio $p(O1)/p(O2)$ along 550 ms from NP onset. Predictors are Time (Linear, $Time^1$, Quadratic, $Time^2$), prime (HA, −0.5 vs. LA, 0.5), target (HA, −0.5 vs. LA, 0.5) and Experiment (Experiment 3, −0.5; Experiment 4, 0.5).

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>S.E.</th>
<th>t-value</th>
<th>p</th>
</tr>
</thead>
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<tr>
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<td>-0.105</td>
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<td>0.761</td>
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<tr>
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<td>0.084</td>
<td>-2.123</td>
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<tr>
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<tr>
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<td>0.253</td>
</tr>
<tr>
<td>exp</td>
<td>0.044</td>
<td>0.080</td>
<td>0.550</td>
<td>0.583</td>
</tr>
<tr>
<td>prime: $Time^1$</td>
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<td>0.057</td>
<td>-2.422</td>
<td>0.015</td>
</tr>
<tr>
<td>prime: $Time^2$</td>
<td>0.008</td>
<td>0.057</td>
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<td>0.889</td>
</tr>
<tr>
<td>target: $Time^1$</td>
<td>-0.378</td>
<td>0.058</td>
<td>-6.576</td>
<td>&lt; 0.001</td>
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<tr>
<td>target: $Time^2$</td>
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<td>-3.363</td>
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<td>$Time^1$:exp</td>
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<td>prime:exp</td>
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<td>1.424</td>
<td>0.154</td>
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<tr>
<td>target:exp</td>
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<td>0.115</td>
<td>0.312</td>
<td>0.755</td>
</tr>
</tbody>
</table>

4.5.1. General discussion

In this Chapter, we reported two visual-world eye-tracking experiments that investigated how repetition of syntactic structures in previously experienced prime sentences changed participants’ predictions of forthcoming linguistic input when concurrently viewing a visual context.

In Experiment 3, participants read aloud one or two prime sentences that included a relative clause morphologically disambiguated to an HA or LA interpretation and then heard a sentence containing an RC that was temporarily ambiguous between an HA or LA attachment. After reading a single prime sentence, participants made anticipatory fixations to the object congruent with the primed structure as they heard the critical region including the verb (e.g., looking more at the object congruent with an HA interpretation after an HA prime than after an LA prime). This result is consistent with previous evidence of anticipatory priming effects associated with prediction of verb arguments after a single prime presentation (e.g., Arai et al., 2007). However, after reading two prime sentences with the same structure, participants made anticipatory fixations to the object consistent with the non-primed structure (e.g., looking more at the object...
consistent with an HA interpretation after reading two LA primes than after reading two HA primes). Experiment 4 replicated this pattern in a design that used two HA or LA primes alongside a condition involving two sentences that did not include relative clauses, and demonstrated further that this pattern reflected an increased tendency to anticipate the non-primed alternative, relative to the baseline condition where there was no previous exposure to either structure. Combined analyses of Experiments 3 and 4 corroborated these findings, and also showed that the effects were stronger in Experiment 4.

These results provide evidence about the way in which experience of syntactic structures affects people’s immediate expectations about syntactic structure during comprehension. It is uncontroversial that prior exposure to particular syntactic structures affects subsequent syntactic processing, and that such syntactic priming effects reflect variations in the activation of alternative structures during processing of the target sentence. However, the precise relationship between previous experiences and subsequent activation levels remains uncertain. The simplest assumption would be a simple linear relationship between instances of experience of a structure and subsequent increased activation of that structure; such assumption underlies the design of at least some priming studies (e.g., Pickering & Branigan, 1998, Experiment 2, for language production). Some studies have provided evidence consistent with the hypothesis that multiple primes yield stronger priming in comprehension than single primes (e.g., showing priming in the absence of lexical repetition following multiple primes but not single primes (e.g., Noppeney & Price, 2004; see also Mehler & Carey, 1967). Other studies have shown cumulative priming effects in language production across trials (e.g., Kaschak, Loney, & Borreggine, 2006; Kaschak, 2007; Jaeger & Snider, 2013)\(^ {19} \).

Recent evidence suggests a more complex relationship between exposure and priming effects, at least over relatively extended periods of time. For example, Fine et al. (2013) showed that a sentence’s priming effect depended on how unexpected its structure was within the experiment. That is, the same sentence would affect the activation level of the primed structure differently depending on characteristics of other previously experienced sentences, consistent with error-based learning mechanisms (e.g., Chang et al., 2006).

Our experiments were concerned with immediate syntactic priming effects in comprehension, where participants processed target sentences immediately after exposure to one or more primes. Evidence suggests that priming in these contexts might be associated with residual activation of syntactic representations (either in place of, or in conjunction with, implicit learning mechanisms; Hartsuiker et al., 2008; Pickering & Branigan, 1998). Such a mechanism could plausibly yield stronger priming following

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\(^ {19} \) Note that these studies were designed to strongly bias participants towards one of the alternative syntactic structures, including conditions where participants were only exposed to one type of prime structure.
more than one prime, although it might be susceptible to ceiling effects. A more intriguing possibility, consistent with previous lexical priming research (Huber et al. 2002; Huber & O’Reilly 2003), is that spreading activation mechanisms might yield reduced priming effects, or even facilitation for the non-primed alternative, following two primes.

Our results provide evidence against the simplest, and perhaps most intuitive, assumption for how syntactic experience would affect immediate syntactic expectations: Exposure to two primes with the same structure did not increase participants’ expectation for that structure in a subsequent sentence to a greater degree than exposure to a single prime. Instead, the pattern that we found suggests that whereas a single exposure to a structure raises that structure’s subsequent activation level, exposure to a structure twice consecutively can temporarily reduce its subsequent activation level. Thus, our critical finding is that activation for a syntactic structure in comprehension does not simply increase linearly with exposure to instances of that structure. This result adds further evidence to support recent findings that prior syntactic experience can affect subsequent syntactic processing in complex ways, and that a more nuanced account of the relationship between experience and subsequent activation of syntactic structures is necessary.

Why might this pattern have arisen? In particular, why might exposure to two primes have resulted in anticipation of the alternative structure? Note that within the experiments, it was equally likely that two primes with an HA structure would be followed by an HA target or an LA target; the same is true for primes with an LA structure. It therefore seems unlikely that the results could be explained in terms of expectations based on contingencies within the experiment.

We tentatively suggest that one possible account of our findings might make reference to the phenomenon of repetition suppression, which is well established in other domains of cognition. Although it has mainly been studied in low-level cognitive tasks where processing is determined largely by physical properties of the stimuli (such as object shape, e.g., Kourtzi & Kanwisher, 2000, 2001), it also appears relevant to high-level cognitive phenomena (e.g., Lombardi et al., 1987; Wheatley, Weisberg, Beauchamp, & Martin, 2005). Repetition suppression occurs when people are repeatedly exposed to a stimulus, and manifests itself through reduced neural activity. Interestingly, repetition suppression has been linked to patterns of lexical priming. Huber and colleagues found that in a forced-choice lexical priming task, participants were more likely to choose the non-primed alternative when they had been exposed to the prime for an extended period of time; Huber et al., 2001, 2002; Huber & O’Reilly 2003). This pattern stood in contrast to the standard lexical priming effect when participants were exposed to the prime for a short duration.
Huber et al. (2002) explained their results in terms of spreading activation within the lexicon, based on mechanisms of lateral inhibition, persistence and accommodation. They proposed that when one representation is activated, it competes with, and therefore inhibits, the related alternative representation. However, the initial persistence of the activated representation is progressively weakened by accommodation, which allows the alternative representation to take precedence. Such evidence might provide a possible explanation of our results. When a syntactic structure (e.g., HA) is first processed, the level of its representation activation raises, while that of the alternative (LA) is inhibited. On repeated presentation of an HA structure, however, there is a decrease in the HA representation’s activation, and concurrent emergence of the competitor LA structure, so that the relative levels of activation of LA and HA are reversed. According to this hypothesis, prime repetition ‘encourages’ the expectation for the non-primed structure (i.e., raises its activation above resting level) and ‘discourages’ the expectation for the primed structure (i.e., lowers its activation below resting level).

Repetition suppression (RS) has been assumed to be a largely automatic neural process and, therefore, effective over short time periods. We would expect it to be apparent when – as in our experiments – repetition occurred over consecutive stimuli within a short period of time. Our findings do not argue against an implicit learning component of syntactic priming that would impact activation levels of primed structures effects over the longer term. That is, long-term priming effects such as cumulativity could arise from an implicit learning mechanism that acted alongside a short-term activation-based mechanism that was susceptible to repetition suppression, in keeping with proposals for hybrid accounts of syntactic priming (e.g., Hartsuiker et al., 2008; Reitter et al., 2011). More interestingly, it has been suggested that repetition suppression may reflect less automatic processes, such as reduction in top-down perceptual ‘prediction error’ (Summerfield, Trittschuh, Monti, Mesulam, & Egner, 2008). Likewise, RS has been shown to be larger for expected than unexpected repetitions in experiments where, in different blocks of stimuli, repetition was either more or less probable (Todorovic, van Ede, Maris, & de Lange, 2011). Indeed, these RS long-term effects seem compatible with evidence of expectation-adaptation in syntactic priming in production (Jaeger & Snider, 2013), whereby repetition of a structure in a design block makes it less surprising (more expected) and reduces its strength as a prime. This would also explain why we found stronger effects of expectation for the non-primed structure in Experiment 4 than in Experiment 3: In Experiment 4, repetition was more probable both because all trials had two primes, and because there was a greater number of items for each of the Prime conditions (16 per condition, as compared with 12 per condition in Experiment 3).

This possible explanation for our findings is however tentative; Our experiments were designed to examine how activation for a structure changed as a function of prior
experience of one or two instances of that structure, and not to investigate a repetition suppression account. Further work is therefore required to directly explore this account. But our results, in conjunction with other recent research, suggest that there are still many open questions about the precise mechanisms involved in syntactic priming that merit further research.

One final issue is to consider how our results fit with those of earlier studies. The finding that prior exposure to one instance of an HA or LA structure led to anticipation of that structure in a subsequent sentence is consistent with Arai et al.’s (2007) results for a different structural alternation (dative structures). In fact, our results were very similar in this respect. As with Arai et al., we found effects in a window that contained the verb but did not contain the disambiguating NP: Participants looked more often to the object that was a congruent object for the verb under the primed interpretation than under the non-primed interpretation. The fact that these effects occurred prior to encountering the disambiguating noun demonstrates that they must have been anticipatory, driven only by processing of linguistic information at the verb (and auxiliary verb, which indicates a forthcoming action). Our results are also consistent with those of Kamide (2012), who likewise found anticipatory effects of relative clause attachment during processing of the verb, manifested by differential fixations to objects that could be verb arguments (in her study, the relevant expectations were associated with contingencies between particular speakers and particular structures).

Our results also show a similar pattern of results to Thothathiri and Snedeker’s (2008) results in some respects (Experiment 3). They examined participants’ fixations to objects that could act as patient or theme for a dative action after hearing two sentences involving a prepositional object or double object structure. They found that in a post-verbal window (that may have included disambiguation of the target noun), both Prime and Target structure influenced fixation patterns. We also found both effects of Prime and Target interacting with Time, whereby participants increasingly looked at the object congruent with the primed RC attachment. We additionally observed an interaction of the two predictors, indicating a more complex pattern of fixations in this window, as discussed before. The different effects of structural priming observed at the anticipatory and disambiguating window open intriguing questions regarding the actual time-course of short-term activation, and the interplay with other mechanisms such as repetition suppression. In fact, it could be possible that repetition suppression is stronger when the linguistic input parsed is insufficient to make strong prediction about upcoming arguments (i.e., prior/during the verb); and instead becomes weaker as the structural representation of the sentence gets completed. Another possibility would be that, after having anticipated the non-primed structure, comprehenders are evaluating the other possible attachment of the RC. In both cases, anticipation for the non-primed structure
occurs, and our data suggest it is still present in the disambiguating window. As we discussed before, our experiments might have had a design/analysis more suitable to detect time-course changes on fixations reflecting incremental language processing in a visual-world paradigm.

4.6. Conclusions

In conclusion, our experiments show that predictions for upcoming syntactic structures are affected in the short-term by immediately prior syntactic experience, but that – contrary to some previous assumptions – there is not a straightforward relationship between instances of exposure and enhanced priming. In particular, the finding that repeated consecutive exposure to a structure can lead to immediate prediction of the alternative structure raises interesting connections with evidence of repetition suppression. Moreover, it highlights a potential research avenue examining the exact temporal dynamics governing repetition suppression due to structural priming during situated language understanding.
5. Individual differences in reading and viewing in a syntactic priming VWP task: WM mediation

5.1. Introduction

As we saw in section 1.4, working memory (WM) is a cognitive function taken to influence language processing. In particular, it has been suggested that the way we resolve ambiguity might be a function, among other factors, of individual differences in our memory capacity. WM is taken either to constrain the system principles (e.g., Frazier & Rayner (1982)’s garden-path theory) or to determine the extent to which multiple interpretations can be maintained in parallel (e.g., Just & Carpenter (1992)’s capacity theory). On the other hand, syntactic priming, resulting from the influence of processing one sentence in the processing of a following sentence, might be modulated by our capacity to retain in memory representations or processes. However, the relation between WM and syntactic priming has not been much explored.

In this Chapter, we present analyses on a subset of the data\textsuperscript{20} collected in Experiment 3, where participants first read aloud prime sentences and were then presented with spoken targets while inspecting a visual display. By investigating how fixations on visual contexts while resolving ambiguity are a function of previous reading patterns and WM capacity, we shed new light on how WM mediates both ambiguity resolution and priming.

\textsuperscript{20} For simplicity, we restrict the analyses to the Activation 2 condition, i.e., the condition where participants were presented with two primes (with the same attachment) before the target.
5.2. Background

As we noted in section 1.3.2, structural ambiguity has always played a pivotal role for research on sentence processing and theories of syntactic parsing. Psycholinguistic research on ambiguity resolution has tried to distinguish between two-stage accounts of syntactic processing (which assume initial parsing is only determined by syntactic principles, e.g., Frazier & Rayner (1982)’s garden-path theory) and interactive theories (that assume non-syntactic information can immediately influence parsing; e.g., Ford, Bresnan & Caplan, 1982). Accordingly, substantial research has focused on processing of relative clauses (RCs) modifying a complex NP, which can be ambiguous regarding to what previous noun phrase they refer to. So, in the famous example the servant of the actress who was on the balcony, a high attachment (HA) reading implies that it is the servant who was on the balcony, while if the relative clause attaches to the lowest NP in the hierarchy of the sentence it is the actress the antecedent of the relative pronoun.

Cuetos and Mitchell (1988) presented evidence against the universality of garden-path’s late closure principle (LC: attachment of incoming material to the clause or phrase being processed) by showing that it fails to apply in Spanish to the parsing of RCs preceded by complex NPs. Instead of attaching the RC in (32) (who had had the accident) to the NP2 (the colonel) of the complex NP (NP1 of NP2), as would be predicted by the late closure strategy, Spanish speakers prefer to take the NP1 (the daughter) as the host of the RC.

(32) *El periodista entrevistó a la hija del coronel que tuvo el accidente.*
The journalist interviewed the daughter of the colonel who had had the accident.

Other studies have shown that, while English has a preference for a low-attachment (LA) of the RC of a complex NP, Spanish seems to have a preference for HA. Gilboy and Sopena (1996, cited by Carreiras & Clifton 1999), however, questioned the often replicated evidence of HA preference in Spanish by arguing that the results reflected the effects of how the materials, in the self-paced reading experiments that have been conducted in Spanish, were segmented. In order to capture any subtle on-line reading time effects, as well as to overcome any bias of the segmentation of the materials, Carreiras and Clifton (1999) recorded eye-movements. It has been argued that eye-tracking during reading is an unobtrusive measure that avoids problems of the segmentation of materials, as it occurs with other self-paced methods, and is more sensitive to initial syntactic processing than are other response measures (e.g., Rayner, Sereno, Morris, Schmauder, & Clifton, 1989). Carreiras and Clifton obtained the usual effect of an on-line preference for HA only with the large segmentation in (33), but not with the small segmentations in (34).
An explanation of how experimental material segmentation influences attachment is given by J. D. Fodor (1998)’s implicit prosody hypothesis (IPH): differences do not depend on language parameters but on phonological aspects influencing ambiguity resolution. The IPH assumes that readers engage their phonological processor to ‘chop up’ the input into manageable chunks or packages and that a phonological factor that leads to the insertion of a prosodic break in speaking will equally likely promote the insertion of a package boundary in reading. Readers are taken not only to create prosodic boundaries but, crucially, to use them as signal for syntactic processing, by aligning syntactic boundaries with them. J. D. Fodor (1998, p. 303) assumes that in silent reading a prosodic contour is imposed on the input string, and that the syntactic parser is sensitive to the prosodic phrase boundaries even though they were fabricated by the perceptual system itself. In short, prosodic phrasing influences the first-pass syntactic structure assignment.

The prosodic processor that makes the packaging favours balanced structures in which sister constituents are roughly equal in prosodic weight (number and/or size of prosodic units). In (35a), for example, a one-word package with out would be avoided, so it would be integrated with eating. Short items such as this can be mispackaged. Because it is so short and appears after a long constituent (the apple she had been eating), it is absorbed into eating (although it could be related to Mary threw…) When not isolated, as in (35b), the long out-PP sequence is more easily attached to the higher clause.

Likewise, attachment can depend on the lengths of the NPs: if NP1 is short and NP2 is long, for example, a boundary is likely to be inserted after NP2, rendering the attachment of the relative clause to NP2 difficult, resulting in an NP1 attachment bias. In the contrast in (36), informants typically take (a) to refer the daughter of a divorced bishop, with a left-branching structure, or else they find it equally comfortable with either this or the right-branching interpretation denoting the divorced daughter of a bishop.

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But in (b) where there are four elements, the balance principle sets in and there is a rather clear preference for the reading on which the bishop's daughter is recently divorced. Interestingly, this preference can be eliminated by lengthening the noun to balance out the lengthened modifier. In (c) it is once again the bishop who is recently divorced. This provides further support for the idea that package length is relative (J. D. Fodor, 1998: 306).

Apparent different preferences across languages for ambiguity resolution have been seen as an argument for the necessity of postulating learning along with a putative innate parsing mechanism with universal principles such as late closure. Speakers could learn either the setting of particular parameters for their language, or learn the frequency of occurrence of constructions in the ambient language. According to Mitchell and Cuetos (1991)’s Tuning Hypothesis, for example, when the parser is faced with a choice between structures to build, it favours whichever analysis occurs more frequently in the language.

Evidence for European Portuguese suggests a LA preference. Taking into consideration the IPH, Maia, Fernández, Costa, and Lourenço-Gomes (2007) manipulated the length of the RCs to control for the influence of prosodic breaks; long relative clauses would more probably be read with a separate prosodic phrasing of the RC, which would presumably increase HA rates. Maia et al. conducted a self-paced reading experiment where native speakers of Brazilian and European Portuguese (BP and EP) read 24 target items of four experimental conditions crossing RC attachment (forced high or low) and RC length (short or long), as in (37): HA-Short (37a), HA-Long (37b), LA-Short (37c) and LA-Long (37d).

(37) (a) A vítima reconheceu / os cúmplices [pl] do ladrão [sg] que fugiram [pl].
(c) A vítima reconheceu / o cúmplice [sg] dos ladrões [pl] que fugiram [pl].

The victim recognized the accomplice(s) of the thief (thieves) who ran away [3rdPl] (after the bank robbery).

Attachment was forced by the configuration of number agreement features in the complex NP and the RC verb. Reading times for the underlined region where disambiguation occurred revealed a main effect of RC Attachment: participants took 281...
ms. longer on average to read materials forced to attach high. Importantly, the preference for LA was the same for materials of either length.

Working memory (WM) has also been shown to influence ambiguity resolution, and in fact has been taken into account, more broadly, in sentence processing theories. On the one hand, two-stage accounts like the garden-path theory consider WM can constrain the system WM principles. So, for example, the late closure principle is a natural consequence of limited WM capacity, as it is less costly to attach incoming linguistic material to the currently being processed phrase. On the other hand, constraint-based models (refer to MacDonald & Seidenberg, 2006, for a review) see WM capacity as limiting the extent to which the processor can hold all possible interpretations constructed when an ambiguity is encountered. Just and Carpenter (1992), in particular, propose that all comprehenders can construct multiple interpretations when encountering an ambiguity, but that WM capacity constrains the duration the sentence processor can maintain multiple interpretations. Thus, while high-span readers can hold more efficiently in memory multiple representations, low-span ones have difficulties maintaining more than one interpretation, and therefore abandon the less preferred one.

A relevant study investigating how RC attachment resolution is sensitive to WM capacity is Traxler (2007). Participants, assessed on WM reading span, were eye-tracked as they read sentences such as (38). In (38a) RC must be high-attached, i.e., the NP antecedent of that is the writer (and cannot be the letter). In (38b), instead, the RC must be low-attached, whereby it refers the same animate constituent the writer.

(38)  (a) The writer of the letter that had blond hair arrived this morning.  
      (b) The letter of the writer that had blond hair arrived this morning.

Among other corroborating measures, total time in and regressions from a post-disambiguating region (arrived this) decreased with increases in WM in HA compared to LA, which is interpreted as an easier processing or preference for HA reading, at least by high-span readers.

This and other reading studies of ambiguity resolution take eye-movement responses as an index of processes of attachment interpretation like reanalysis. That re-reading previous ambiguous regions reflects reanalysis is, indeed, a general prediction of garden-path theories: when the processor realizes it pursued an incorrect analysis, it has to revise the initial parsing, namely, by regressing to the region where it went wrong. However, these theories are not explicit concerning where to (NP1 or NP2), in such RCs,
readers regress when encountering ambiguity. That is, reading studies have considered as main measures of interest the time participants take to read, and the associated number of regressions made from, disambiguating regions (reflecting difficulty in processing because the pursued analysis was wrong).

In our Experiment 3, participants first read sentences like The helper (helpers) of the bakers (baker) who will [sg] deliver the bread has (have) arrived, where the morphology of will disambiguated the attachment. They then heard a spoken sentence like The father of the baby who will [sg] drink the beer (the baby bottle) is tall, while viewing a visual context depicting the mentioned subjects (S1, THE FATHER; S2, THE BABY) and the corresponding objects of the verb in the RC (O1, THE BEER; O2, THE BABY BOTTLE).

In the study we reported in Chapter 4, we analysed anticipatory eye-movements to O1 and O2, when participants heard will drink, as reflecting the online pursued interpretation. Yet, there is also evidence of online pronoun resolution in situated language understanding, by which comprehenders make rapid eye-movements to the depicted referent of the heard pronoun. Arnold, Eisenband, Brown-Schmidt, and Trueswell (2000), for example, showed that participants made use of gender information immediately after hearing the pronoun He or She in (39) while seeing one of the images in Figure 5.1. This was reflected in looks to the pronoun possible referent consistent with the interpretation being pursued, whereby participants made more looks at MINNIE when

(39) Donald is bringing some mail to Minnie while a violent storm is beginning. He's/She's carrying an umbrella, and it looks like they're both going to need it.

Figure 5.1: Arnold et al. (2000); example pictures that could be presented with the spoken sentence Donald is bringing some mail to Minnie while a violent storm is beginning. He's/She's carrying an umbrella, and it looks like they're both going to need it. The character carrying the umbrella is the referent of the pronoun.

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23 Frazier and Rayner (1982) only provide a descriptive analysis of regressions. See von der Malsburg & Vasishth (2011) for quantitative evidence for different regressive patterns used by readers to reanalyse garden-path sentences.
hearing she and at Donald when hearing he, regardless if that interpretation would or not have to be revised, depending on the combination of sentence and picture (i.e., DONALD would be the referent of he only in the picture on the left, and MINNIE the referent of she only in the picture of the right).

Accordingly, we might expect that participants in our Experiment 3 make looks to THE FATHER or THE BABY, while hearing the pronoun who (and before the pragmatic disambiguating information is assessed) in The father of the baby who will [sg] drink the beer (the baby bottle) is tall, consistent with their online interpretation. That is, upon hearing who, the online interpretation of the RC as high- or low-attached should reveal itself in fixations to S1 (THE FATHER) or S2 (THE BABY), respectively.

Previous reading of prime RCs, on the other hand, may be informative of attentional patterns occurring when RCs are understood, by the same individual, in a visual context. As we noted above, reading studies of such ambiguity resolution (e.g., Traxler, 2007) have not analysed the reading regions of NP1 and NP2, separately. Moreover, theories of ambiguity resolution do not predict a pattern of eye-movements in reading for NP1 and NP2 (cf. fn. 23). That is to say, it is not clear if re-reading NP2, for example, should be taken as indexing an LA interpretation (i.e., the reader is confirming the interpretation of NP2 as the pronoun antecedent) or an HA interpretation (i.e., the reader finds he made a wrong interpretation and gets back to where the analysis went wrong).

In this Chapter, we will analyse fixations, on the targets’ visual context, to S1 or S2 (upon hearing who), as an index of HA or LA online interpretations, respectively. Likewise, we will take second-pass reading of NP1 and NP2 in the prime sentences as indexing evaluation of the HA and LA interpretations. By ‘evaluation’ we mean that the parser is making the corresponding interpretation, regardless of the fact that it may (or not) be making a reanalysis.

We are concerned with how these two measures of visual attention are related and, in particular, with how pronoun resolution at viewing can be predicted by reading patterns of previous ambiguity resolution in reading. In other words, we aim at investigating if, and how, the acquisition of structural information during reading can determine its proactive re-use during situated understanding. To the best of our knowledge, attachment resolution of RCs has been studied independently in reading (e.g., Traxler, 2007) and during situated language processing (e.g., Kamide, 2012). Therefore, the question we are addressing has not yet been investigated.

In addition, we investigate how individual differences in WM can mediate this process of information transfer from reading to viewing. Our Experiment 3 results showed how participants, when primed with two written sentences, made anticipatory looks (to the verb’s possible arguments), at the subsequent target, congruent with the
alternative, non-primed attachment. Building on Just and Carpenter (1992)’s capacity theory, we hypothesize that high WM individuals can (more than low-span ones do) maintain in memory multiple analyses of a processed sentence and, therefore, evaluate them on the visual context once attachment ambiguity needs to be resolved during situated language understanding.

5.3. Participants, Design and Materials

Table 5.1 reproduces Table 4.1, presenting the stimuli used in Experiment 3, restricted to the Activation 2 condition that we are concerned with. The primes were sentences containing RC’s disambiguated towards a high-(HA) or low-attachment (LA), and the targets were sentences containing a temporary ambiguous RC (refer to Figure 4.2, repeated below as Figure 5.2, for an illustration of a trial run). Accordingly, we now just have a $2 \times 2$ design crossing Prime (HA vs. LA) and Target (HA vs. LA). As mentioned in 4.3.1, twenty-four students from the University of Lisbon who were native speakers of European Portuguese participated voluntarily in the experiment.

Table 5.1: Example of stimuli in the Activation 2 condition of Experiment 3.

<table>
<thead>
<tr>
<th>(1)</th>
<th>Written primes in Activation 2 condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>High attachment: to NP1 (Low attachment: to NP2)</td>
</tr>
<tr>
<td></td>
<td>O irmão (irmãos) dos herdeiros (do herdeiro) que vai ler o testament é/ são de França.</td>
</tr>
<tr>
<td></td>
<td><em>The brother (brothers) of the heirs (heir) who will [sg] read the will is (are) from France.</em></td>
</tr>
<tr>
<td>(b)</td>
<td>High attachment: to NP1 (Low attachment: to NP2)</td>
</tr>
<tr>
<td></td>
<td>O ajudante (ajudantes) dos padeiros (do padeiro) que vai distribuir o pão chegou (chegaram).</td>
</tr>
<tr>
<td></td>
<td><em>The helper (helpers) of the bakers (baker) who will [sg] deliver the bread has (have) arrived.</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(2)</th>
<th>Visual-World Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High attachment: to NP1 (Low attachment: to NP2)</td>
</tr>
<tr>
<td></td>
<td>O pai do bebé que vai beber a cerveja (o biberão) é alto.</td>
</tr>
<tr>
<td></td>
<td><em>The father of the baby who will [sg] drink the beer (the baby bottle) is tall.</em></td>
</tr>
</tbody>
</table>

5.4. Procedure

The procedure was as indicated in section 4.3.4. All participants were also screened for WM, prior or after (counterbalanced between-participants) the eye-tracking session.

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$^{24}$ Traxler (2007)’s results, reported above, are said to support the capacity theory of Just and Carpenter (1992), in that high-span readers should retain more easily in memory the representations of linguistic material that was processed earlier. A particular assumption of the capacity theory relative to ambiguity resolution is, however, that WM determines readers’ capacity to retain and evaluate multiple analyses of attachment resolution.
5.5. Working Memory assessment

Participants’ WM was assessed through verbal (reading and backward-digit) and non-verbal (spatial) WM span tasks. We followed Swets, Desmet, Hambrick, and Ferreira (2007) in including a spatial working memory span measure to assess the effects on a nonverbal factor in ambiguity resolution. As noted by Swets et al. (2007), although reading span is the most common measure used in language processing research, domain-general memory factors may influence processing, thus the use of only a reading span task is a limitation of previous studies. Furthermore, WM measures are more reliable when resulting from composite measures of the scores in several tasks (Waters & Caplan, 2003; Salthouse, 1994). We thus administered three tasks to assess verbal, spatial and digit spans.

The reading span task was modelled on the Daneman and Carpenter (1980) task, as modified by Turner and Engle (1989). While in the traditional task participants just read aloud increasingly longer sequences of sentences and have to recall, at the end of each sequence, the final word of that sequence sentences, the modified version introduced a processing component, whereby subjects make judgements about the acceptability of the sentences (half of which containing misorderings of words). The rationale behind this procedure is that WM refers also to processing, and not only to storage of elements (Baddeley & Hitch, 1974), so the task should tap on both the components. In the new version, the total number of correctly recalled words from all trials (total memory span) is also taken as the measure of WM capacity (instead of the longest list length the
participant could recall), which has been shown to be a more accurate measure (Miyake, Emerson, & Friedman, 1999).

Gaspar and Pinto (2001) have made an adaptation of Daneman and Carpenter (1980)’s task for European Portuguese. We used the materials they kindly provided to us, to which ten new sentences were added in order to have 70 critical sentences and 6 additional training sentences with around 12–13 words. Half of these sentences were slightly changed in order to have misorderings of words to allow for the acceptability judgement after each sentence.

Each subject was given sets of sentences like (40), where the last word was in CAPITAL letters. At each set, sentences were presented one at a time for 5 seconds, and participants had to read them aloud. After each sentence, the participant had to say whether the sentence was grammatical or ungrammatical, while keeping in memory the last word in the sentence (FAROL). After all the items in a given set had been presented, the recall prompt recall the words appeared, signalling that a trial has ended and the participant should recall the last word of each of the sentences in the order in which they had occurred, and write them in the screen using the keyboard. The duration of this prompt varied as a function of the set size of the trial: for each set participants had 4 s per sentence. So, for set sizes of two, 8s were allowed for recall; for set sizes of three, 12 s were allowed for recall; and so on. After that time limit a new trial was presented on the screen. There were five sets of 2, five sets of 3, five sets of 4 and five sets of 5 sentences, so that there were a total of 20 sentence sets in this test, 5 sets for each set size. The total number of correct items from the reading span task was taken as the indicator for verbal working memory.

(40) *O capitão avistou um navio perto do rochedo e acendeu o FAROL.*
The captain saw a ship near the rock and lighted the LIGHTHOUSE.

The spatial span task was adapted from Shah and Miyake (1996). The task requires participants to perform a spatial transformation (i.e., mental rotation) while keeping track of spatial information (i.e., the spatial orientation) while seeing letters (refer to Figure 5.3). Trials consisted of five sets of 2, five sets of 3, five sets of 4 and five sets of 5 letters, so that there were a total of 20 letters sets in this test, 5 sets for each set size.

A single trial consisted of the individual presentation of a set of normal or mirror-imaged letters (F, J, L, P, or Q) on a computer screen. The same letter was used within a set, and participants were told which letter would appear on the screen in that particular trial. Each letter was presented in one of seven possible orientations (in 45° increments, excluding the upright orientation), and each of the 70 possible combinations (5 letters × 7

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25 We thank Nuno Gaspar and Amâncio da Costa Pinto for the use of their materials.
orientations × 2 normal/mirror-image status) appeared once in the task. The presentation of letters was constrained such that opposing orientations were not presented successively within a set and that the same orientation could appear only once in the same set. Each participant viewed the same items in the same order. There was a 50/50 split of items on the normal/mirror-reversed dimension.

Each letter in a given trial was presented for 3 seconds. After that, a screen presented a question about the normal or mirror-image status of the letter. In that screen the words ESPELHO (mirror) and NORMAL (normal) appeared in red and green, at the left and right side of the screen, respectively. Participants answered by pressing the green (for NORMAL) or red (for MIRROR) labelled keys in the keyboard. Immediately after the answer the next letter was presented. After all of the items in a given set had been presented, the recall prompt recall the orientations appeared, signalling that a trial has ended and that he should recall the orientations of each of the letters in the order in which they had occurred, and write them down in the given answer sheet. The duration of this prompt varied as a function of the set size of the trial, the same way it did for the reading span task. The total number of correct items was taken as the indicator for spatial working memory.

Figure 5.3: Example trial (set size is 2) of the spatial span task: participants judge whether each individually presented letter is normal or mirror-imaged while keeping track of the orientation of the letters. At the end of the trial, the participant recalls the orientation of each letter in the order in which it appeared.

In the backward digit span task, on each trial, subjects were required to repeat a series of digits in reverse order of presentation. Because this task is easier than the reading and the spatial span tasks (as there is not a processing question after each item and items are simple digits), the set sizes used here were from 2 to 8. In order to have a total number of items comparable with the one of the other tasks (70), trials consisted of two sets of 2, two sets of 3, two sets of 4, two sets of 5, two sets of 6, two sets of 7 and two sets of 8 digits. The digits were presented on the screen, one at a time, for 700 ms; at the end of the set, participants attempted to recall the digits in that set in reverse order of presentation. The duration for this recalling varied as a function of the set size of the trial:
4 s for size 2, 6 s for size 3, 8 s for size 4, 10 s for size 5, 12 s for size 6, 14 s for size 7 and 16 s for size 8. The span score was the total number of correctly recalled items.

For each participant, we computed a composite measure based on the average of the scores of the three tasks, and standardized it into z-scores. This procedure increases reliability of the scores, and their generalizability across tasks (Salthouse, 1994).

5.6. Analyses

5.6.1. Reading measures

We consider second-pass on NP1 and NP2 (The helper and of the bakers in The helper of the bakers who will deliver the bread has arrived), as the sum of all fixations’ duration, beginning with the first re-entry in the region and ending when the reader leaves it, in any direction. Length-residualized values, i.e., the differences between predicted (by linear regression as function of word length) and observed values, were computed for each subject, to account for length variability (refer to section 2.2.2). As stated before, each reading trial had two prime sentences with the same structure (either HA or LA). In order to have a unique reading measure to use as predictor of fixation, we consider the mean second-pass between the first and second sentences. If the eye-movement of a trial did not record two or more of seven AOIs considered (indicated by the slashes in The helper | of the bakers | who will | deliver | the bread | has arrived), we removed it, assuming mis-calibration. This procedure removed 148 of 1150 trials (12.8%).

5.6.2. Visual-world measures

We followed the same procedure as indicated in section 4.3.5, but fixations were aligned, this time, item-by-item, to the onset of the pronoun who, creating a time window up to 400 ms after it (with 200 ms added to account for oculo-motor programming). Fixation points were aggregated in 50 ms bins, and the percentage of fixations on each visual object was calculated relative to the total amount of fixation on every other object. For fixations on S1 and on S2, we took the mean percentage of fixations in these entities across 8 bins (i.e., 400 ms), and obtained a unique measure of fixation to correlate with the second-pass reading time observed in the same trial.

Our dependent variable is the percentage of fixations on S1 (and S2), predicted as a function of reading NP1 (and NP2), prime type (HA vs. LA) and WM z-scores in a maximal-random mixed effect models (Barr, Levy, Scheepers, & Tily, 2013). The predictors are centered, as a precaution, to avoid co-linearity between predictors. Participant (24) and Item (48) are the random effects, entered as intercept (e.g., (1 |
Participant), as well as uncorrelated slopes for the predictors (e.g., (0 + Prime | Participant), in R syntax).

5.7. Results

In Figures 5.4 and 5.5, we scatter percentage of fixations to S1 and S2, as a function of second-pass readings on NP1 and NP2 respectively, for high and low WM groups in the two priming conditions (HA - left panels, LA - right panels). We observe that fixations to S1 and S2 are differently modulated by second-pass reading times on NP1 and NP2, the type of Prime, and WM. In particular, starting with fixation to S1, we observe a significant two-way interaction between prime and second-pass, whereby stronger anticipation to S1 is observed with longer second-passes, especially when the prime is LA (two-way interaction prime:secondpass, refer to Table 5.2 for the model coefficients). Moreover, this effect is especially strong in individuals with high WM (prime:secondpass:WM, visualized in Figure 5.4, right LA panel).

This result shows that WM capacity enables comprehenders to encode and recall the HA alternative when primed with the preferred LA structure. Most importantly, this happens when they reread for longer NP1, indicating that they evaluated an HA interpretation of the sentence.

![Figure 5.4: Scatter plot of Percentage of fixation on S1 as a function of residual Second-pass time on NP1 in HA (left) vs. LA (right) prime and low (dashed) vs. high (solid) WM.](image)

Note the WM grouping (considering two halves of the distribution) is only for purposes of visualization; the WM scores were introduced as a continuous measure in the model.
Fixations to S2 corroborate this result. Here, we observe less anticipatory looks to S2, for longer second-pass reading NP2 in LA primes, for high-WM individuals, as reflected in the three-way interaction prime:secondpass:WM (refer to Table 5.3 to the coefficients of the model).

**Figure 5.5:** Scatter plot of Percentage of fixation on S2 as a function of residual Second-pass time on NP2 in HA vs. LA prime and low vs. high WM.

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>SE</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>13.378</td>
<td>2.042</td>
<td>6.552</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>prime</td>
<td>5.325</td>
<td>3.084</td>
<td>1.727</td>
<td>0.084</td>
</tr>
<tr>
<td>secondpass (NP1)</td>
<td>0.022</td>
<td>0.014</td>
<td>1.568</td>
<td>0.117</td>
</tr>
<tr>
<td>WM</td>
<td>1.037</td>
<td>2.040</td>
<td>0.508</td>
<td>0.611</td>
</tr>
<tr>
<td>prime:WM</td>
<td>-1.706</td>
<td>3.204</td>
<td>-0.532</td>
<td>0.594</td>
</tr>
<tr>
<td>prime:secondpass</td>
<td><strong>0.070</strong></td>
<td><strong>0.028</strong></td>
<td><strong>2.530</strong></td>
<td><strong>0.011</strong></td>
</tr>
<tr>
<td>secondpass:WM</td>
<td>-0.001</td>
<td>0.013</td>
<td>-0.074</td>
<td>0.941</td>
</tr>
<tr>
<td>prime:secondpass:WM</td>
<td><strong>0.050</strong></td>
<td><strong>0.025</strong></td>
<td><strong>2.023</strong></td>
<td><strong>0.043</strong></td>
</tr>
</tbody>
</table>

Table 5.2: Summary of the MLMEM fitted to Fixations on S1 as a function of Second-Pass Residual Reading times, Prime and WM. For each effect, we report the coefficient estimate (in percentage of fixation), its standard errors and significance tests (t and p-values). Prime (HA = −0.5; LA = 0.5), Reading (ranging from −64 to 501 ms) and WM (ranging from −2 to 1.6) are continuous measures.
Table 5.3: Summary of the MLMEM fitted to Fixations on S2 as a function of Second-Pass Residual Reading times, Prime and WM. For each effect, we report the coefficient estimate (in percentage of fixation), its standard errors and significance tests (t and p-values). Prime (HA = −0.5; LA = 0.5), Reading (ranging from −212 to 719 ms) and WM (ranging from −2 to 1.6) are continuous measures.

<table>
<thead>
<tr>
<th>Estimate</th>
<th>SE</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>42.400</td>
<td>3.570</td>
<td>11.878</td>
</tr>
<tr>
<td>prime</td>
<td>-1.774</td>
<td>3.811</td>
<td>-0.465</td>
</tr>
<tr>
<td>secondpass (NP2)</td>
<td>-0.006</td>
<td>0.011</td>
<td>-0.524</td>
</tr>
<tr>
<td>WM</td>
<td>-0.336</td>
<td>3.529</td>
<td>-0.095</td>
</tr>
<tr>
<td>prime:WM</td>
<td>-1.285</td>
<td>3.962</td>
<td>-0.324</td>
</tr>
<tr>
<td>prime:secondpass</td>
<td>-0.034</td>
<td>0.021</td>
<td>-1.617</td>
</tr>
<tr>
<td>secondpass:WM</td>
<td>-0.013</td>
<td>0.011</td>
<td>-1.133</td>
</tr>
<tr>
<td>prime:secondpass:WM</td>
<td>-0.042</td>
<td>0.021</td>
<td>-1.961</td>
</tr>
</tbody>
</table>

5.8. Discussion

Our results can be motivated by the capacity-theory of sentence processing, where WM holds multiple possible representations for the same sentence. The interaction, however, was stronger on fixations to S1 with respect to the second-pass readings on NP1. This result might reflect the preference of Portuguese readers for LA. In fact, percentage of fixations to S2 (LA interpretation, Figure 5.5) is overall higher than anticipation of S1 (HA interpretation, Figure 5.4), reflecting a bias towards LA. In Just and Carpenter (1992)’s theory, the higher WM is, the more the individuals can construct and maintain multiple representations when faced with an ambiguity, which levels of activation are determined by other factors such as the frequency of occurrence in the language.

In our data, high-WM readers, as expected, show less difficulty with the dispreferred high-attachment; they do not have to re-inspect NP1 in reading HA to further anticipate S1\(^{27}\), confirming that HA sentences are not so demanding for high-capacity readers. Yet, the capacity model assumes that the less frequent alternative (here HA) should have an a priori lower level of activation, even when high-memory allows for its activation. Why, then, should high-WM readers strongly anticipate S1, rather than S2, when presented with two LA primes? A possible answer is that memory capacity not only allows for encoding of multiple alternatives but also leads to strategic strengthening of less frequent representation, to avoid future prediction errors, as proposed by learning accounts of priming (e.g., Chang, Dell, & Bock, 2006). This strategy involves a greater allocation of attention to the syntactic elements associated with alternative interpretation.

\(^{27}\) Additional analysis on residual second-pass on NP1 as a function of WM and Prime revealed a main effect of WM ($\beta = -24.61, p = 0.036$).
a process allowing transfer of structural information when needed to be recalled in a visual context.

Our results also raise interesting questions when we take into consideration the findings we reported before. In the previous Chapter, we suggested that the anticipation of the alternative, non-primed attachment could result from supressing the type of prime presented repeatedly. We also hypothesized that this short-term phenomenon could be the behavioural correlate of neural repetition suppression (RS). Although taking a different measure in the analyses reported in the present Chapter (namely, indexes of pronoun resolution and not of verb’s argument anticipation), these results corroborate the findings we reported in Chapter 4 in showing anticipation of the non-primed attachment. They suggest, moreover, that this pattern of results is particularly prominent for high-memory comprehenders. Could high-memory individuals be more prompt or able to use an RS mechanism? Could better WM be associated with higher inhibitory control? We cannot answer these questions without investigating if indeed RS can be seen in repeated processing of sentences containing the same attachment resolution, and if high-memory is positively correlated with inhibitory control. We highlight, however, that these are questions that open a new research avenue.

5.9. Conclusions

In the study reported in this Chapter we provided, for the first time, linking evidences between online reading measures of sentences and online measures of their incremental processing when situated in a visual context. Furthermore, we aimed to reconcile the dynamics of these processes with working memory capacity. We did it by showing that ambiguity resolution strategies at reading can directly inform on anticipatory mechanisms during language understanding, and are mediated by WM capacity.

Our results lend support to parallel processing accounts of syntactic ambiguity resolution and, in particular, to Just and Carpenter (1992)’s capacity theory. They also directly contribute to advance such theory by showing that translational mechanisms are at place when comprehenders engage into reading and situated language understanding. More interestingly, when seen in conjunction with the results we reported in Chapter 4, they raise new research questions that should be addressed in further work.
6. Conclusions

In this thesis, we investigated the representational and experiential basis of syntactic processing during comprehension through the behavioural tool of syntactic priming. We demonstrated how syntactic priming can tap into both mental representations and the way these are used during language processing. Moreover, we uncovered new mechanisms modulating comprehension of syntactic structures; namely, the amount of experience with structures at a short-term timeframe, and individual differences in working memory capacity.

6.1. Contributions

Language processing is a highly complex interplay between linguistic knowledge and processes. Both linguistic knowledge (competence) and use (performance) are since long in the agenda of the cognitive sciences. In our work, we used syntactic priming to provide empirical findings that can contribute to a better understanding of these mental representations and processes. We focused on the comprehension modality and in two particular instantiations of syntactic structure: the locative alternation and the attachment of relative clauses to a complex NP.

We showed that a syntactic priming self-paced reading task can help to distinguish between theories of representation for the locative alternation. Previous literature on syntactic priming (Chang et al., 2003) has addressed this question and showed that the order of thematic-roles could be primed in a production task. The results are said to
support constructionist approaches postulating (lexically independent) associations of semantic roles and grammatical functions (Goldberg, 1995). Our results add to these previous findings in that they show the priming effect is not of the same magnitude for the two variants. Our finding that the LT variant is a better prime and could facilitate both variants is consistent with a projectionist proposal considering LT a more complex (namely, by entailing the meaning of the TL alternative) variant (Rappaport & Levin, 1988). Our first contribution was, therefore, to provide evidence of a different pattern of priming observed for the two variants.

The amount with which alternative syntactic structures are experienced has also been shown to modulate syntactic priming. Previous work, however, has investigated these dynamics in long-term timeframes such as an experiment (e.g., Jaeger & Snider, 2013). Our second contribution was, thus, to show how the amount of experience with structures impacts on short-term priming. Importantly, we found reversed priming when comprehenders were exposed to two primes that repeated a syntactic structure in an experimental trial. This finding, whereby repetition of a primed structure leads to the expectation for the alternative, non-primed structure, was not reported before in syntactic priming literature, and indeed challenges the (at least tacit) assumption of a linear positive relation between exposure and strength of priming. Assuming the existence of an activation mechanism underlying short-term syntactic priming, we tentatively suggested that our results may be explained by a mechanism of deactivation of the processed stimuli, after the first time it is processed. Thus, our work raises important questions for the (under debate) explanations of syntactic priming, by suggesting another mechanism can be at place, at least at short-term priming.

There is, after thirty years of research on syntactic priming, a large and complex pattern of results, with current debate focusing on the cognitive mechanisms underlying the effects. Previous work has not investigated systematically the relation between syntactic priming and working memory (WM), although the latter is taken to be a relevant component of the first. Our third contribution was to give new insights concerning this relationship. We showed that the reversed priming found in Experiment 3 was positively correlated with WM capacity, whereby higher-capacity individuals predicted more the non-primed interpretation. Moreover, we demonstrated that the pattern of anticipatory fixations at targets also correlated positively with the amount of reading, in prime sentences, the expression referring the entity associated with that interpretation. By assessing these effects in a visual-world priming task we also provided, for the first time, linking evidences of online measures during reading and online measures of subsequent image viewing.

Our findings highlight that syntactic priming is a unified framework to investigate syntactic processing, tapping into both its representational and experiential basis.
6.2. Future work

In Experiments 1 and 2, we showed that the frequency or preference of particular verbs for one or the other variant influences priming. Indeed, most of the verbs we used had a TL preference. This may limit the conclusions we can draw from our data. In fact, the stronger effects of priming for the LT variant can arguably be attributed to either the fact that LT has a more complex representation, or that it is a less frequent structure (therefore inducing stronger priming, under implicit learning accounts). We note that the explanations are not mutually exclusive, and may well be related. That is, it is possible that, for example, there is an overall preference in the language for the TL variant resulting from the language system choosing preferentially a simpler structure to convey a similar message. Or, the other way around, the fact that TL is more frequent would make the system recognize LT as a more difficult alternative.

In order to answer these questions, some approaches would be useful in further work. Analyses of corpora could inform on the relative frequency of the variants, both in the language and for each particular verb. With that knowledge, further experiments could manipulate, with greater certainty, the previous experience (i.e., in the language) with the structures. An interesting question would be whether verbs with a strong LT preference would show the corresponding pattern we found for verbs biased towards TL. If the dispreferred TL structure would show stronger priming, this would be evidence against the claim of an overall higher complexity of the LT representation. Instead, such results would emphasize the contribution of frequency biases in the task, compatible with implicit learning accounts of syntactic priming.

A final issue that we did not address concerns the lexical (in)dependency of the effects. In order to assess the extent to which our effects rely on lexical repetition of the verb across prime and target, a follow up experiment would have to test prime and target pairs with different verbs. If priming would still occur (even if weaker), the results would cast doubt on the proposed representations of Rappaport and Levin (1988), as the structures are assumed to be associated with the lexical item. However, additional assumptions of separated structural representation and lexical item would still be possible, while maintaining the difference in complexity in the representations.

Experiments 3 and 4 revealed surprising effects of within-trial reversed priming, which we suggested might result from a mechanism like repetition suppression (RS). However, we did not test explicitly the phenomenon of a reduced neural activity upon stimuli repetition. Thus, this hypothesis would have to be tested using behavioural tools measuring neural activity, such as fMRI. In addition, cognitive assessment of inhibitory control could be pertinent, as individuals vary in their capacity of inhibition and repetition suppression has been related with cognitive inhibition (e.g., Juvina & Taatgen, 2009). Another question that remains to be answered is whether this pattern of results may be
restricted to tasks where prediction during incremental language processing is assessed (as the VWP) and to stimuli where prediction is arguably easier to detect as temporary ambiguity. Therefore, future research should test these effects using these (to replicate the present results) and other stimuli/tasks (to further investigate the origin of the effects).

The task we used in Experiments 3 and 4 allowed us to investigate how information of syntactic ambiguity resolution is transferred from a reading modality to the subsequent modality of visually situated language understanding. In addition, we investigated individual differences in WM. Our findings corroborate the necessity of psycholinguistic research to study language processing integrated in the complex interplay of different cognitive systems or modules.
References


Appendices

A – Sentences

Experiment 1

No armazém o empregado carregou a carrinha comercial com a mercadoria vendida (a mercadoria vendida na carrinha comercial) para entregar ao cliente.
*In the warehouse the employee loaded the commercial van with the sold merchandise (the sold merchandise into the commercial van) to deliver to the client.*

No multibanco a rapariga carregou o cartão telefónico com o dinheiro necessário (o dinheiro necessário no cartão telefónico) e ligou logo ao namorado.
*In the cash machine the girl charged the phone card with the necessary amount (the necessary amount into the phone card) and immediately called her boyfriend.*

Durante o exercício o soldado carregou a arma nova com as balas reais (as balas reais na arma nova) e disparou acidentalmente sobre os colegas.
*During the exercise the soldier loaded a new gun with real bullets (the real bullets into a new gun) and accidentally shot his colleagues.*

Antes de anoitecer o produtor carregou o tractor grande com o feno seco (o feno seco no tractor grande) para armazenar num local coberto.
*Before sundown the farmer loaded the large tractor with dry hay (the dry hay into the large tractor) to store in a sheltered place.*

No porto de Lisboa a tripulação carregou o navio português com os alimentos doados (os alimentos doados no navio português) e seguiu rumo ao seu destino.
*In the port of Lisbon the crew loaded the Portuguese ship with the donated food (the donated food into the Portuguese ship) and continued to its destination.*

À porta do hotel o motorista carregou a bagageira vazia com as malas pesadas (as malas pesadas na bagageira vazia) para levar os hóspedes ao aeroporto.
*At the door of the hotel the driver loaded the empty trunk with the heavy luggage (the heavy luggage into the trunk) to take the guests to the airport.*
Na vinha do Douro o ajudante carregou o tractor maior com os cestos vindimos (os cestos vindimos no tractor maior) para serem levados para o lagar.  
*In the vineyard of the Douro the assistant loaded the largest tractor with grape baskets (the grape baskets into the largest tractor) to be taken to the wine press.*

Na ourivesaria o assaltante carregou os sacos pretos com as jóias roubadas (as jóias roubadas nos sacos pretos) e pôs-se em fuga rapidamente.  
*In the jewellers the robber loaded the black bags with stolen jewels (the stolen jewels into the black bag) and quickly made a getaway.*

Durante a tarde o trabalhador carregou o vagão ferroviário com as camas hospitalares (as camas hospitalares no vagão ferroviário) para transportar para França.  
*During the afternoon the worker loaded the train wagon with the hospital beds (the hospital beds into the train wagon) to transport to France.*

Na plataforma o armador carregou o cargueiro norueguês com o petróleo bruto (o petróleo bruto no cargueiro norueguês) para ser transportado para a refinaria.  
*In the platform the ship-owner loaded the Norwegian freighter with crude oil (the crude oil into the Norwegian freighter) to be transported to the refinery.*

Na loja o informático carregou o disco externo com os ficheiros todos (os ficheiros todos no disco externo) antes de proceder à desfragmentação.  
*In the shop the IT technician loaded the hard disk with all the files (all the files into the hard disk) before beginning the defragmentation.*

No alto mar o empresário carregou a lancha rápida com a droga traficada (a droga traficada na lancha rápida) mas foi depois interceptado pela polícia.  
*At high sea the businessman loaded the speedboat with the smuggled drugs (the smuggled drugs into the speedboat) but was later intercepted by the police.*

Na gráfica o técnico imprimiu os folhetos vermelhos com o texto político (o texto político nos folhetos vermelhos) para distribuir na acção de protesto.  
*In the print shop the technician printed the red flyers with political text (the political text onto the red flyers) to distribute during the rally.*

Em Janeiro o comerciante imprimiu o cartão pessoal com o logotipo novo (o logotipo novo no cartão pessoal) para promover a imagem da empresa.  
*In January the merchant printed the business card with a new logo (the new logo on the business card) to promote the company’s image.*

Antes do casamento a noiva imprimiu os convites brancos com o desenho dourado (o desenho dourado nos convites brancos) e enviou para os convidados.  
*Before the marriage the bride printed the white invitations with the golden drawing (the golden drawing on the white invitations) and sent them to the guests.*

Logo pela manhã o chefe imprimiu a cartolina branca com o menu semanal (o menu semanal na cartolina branca) e afixou-a à entrada do restaurante.  
*Early in the morning the boss printed the white card with the weekly menu (the weekly menu on the white card) and displayed it at the restaurant’s entry.*

Na agência de viagens o gerente imprimiu a brochura publicitária com as fotos novas (as fotos novas na brochura publicitária) para divulgar outros destinos.  
*In the travel agents the manager printed the advertising brochure with new photos (the new photos on the advertising brochure) to publicize new destinations.*

No escritório a secretária imprimiu os postais natalícios com os nomes escolhidos (os nomes escolhidos nos postais natalícios) para enviar aos melhores clientes.  
*In the office the secretary printed the Christmas cards with the chosen names (the chosen names on the Christmas cards) to send to their best clients.*
No fim do torneio o futebolista imprimiu a t-shirt usada com o número dez (o número dez na t-shirt usada) e ofereceu-a à entidade organizadora.

At the end of the tournament the soccer player printed a used t-shirt with the number ten (the number ten on a used t-shirt) and gave it to the organizing entity.

A pedido do autor o tipógrafo imprimiu a capa castanha com as letras pretas (as letras pretas na capa castanha) embora contra a vontade do editor.

At the request of the author the typographer printed a brown cover with black letters (black letters on a brown cover) despite it being against the editor’s wishes.

Na escola a educadora imprimiu o postal branco com o desenho colorido (o desenho colorido no postal branco) para o menino oferecer à mãe.

At school the educator printed the white postcard with a colourful drawing (the colourful drawing on the white postcard) for the boy to give to his mother.

No ano passado a tabaqueira imprimiu os maços de tabaco com as fotos chocantes (as fotos chocantes nos maços de tabaco) para tentar diminuir o consumo.

Last year the tobacco company printed cigarette packets with shocking pictures (shocking pictures on cigarette packets) to try to diminish consumption.

Antes da viagem a agência imprimiu os guias individuais com a rota prevista (a rota prevista nos guias individuais) e distribuiu a todos os turistas.

Before the trip the agency printed the individual guides with the planned itinerary (the planned itinerary on the individual guides) and gave them out to all the tourists.

Como recomendado o jardineiro borrifou a planta doente com o produto químico (o produto químico na planta doente) para tratar as folhas e flores.

As recommended the gardener sprayed the sick plant with the chemical product (the chemical product on the sick plant) to treat the leaves and flowers.

No quarto de hóspedes a empregada borrifou os lençóis novos com a fragância floral (a fragância floral nos lençóis novos) e fez um caderno para o namorado.

In the guest room the maid sprayed the new sheets with the floral fragrance (the floral fragrance on the new sheets) and did a notebook for her boyfriend.

Depois de limpar a mulher borrifou a casa toda com a água benta (a água benta na casa toda para) purificar e eliminar más energias.

After cleaning the woman sprayed the whole house with holy water (holy water on the whole house) to purify and eliminate negative energies.

Na cozinha o aprendiz borrifou o tomate cereja com o azeite virgem (o azeite virgem no tomate cereja) e levou ao forno forte para gratinar.

In the kitchen the apprentice sprayed the cherry tomatoes with olive oil (the olive oil on the cherry tomatoes) and put it in the strong oven to bake.
Depois da praia a senhora borrifou o rosto ressequido com a água termal (a água termal no rosto ressequido) para prevenir a sua desidratação.

After the beach the lady sprayed her dry face with thermal water (thermal water on her dry face) to prevent it from dehydrating.

Na casa de banho a mulher borrifou a parede húmida com a lixívia diluída (a lixívia diluída na parede húmida) e deixou actuar alguns minutos.

In the bathroom the lady sprayed the humid wall with diluted bleach (diluted bleach on the humid wall) and let it act for a few minutes.

No salão a cabeleireira borrifou o cabelo seco com a água fria (a água fria no cabelo seco) para poder facilmente executar o penteado.

In the hair salon the hairdresser sprayed the dry hair with cold water (cold water on the dry hair) to ease the combing.

Sobre o lume o criado borrifou os bifes fritos com o vinho branco (o vinho branco nos bifes fritos) antes de adicionar as natas para fazer o molho.

On the hot pan the cook sprayed the fried steaks with white wine (white wine on the fried steaks) before adding the cream to make the sauce.

Na estufa o horticultor borrifou as alfaces biológicas com o fungicida orgânico (o fungicida orgânico nas alfaces biológicas) para evitar a propagação da doença.

In the greenhouse the gardener sprayed the biological lettuce with organic fungicide (organic fungicide on the biological lettuce) to avoid spreading of the disease.

Na sala a empregada borrifou as carpetes sujas com a solução amoniacal (a solução amoniaca nas carpetes sujas) para remover facilmente as nódoas.

In the living room the maid sprayed the dirty carpets with the ammonia solution (the ammonia solution on the dirty carpets) to remove the stains more easily.

Num dia apenas o empregado pintou a parede toda com as ramagens verdes (as ramagens verdes na parede toda) conforme o projecto do decorador.

In only one day the employee painted the whole wall with green branches (green branches on the whole wall) as specified by the decorator’s project.

No seu ateliê o artista pintou a tela gigante com as figuras abstractas (as figuras abstractas na tela gigante) iniciando uma nova corrente artística.

In his atelier the artist painted the giant canvas with abstract figures (the abstract figures on the giant canvas) starting a new artistic movement.

Antes do jogo o adepto pintou a face esquerda com a bandeira nacional (a bandeira nacional na face esquerda) para manifestar o seu apoio à selecção.

Before the game the fan painted the left side of his face with the national flag (the national flag on the left side of his face) to show his support for the team.

Na nova coleccção o criador pintou os lenços azuis com os girassóis amarelos (os girassóis amarelos nos lenços azuis) revelando a influência de Van Gogh.

In the new collection the creator painted the blue sheets with yellow sunflowers (the yellow sunflowers in the blues sheets) revealing the influence of Van Gogh.

Na escola a turma pintou o muro cinzento com as flores coloridas (as flores coloridas no muro cinzento) e preparou a festa de final do ano lectivo.

At school the class painted the grey wall with colourful flowers (the colourful flowers on the grey wall) and prepared the end of school year party.

No teatro o cenarista pintou a tela gigante com os faraós egípcios (os faraós egípcios na tela gigante) para usar no primeiro acto da ópera Aida.

In the theatre the set designer painted the giant canvas with Egyptian pharaohs (Egyptian pharaohs on the giant canvas) to use in the first act of the Aida opera.
No quarto da filha a mãe pintou o tecto branco com as estrelas azuis (as estrelas azuis no tecto branco) e pendurou um candeeiro em forma de lua. 

**In the room of the daughter the mother painted a white ceiling with blue stars (blue stars on the white ceiling) and hung a moon-shaped chandelier.**

À entrada do congresso a organizadora pintou um painel grande com rostos femininos (rostos femininos num painel grande) para ilustrar o tema do debate. 

**At the entry of the congress the organizer painted the large panel with the feminine faces (the feminine faces on the large panel) to illustrate the theme of the debate.**

Na Nazaré o marinheiro pintou o barco novo com o nome familiar (o nome familiar no barco novo) e preparou a saída para pesca no alto mar. 

**In Nazareth the sailor painted the new boat with the family name (the family name on the new boat) and prepared to go fishing in deep waters.**

No ATL a menina pintou o azulejo branco com a flor amarela (a flor amarela no azulejo branco) como tinha desenhado no papel anteriormente. 

**In the after-school atelier the girl painted the white tile with the yellow flower (the yellow flower on the white tile) as she had drawn on the paper beforehand.**

No Brasil a equipa pintou o Ferrari vermelho com o número onze (o número onze no Ferrari vermelho) antes de iniciar a etapa do Grande Prémio. 

**In Brazil the team painted the red Ferrari with the number eleven (the number eleven on the red Ferrari) before starting the Grand Prize phase.**

Na igreja o artista pintou a parede frontal com as figuras religiosas (as figuras religiosas na parede frontal) e o arcebispo realizou a missa inaugural. 

**In the church the artist painted the front wall with religious figures (the religious figures on the front Wall) and the archbishop held the inaugural mass.**

Depois da vitória o ourives gravou a medalha ganha com o nome do vencedor (o nome do vencedor na medalha ganha) para ser entregue na cerimónia final. 

**After the victory the goldsmith engraved the medal awarded with the name of the winner (the name of the winner on the medal awarded) to be given at the final ceremony.**

Antes do concerto a cantora gravou a face direita com o símbolo nazi (o símbolo nazi na face direita) e publicou um vídeo polémico na internet. 

**Before the concert the singer painted the right side of her face with the Nazi symbol (the Nazi symbol on the left side of her face) and published the video on the internet.**

Antes do casamento o casal gravou as alianças douradas com os nomes próprios (os nomes próprios nas alianças douradas) como era tradição familiar. 

**Before the marriage the couple engraved the wedding rings with their names (their names on the wedding rings) as was the family tradition.**

No aniversário a banda gravou o disco comemorativo com a obra integral (a obra integral no disco comemorativo) para satisfação dos milhares de fãs. 

**In the anniversary the band recorded a commemorative disk with the complete collection (the complete collection on a commemorative disk) to the satisfaction of the fans.**

Em Inglaterra o governo gravou as moedas novas com a efigie real (a efigie real nas moedas novas) para comemorar o aniversário da Rainha. 

**In England the government engraved new coins with the royal effigy (the royal effigy on new coins) to celebrate the Queen’s birthday.**

Em Dezembro a editora gravou o CD natalício com as canções antigas (as canções antigas no CD natalício) recorrendo ao seu grande acervo musical. 

**In December the record label recorded a Christmas CD with the old songs (the old songs on a Christmas CD) using its large music collection.**
No ministério o jornalista gravou o disco compacto com o ficheiro confidencial (o ficheiro confidencial no disco compacto) e foi acusado de violar regras éticas. In the ministry the journalist recorded the compact disk with the confidential file (the confidential file on the compact disk) and was accused of breaking ethical rules.

Como pedido o escultor gravou a pedra tumular com a inscrição hebraica (a inscrição hebraica na pedra tumular) em homenagem às origens do escritor. As asked the sculptor engraved the tombstone with the Hebraic inscription (the Hebraic inscription on the tombstone) in homage to the writer’s origins.

Para o torneio o clube gravou a taça prateada com o emblema regional (o emblema regional na taça prateada) como agradecimento à câmara municipal. For the tournament the club engraved the silver cup with the regional emblem (the regional emblem on the silver cup) as a way of thanking the town council.

Para o baptizado a madrinhã gravou o fio dourado com as iniciais da menina (as iniciais da menina no fio dourado) e os pais ficaram muito felizes. For the baptism the godmother engraved the golden pendant with the girl’s initials (the girl’s initials on the golden pendant) and the parents were very happy.

Na fábrica o técnico gravou o prato cerâmico com o desenho floral (o desenho floral no prato cerâmico) para a nova coleção de louça decorativa. In the factory the technician engraved the ceramic plate with the floral design (the floral design on the ceramic plate) for the new collection of decorative dishes.

No jardim botânico o rapaz gravou a árvore famosa com o nome da namorada (o nome da namorada na árvore famosa) como é tradição naquele lugar. In the botanic garden the boy engraved the famous tree with the name of his girlfriend (the name of his girlfriend in the famous tree) as is the tradition there.

A meio de Abril o lavrador plantou o terreno fertilizado com o feijão manteiga (o feijão manteiga no terreno fertilizado) para ser colhido em Dezembro. In mid-April the farmer sowed the fertilized soil with butterbeans (the butterbeans in the fertilized soil) to be harvested in December.

Naquela semana a câmara plantou o jardim municipal com os choupos brancos (os choupos brancos no jardim municipal) de acordo com o plano paisagista. That week the council planted the municipal garden with the white poplars (the white poplars in the municipal garden) as set by the landscape plan.

Na varanda a empregada plantou o canteiro pequeno com o tomate cereja (o tomate cereja no canteiro pequeno) para utilizar nas saladas no Verão. In the veranda the maid sowed the small flowerbed with cherry tomatoes (the cherry tomatoes in the small flowerbed) to use in the summer salads.

Antes da eleição a câmara plantou a avenida principal com árvores frondosas (árvores frondosas na avenida principal) e inaugurou uma nova escola. Before the election the council planted the main avenue with leafy trees (leafy trees along the main avenue) and inaugurated a new school.

O ano passado o enólogo plantou a encosta duriense com as uvas trincadeira (as uvas trincadeira na encosta duriense) para produzir um novo vinho. Last year the winemaker planted the Douro slope with trincadeira grapes (trincadeira grapes on the Douro slope) to produce a new wine.

Na Escócia a população plantou os terrenos abandonados com pomares públicos (pomares públicos nos terrenos abandonados) para evitar importar fruta. In Scotland the population planted the abandoned plots with public orchards (public orchards on the abandoned plots) to avoid importing fruit.
Como investimento o empresário plantou o monte alentejano com os sobreiros novos (os sobreiros novos no monte alentejano) para venda futura da cortiça.

As an investment the businessman sowed the Alentejo mount with new oaks (new oaks on the Alentejo mount) for future sale of cork.

Nos Estados Unidos o governo plantou áreas extensas com milho transgénico (milho transgénico em áreas extensas) para obter culturas mais resistentes.

In the United States the government sowed extensive areas with transgenic corn (transgenic corn in extensive áreas) to obtain stronger crops.

Em Setembro o lavrador plantou a terra lavrada com as couves galegas (as couves galegas na terra lavrada) para ter uma colheita na consoada.

In September the farmer sowed the drawn soil with Galician sprouts (Galician sprouts in the drawn soil) to have a harvest on Christmas Eve.

Em 2011 a empresa plantou o terreno comprado com eucaliptos novos (eucaliptos novos no terreno comprado) para produzir madeira para fazer papel.

In 2011 the company planted the purchased plot with new Eucalyptuses (new Eucalyptuses on the purchased plot) to produce wood for paper making.

Na moradia o proprietário plantou o jardim interior com espécies exóticas (espécies exóticas no jardim interior) de modo a valorizar o imóvel.

In the house the landlord planted an indoor garden with exotic species (exotic species in the indoor garden) to raise the property value.

No ano seguinte a câmara plantou as vias municipais com árvores diferentes (árvores diferentes nas vias municipais) para evitar as alergias aos plátanos.

The following year the council planted the town roads with different trees (different trees on the town roads) to avoid sycamore allergies.

Pela manhã o homem semeou o terreno preparado com o milho doce (o milho doce no terreno preparado) e adubou a terra com fertilizantes próprios.

In the morning the man sowed the prepared plot with sweet corn (the sweet corn on the prepared plot) and fertilized the soil with his own fertilizers.

No Outono o avô semeou a propriedade nova com o centeio comprado (o centeio comprado na propriedade nova) para a produção de farinha no Verão seguinte.

In autumn the grandfather sowed the new property with the purchased rye (the purchased rye on the new property) for the production of flour the following Summer.

No quintal a mulher semeou os vasos novos com as flores brancas (as flores brancas nos vasos novos) e colocou-os a enfeitar a entrada principal.

In the garden the woman sowed the new vases with white flowers (the white flowers in the new vases) and placed them to adorn the main entry.

No Outono o aldeão semeou a terra livre com o nabo redondo (o nabo redondo na terra livre) e estrumou a restante para as plantações de Verão.

In autumn the villager sowed the free soil with the round turnips (the round turnips on the free soil) and fertilized the rest for summer plantations.

Em Outubro o lavrador semeou a fazenda beirã com as hortaliças diversas (as hortaliças diversas na fazenda beirã) e tapou-as para proteger das geadas.

In October the farmer sowed the Beira farm with various vegetables (various vegetables on the Beira farm) and covered them to protect them from frost.
No horto o jardineiro semeou os vasos grandes com os pinheiros mansos
(os pinheiros mansos nos vasos grandes) para serem vendidos depois de crescerem.

In the garden the gardener sowed the large vases with the stone pines
(the stone pines in the large vases) to be sold when they were taller.

No Alentejo a população semeou os solos ricos com o trigo branco
(o trigo branco nos solos ricos) para fornecer a indústria da panificação.

In Alentejo the population sowed the rich soils with white wheat
(white wheat on the rich soils) to supply the bread making industry.

No jardim a senhora semeou os potes cerânicos com as margaridas amarelas
(as margaridas amarelas nos potes cerânicos) e colocou ao sol depois de regar.

In the garden the lady sowed the ceramic pots with yellow daisies
(yellow daisies in the ceramic pots) and placed them in the sun after watering them.

Na vila o homem semeou a terra arrendada com as variedades novas
(as variedades novas na terra arrendada) para comparar a sua resistência ao clima.

In the town the man sowed the holding with new varieties
(new varieties on the holding) to compare their climate resistance.

Em Setembro a mulher semeou o jardim campestre com os cravos turcos
(os cravos turcos no jardim campestre) para florescerem na Primavera seguinte.

In September the woman sowed the rural garden with the Turkish carnations
(the Turkish carnations on the rural garden) for them to blossom the following Spring.

No concelho o autarca semeou a terra doada com as árvores autóctones
(as árvores autóctones na terra doada) para preservar o património natural.

In the council the mayor sowed the donated land with the local trees
(the local trees on the donated land) to preserve the natural heritage.

No balneário o atleta esfregou os músculos doridos com o gel analgésico
(o gel analgésico nos músculos doridos) para aliviar a dor devida ao esforço.

In the bathhouse the athlete rubbed the aching muscles with the analgesic gel
(the analgesic gel on the aching muscles to relieve from the strain-induced pain).

Na banheira a mulher esfregou o corpo molhado com o creme exfoliante
(o creme exfoliante no corpo molhado) para depois enxaguar com água morna.

In the bathtub the woman rubbed the wet body with the exfoliating cream
(the exfoliating cream on the wet body) to later rinse with warm water.

Na sala de reuniões a empregada esfregou o soalho flutuante com a cera castanha
(a cera castanha no soalho flutuante) e depois de secar puxou o lustro.

In the meeting room the maid rubbed the parquet flooring with the brown wax
(the brown wax on the parquet flooring) and after letting it dry she polished it.

Já em casa o doente esfregou a pele inflamada com a solução salina
(a solução salina na pele inflamada) como indicado pelo seu dermatologista.
At home the sick man rubbed the inflamed skin with the saline solution
(the saline solution on the inflamed skin) as indicated by his dermatologist.

Na oficina o carpinteiro esfregou a tábua pintada com a lixa fina
(a lixa fina na tábua pintada) para remover a tinta e aplicar o verniz.

In the workshop the carpenter rubbed the painted plank with the fine sandpaper
(the fine sandpaper on the painted plank) to remove the paint and apply the varnish.

Antes da festa a rapariga esfregou os brincos prateados com a pasta dentífrica
(a pasta dentífrica nos brincos prateados) para os tornar mais brilhantes.

Before the party the girl rubbed the silver earrings with the toothpaste
(the toothpaste on the silver earrings) to make them shinier.
À noite o cozinheiro esfregou o frango inteiro com a mistura aromática (a mistura aromática no frango inteiro) e deixou a marinar até ao dia seguinte.

At night the cook rubbed the whole chicken with the aromatic mix (the aromatic mix on the whole chicken) and let it marinate until the next day.

Na cozinha a senhora esfregou a pedra mármore com a solução ácida (a solução ácida na pedra mármore) para limpar as manchas e devolver o brilho.

In the kitchen the lady rubbed the marble stone with the acid solution (the acid solution on the marble stone) to clean the stains and recover the shine.

No dia seguinte a empregada esfregou as nódoas secas com o sabão azul (o sabão azul nas nódoas secas) antes de lavar a toalha na máquina.

The next day the maid rubbed the dry stains with the blue soap (the blue soap on the dry stains) before washing the towel in the washing-machine.

Antes do jantar a anfitriã esfregou os talheres dourados com o vinagre puro (o vinagre puro nos talheres dourados) e secou-os com um pano de algodão.

Before dinner the host rubbed the golden cutlery with the pure vinegar (pure vinegar on the golden cutlery) and dried them with a cotton cloth.

Em casa o desportista esfregou as nódoas negras com o álcool etílico (o álcool etílico nas nódoas negras) antes de aplicar o creme hidratante.

At home the athlete rubbed the bruises with the ethanol (the ethanol on the bruises) before applying the hydrating cream.

No salão a cabeleireira esfregou o cabelo da cliente com o creme amaciador (o creme amaciador no cabelo da cliente) e deixou actuar antes de enxaguar.

At the salon the hairdresser rubbed the client’s hair with the conditioner cream (the conditioner cream on the client’s hair) and allowed it to act before rinsing.
Experiment 2

Na gráfica o técnico imprimiu os folhetos vermelhos com o texto político (o texto político nos folhetos vermelhos) para distribuir na acção de protesto.

1

In the print shop the technician printed the red flyers with political texto (the political text onto the red flyers) to distribute during the rally.

Em Janeiro o comerciante imprimiu o cartão pessoal com o logotipo novo (o logotipo novo no cartão pessoal) para promover a imagem da empresa.

2

In January the merchant printed the business card with a new logo (the new logo on the business card) to promote the company’s image.

Antes do casamento a noiva imprimiu os convites brancos com o desenho dourado (o desenho dourado nos convites brancos) e enviou para os convidados.

3

Before the marriage the bride printed the white invitations with the golden drawing (the golden drawing on the white invitations) and sent them to the guests.

Logo pela manhã o chefe imprimiu a cartolina branca com o menu semanal (o menu semanal na cartolina branca) e afixou-a à entrada do restaurante.

4

Early in the morning the boss printed the white card with the weekly menu (the weekly menu on the white card) and displayed it at the restaurant’s entry.

Na agência de viagens o gerente imprimiu a brochura publicitária com as fotos novas (as fotos novas na brochura publicitária) para divulgar outros destinos.

5

In the travel agents the manager printed the advertising brochure with new photos (the new photos on the advertising brochure) to publicize new destinations.

No escritório a secretária imprimiu os postais natalícios com os nomes escolhidos (os nomes escolhidos nos postais natalícios) para enviar aos melhores clientes.

At the request of the author the typographer printed a brown cover with black letters (black letters on a brown cover) despite it being against the editor’s wishes.

No fim do torneio o futebolista imprimiu a t-shirt usada com o número dez (o número dez na t-shirt usada) e ofereceu-a à entidade organizadora.

At the end of the tournament the soccer player printed a used t-shirt with the number ten (the number ten on a used t-shirt) and gave it to the organizing entity.

A pedido do autor o tipógrafo imprimiu a capa castanha com as letras pretas (as letras pretas na capa castanha) embora contra a vontade do editor.

At school the educator printed the white postcard with a colourful drawing (the colourful drawing on the white postcard) for the boy to give to his mother.

Em casa a rapariga imprimiu as folhas perfumadas com os poemas preferidos (os poemas preferidos nas folhas perfumadas) e fez um caderno para o namorado.

At home the girl printed the scented paper with her favourite poems (her favourite poems on the scented paper) and did a notebook for her boyfriend.
No ano passado a tabaqueira imprimiu os maços de tabaco com as fotos chocantes (as fotos chocantes nos maços de tabaco) para tentar diminuir o consumo.

Last year the tobacco company printed cigarette packets with shocking pictures (shocking pictures on cigarette packets) to try to diminish consumption.

Antes da viagem a agência imprimiu os guias individuais com a rota prevista (a rota prevista nos guias individuais) e distribuiu a todos os turistas.

Before the trip the agency printed the individual guides with the planned itinerary (the planned itinerary on the individual guides) and gave them out to all the tourists.

Antes da conferência o jornalista imprimiu a faixa autocolante com o nome completo (o nome completo na faixa autocolante) como exigido pela organização.

Before the conference the journalist printed the sticker band with the full name (the full name on the sticker band) as required by the organization.

Antes da viagem o camionista imprimiu a guia de transporte com a morada final (a morada final na guia de transporte) para acompanhar a mercadoria em circulação.

Before the trip the truck driver printed the transport guide with the final address (the final address on the transport guide) to accompany the merchandise in transport.

Em Dezembro a editora imprimiu um volume único com a poesia completa (a poesia completa num volume único) para comemorar o aniversário do poeta.

In December the editor printed a unique volume with the complete poetry (the complete poetry on a unique volume) to celebrate the poet’s birthday.

Durante o ano a EMI imprimiu os discos editados com uma etiqueta especial (uma etiqueta especial nos discos editados) para comemorar o centenário da empresa.

During the year EMI printed edited discs with the special label (the special label on edited disks) to celebrate the company’s centenary.

Num dia apenas o empregado pintou a parede toda com as ramagens verdes (as ramagens verdes na parede toda) conforme o projecto do decorador.

In only one day the employee painted the whole wall with green branches (green branches on the whole wall) as specified by the decorator’s project.

No seu ateliê o artista pintou a tela gigante com as figuras abstractas (as figuras abstractas na tela gigante) iniciando uma nova corrente artística.

In his atelier the artist painted the giant canvas with abstract figures (the abstract figures on the giant canvas) starting a new artistic movement.

Antes do jogo o adepto pintou a face esquerda com a bandeira nacional (a bandeira nacional na face esquerda) para manifestar o seu apoio à selecção.

Before the game the fan painted the left side of his face with the national flag (the national flag on the left side of his face) to show his support for the team.

Na nova coleção o criador pintou os lenços azuis com os girassóis amarelos (os girassóis amarelos nos lenços azuis) revelando a influência de Van Gogh.

In the new collection the creator painted the blue sheets with yellow sunflowers (the yellow sunflowers in the blues sheets) revealing the influence of Van Gogh.

Na escola a turma pintou o muro cinzento com as flores coloridas (as flores coloridas no muro cinzento) e preparou a festa de final do ano lectivo.

At school the class painted the grey wall with colourful flowers (the colourful flowers on the grey wall) and prepared the end of school year party.

No teatro o cenarista pintou a tela gigante com os faraós egípcios (os faraós egípcios na tela gigante) para usar no primeiro acto da ópera Aida.

In the theatre the set designer painted the giant canvas with Egyptian pharaohs (Egyptian pharaohs on the giant canvas) to use in the first act of the Aida opera.
No quarto da filha a mãe pintou o tecto branco com as estrelas azuis (as estrelas azuis no tecto branco) e pendurou um candeeiro em forma de lua.

In the room of the daughter the mother painted a white ceiling with blue stars (blue stars on the white ceiling) and hung a moon-shaped chandelier.

À entrada do congresso a organizadora pintou um painel grande com rostos femininos (rostos femininos num painel grande) para ilustrar o tema do debate.

At the entry of the congress the organizer painted the large panel with the feminine faces (the feminine faces on the large panel) to illustrate the theme of the debate.

Na Nazaré o marinheiro pintou o barco novo com o nome familiar (o nome familiar no barco novo) e preparou a saída para pesca no alto mar.

In Nazareth the sailor painted the new boat with the family name (the family name on the new boat) and prepared to go fishing in deep waters.

No ATL a menina pintou o azulejo branco com a flor amarela (a flor amarela no azulejo branco) como tinha desenhado no papel anteriormente.

In the after-school atelier the girl painted the white tile with the yellow flower (the yellow flower on the white tile) as she had drawn on the paper beforehand.

No Brasil a equipa pintou o Ferrari vermelho com o número onze (o número onze no Ferrari vermelho) antes de iniciar a etapa do Grande Prémio.

In Brazil the team painted the red Ferrari with the number eleven (the number eleven on the red Ferrari) before starting the Grand Prize phase.

Na igreja o artista pintou a parede frontal com as figuras religiosas (as figuras religiosas na parede frontal) e o arcebispo realizou a missa inaugural.

In the church the artist painted the front wall with religious figures (the religious figures on the front Wall) and the archbishop held the inaugural mass.

No Carnaval o rapaz pintou a cara toda com bolas coloridas (bolas coloridas na cara toda) e vestiu um fato de palhaço.

At the carnival the boy painted the whole face with coloured balls (the coloured balls on his whole face) and wore a clown costume.

Na Basílica o artista pintou a cúpula oval com frescos impressionantes (frescos impressionantes na cúpula oval) que todos os turistas querem apreciar.

At the Basilica the artist painted the oval cupola with impressing frescos (impressing frescos on the oval cupola) that all tourists want to see.

Na avenida a câmara pintou o asfalto negro com a passagem de peões (a passagem de peões no asfalto negro) no local onde tinha ocorrido o acidente fatal.

In the Avenue the council painted the black asphalt with a pedestrian crossing (a pedestrian crossing on the black asphalt) where the fatal accident took place.

No caminho a organização pintou os mecos de pedra com faixas coloridas (faixas coloridas nos mecos de pedra) para indicar aos peregrinos a rota correcta.

On the path the organization painted the stone mecos with coloured stripes (coloured stripes on the stone mecos) to indicate the correct route to pilgrims.

Depois da vitória o ourives gravou a medalha ganha com o nome do vencedor (o nome do vencedor na medalha ganha) para ser entregue na cerimónia final.

After the victory the goldsmith engraved the medal awarded with the name of the winner (the name of the winner on the medal awarded) to be given at the final ceremony.

Antes do concerto a cantora gravou a face direita com o símbolo nazi (o símbolo nazi na face direita) e publicou um vídeo polémico na internet.

Before the concert the singer painted the right side of her face with the Nazi symbol (the Nazi symbol on the left side of her face) and published the video on the internet.
Antes do casamento o casal gravou as alianças douradas com os nomes próprios (os nomes próprios nas alianças douradas) como era tradição familiar.

*Before the marriage the couple engraved the wedding rings with the names of the names on wedding rings) as was the family tradition.*

Antes do funeral o filho gravou a pedra da sepultura com o epitáfio latino (o epitáfio latino na pedra da sepultura) como tinha pedido o pai antes de falecer.

*Before the funeral the son engraved the tombstone with the Latin epitaph (the Latin epitaph on the tombstone) as his father had asked before dying.*

Em Inglaterra o governo gravou as moedas novas com a efígie real (a efígie real nas moedas novas) para comemorar o aniversário da Rainha.

*In England the government engraved the new coins with the royal effigy (the royal effigy on the new coins) to commemorate the Queen’s birthday.*

No consultório a assistente gravou as chapas metálicas com os nomes dos médicos (os nomes dos médicos nas chapas metálicas) para identificar todos os gabinetes.

*In the clinic the assistant engraved the metal plaques with the names of the doctors (the names of the doctors on the metal plaques) to identify all the offices.*

Na guerra o Reich gravou os lingotes novos com datas anteriores (datas anteriores nos lingotes novo) para não ser detectada a origem do ouro roubado.

*In the war the Reich engraved new ingots with past dates (past dates on the new ingots) to avoid detection of the stolen gold.*

Como pedido o escultor gravou a pedra tumular com a inscrição hebraica (a inscrição hebraica na pedra tumular) em homenagem às origens do escritor.

*As asked the sculptor engraved the tombstone with the Hebraic inscription (the Hebraic inscription on the tombstone) in homage to the writer’s origins.*

Para o torneio o clube gravou a taça prateada com o emblema regional (o emblema regional na taça prateada) como agradecimento à câmara municipal.

*For the tournament the club engraved the silver cup with the regional emblem (the regional emblem on the silver cup) as a way of thanking the town council.*

Para o baptizado a madrinhna gravou o fio dourado com as iniciais da menina (as iniciais da menina no fio dourado) e os pais ficaram muito felizes.

*For the baptism the godmother engraved the golden pendant with the girl’s initials (the girl’s initials on the golden pendant) and the parents were very happy.*

Na fábrica o técnico gravou o prato cerâmico com o desenho floral (o desenho floral no prato cerâmico) para a nova coleção de louça decorativa.

*In the factory the technician engraved the ceramic plate with the floral design (the floral design on the ceramic plate) for the new collection of decorative dishes.*

No jardim botânico o rapaz gravou a árvore famosa com o nome da namorada (o nome da namorada na árvore famosa) como é tradição naquele lugar.

*In the botanic garden the boy engraved the famous tree with the name of his girlfriend (the name of his girlfriend in the famous tree) as is the tradition there.*

Como prometido a madrinha gravou a vela branca com o nome do menino (o nome do menino na vela branca) para ser acesa no baptizado do afilhado.

*As promised the godmother engraved the white candle with the name of the boy (the name of the boy on the white candle) to light on her godson’s baptism.*

Em Espanha a monarquia gravou o sinete real com o brasão familiar (o brasão familiar no sinete real) para poder selar toda a documentação oficial.

*In Spain the monarchy engraved the royal signet with the family coat of arms (the family coat of arms on the royal signet) to stamp all official documentation.*
No templo budista o monge gravou a parede rochosa com os versos sánscritos (os versos sánscritos na parede rochosa) conforme a tradição milenar.

In the Buddhist temple the monk engraved the rock wall with Sanskrit verses (the Sanskrit verses on the rock Wall) according to ancient tradition.

Nas oficinas o artesão gravou a lápide polida com o provérbio popular (o provérbio popular na lápide polida) para afixar à entrada da nova biblioteca.

In the workshop the artisan engraved the polished slab with the popular proverb (the popular proverb on the polished slab) to display on the library entry.

A meio de Abril o lavrador plantou o terreno fertilizado com o feijão manteiga (o feijão manteiga no terreno fertilizado) para ser colhido em Dezembro.

In mid-April the farmer sowed the fertilized soil with butterbeans (the butterbeans in the fertilized soil) to be harvested in December.

Naquela semana a câmara plantou o jardim municipal com os choupos brancos (os choupos brancos no jardim municipal) de acordo com o plano paisagista.

That week the council planted the municipal garden with the white poplars (the white poplars in the municipal garden) as set by the landscape plan.

Na varanda a empregada plantou o canteiro pequeno com o tomate cereja (o tomate cereja no canteiro pequeno) para utilizar nas saladas no Verão.

In the veranda the maid sowed the small flowerbed with cherry tomatoes (the cherry tomatoes in the small flowerbed to use in the summer salads).

Antes da eleição a câmara plantou a avenida principal com árvores frondosas (árvores frondosas na avenida principal) e inaugurou uma nova escola.

Before the election the council planted the main avenue with leafy trees (leafy trees along the main avenue) and inaugurated a new school.

O ano passado o enólogo plantou a encosta duriense com as uvas trincadeira (as uvas trincadeira na encosta duriense) para produzir um novo vinho.

Last year the winemaker planted the Douro slope with trincadeira grapes (trincadeira grapes on the Douro slope) to produce a new wine.

Na Escócia a população plantou os terrenos abandonados com pomares públicos (pomares públicos nos terrenos abandonados) para evitar importar fruta.

In Scotland the population planted the abandoned plots with public orchards (public orchards on the abandoned plots) to avoid importing fruit.

Como investimento o empresário plantou o monte alentejano com os sobreiros novos (os sobreiros novos no monte alentejano) para venda futura da cortiça.

As an investment the businessman sowed the Alentejo mount with new oaks (new oaks on the Alentejo mount) for future sale of cork.

Nos Estados Unidos o governo plantou áreas extensas com milho transgénico (milho transgénico em áreas extensas) para obter culturas mais resistentes.

In the United States the government sowed extensive areas with transgenic corn (transgenic corn in extensive areas) to obtain stronger crops.

Em Setembro o lavrador plantou a terra lavrada com as couves galegas (as couves galegas na terra lavrada) para ter uma colheita na consoada.

In September the farmer sowed the drawn soil with Galician sprouts (Galician sprouts in the drawn soil) to have a harvest on Christmas Eve.

Em 2011 a empresa plantou o terreno comprado com eucaliptos novos (eucaliptos novos no terreno comprado) para produzir madeira para fazer papel.

In 2011 the company planted the purchased plot with new Eucalyptuses (new Eucalyptuses on the purchased plot) to produce wood for paper making.
Na moradia o proprietário plantou o jardim interior com espécies exóticas (espécies exóticas no jardim interior) de modo a valorizar o imóvel.

In the house the landlord planted an indoor garden with exotic species (exotic species in the indoor garden) to raise the property value.

No ano seguinte a câmara plantou as vias municipais com árvores diferentes (árvores diferentes nas vias municipais) para evitar as alergias aos plátanos.

The following year the council planted the town roads with different trees (different trees on the town roads) to avoid sycamore allergies.

Em Matosinhos a autarquia plantou a rotunda nova com os pinheiros mansos (os pinheiros mansos na rotunda) nova seguindo a sugestão do novo arquitecto.

In Matosinhos the council planted the new roundabout with the stone pines (the stone pines on the new roundabout) following the new architect’s suggestion.

Em Serralves a Fundação plantou o jardim principal com as ervas aromáticas (as ervas aromáticas no jardim principal) para produzir chá para vender na sua loja.

In Serralves the Foundation planted the central park with aromatic herbs (aromatic herbs on the central park) to produce tea to sell in its shop.

Na Lousã o destilador plantou os pomares antigos com as pereiras novas (as pereiras novas nos pomares antigos) melhorando a qualidade da sua famosa aguardente.

In Lousã the distiller planted the old orchards with new pear trees (the new pear trees on the old orchards) improving the quality of his famous brandy.

No Pico a população plantou o solo vulcânico com a casta verdelha (a casta verdelha no solo vulcânico) e construiu muros para proteger dos ventos do mar.

In Pico the population planted the volcanic soil with verdelha grape (verdelha grape on the volcanic soil) and built walls to protect from the sea winds.

Pela manhã o homem semeou o terreno preparado com o milho doce (o milho doce no terreno preparado) e adubou a terra com fertilizantes próprios.

In the morning the man sowed the prepared plot with sweet corn (the sweet corn on the prepared plot) and fertilized the soil with his own fertilizers.

No Outono o avô semeou a propriedade nova com o centeio comprado (o centeio comprado na propriedade nova) para a produção de farinha no Verão seguinte.

In autumn the grandfather sowed the new property with the purchased rye (the purchased rye on the new property) for the production of flour the following Summer.

No quintal a mulher semeou os vasos novos com as flores brancas (as flores brancas nos vasos novos) e colocou-os a enfeitar a entrada principal.

In the garden the woman sowed the new vases with white flowers (the white flowers in the new vases) and placed them to adorn the main entry.

No Outono o aldeão semeou a terra livre com o nabo redondo (o nabo redondo na terra livre) e estrumou a restante para as plantações de Verão.

In autumn the villager sowed the free soil with the round turnips (the round turnips on the free soil) and fertilized the rest for summer plantations.

Em Outubro o lavrador semeou a fazenda beirã com as hortaliças diversas (as hortaliças diversas na fazenda beirã) e tapou-as para proteger das geadas.

In October the farmer sowed the Beira farm with various vegetables (various vegetables on the Beira farm) and covered them to protect them from frost.

No terraço a menina semeou o canteiro redondo com as rosas vermelhas (as rosas vermelhas no canteiro redondo) como tinha aprendido com a avó materna.

In the terrace the girl sowed the round flowerbed with the red roses (the red roses on the round flowerbed) as she had been taught by her grandmother.
No horto o jardineiro semeou os vasos grandes com os pinheiros mansos
(os pinheiros mansos nos vasos grandes) para serem vendidos depois de crescerem.

In the garden the gardener sowed the large vases with the stone pines
(the stone pines in the large vases) to be sold when they were taller.

No Alentejo a população semeou os solos ricos com o trigo branco
(o trigo branco nos solos ricos) para fornecer a indústria da panificação.

In Alentejo the population sowed the rich soils with white wheat
(white wheat on the rich soils) to supply the bread making industry.

No jardim a senhora semeou os potes cerâmicos com as margaridas amarelas
(as margaridas amarelas nos potes cerâmicos) e colocou ao sol depois de regar.

In the garden the lady sowed the ceramic pots with yellow daisies
(yellow daisies in the ceramic pots) and placed them in the sun after watering them.

Na vila o homem semeou a terra arrendada com as variedades novas
(as variedades novas na terra arrendada) para comparar a sua resistência ao clima.

In the town the man sowed the holding with new varieties
(new varieties on the holding) to compare their climate resistance.

Em Setembro a mulher semeou o jardim campestre com os cravos turcos
(os cravos turcos no jardim campestre) para florescerem na Primavera seguinte.

In September the woman sowed the rural garden with the Turkish carnations
(the Turkish carnations on the rural garden) for them to blossom the following Spring.

No concelho o autarca semeou a terra doada com as árvores autóctones
(as árvores autóctones na terra doada) para preservar o património natural.

In the council the mayor sowed the donated land with the local trees
(the local trees on the donated land) to preserve the natural heritage.

Durante anos o rendeiro semeou a herdade alentejana com a batata roxa
(a batata roxa na herdade alentejana) que vendia nos mercados de todo o país.

For years the farmer sowed the Alentejan homestead with red potato
(red potato on the Alentejan homestead) that he sold on the markets across the country.

Em 2012 a empresa semeou a estufa nova com os produtos hortícolas
(os produtos hortícolas na estufa nova) e fez duas colheitas aumentando as vendas.

In 2012 the company sowed the new greenhouse with the vegetable products
(the vegetable products in the new greenhouse) and made two harvests increasing sales.

Em Julho o produtor semeou o talhão herdado com as couves de Bruxelas
(as couves de Bruxelas no talhão herdado) e limpou as ervas infestantes em todo o terreno.

In July the farmer sowed the inherited plot with Brussels sprouts
(Brussels sprouts on the inherited plot) and cleaned the invading weeds from the whole plot.

No quintal a mãe semeou o canteiro rectangular com a salsa frisada
(a salsa frisada no canteiro rectangular) para utilizar nos cozinhados ao longo do ano.

In the garden the mother sowed the rectangular flowerbed with beaded parsely.
(beaded parsely on the rectangular flowerbed) to use in cooking throughout the year.
Experiments 3 and 4

1. O familiar dos meninos (Os familiares do menino) que vai viajar de avião está (estão) nervoso (s).
   The relative of the boys (The relatives of the boy) who will travel by plane is (are) nervous.
2. O adepto dos jogadores (Os adeptos do jogador) que vai sair do estádio está (estão) chateado (s).
   The fan of the players (the fans of the player) who is leaving the stadium is (are) angry.
3. O tio da menina que vai andar na mota/ no carrossel veio de França.
   The Uncle of the girl who will ride the bike (the carousel) came from France.
4. O cúmplice dos ladrões (Os cúmplices do ladrão) que vai ser preso é (são) americano (s).
   The accomplice of the thieves (the accomplices of the thief) who will be arrested is (are) American (s).
5. O advogado dos autarcas (Os advogados do autarca) que vai ser julgado é (são) conhecido (s).
   The lawyer of the mayors (The lawyers of the mayor) who will be tried is (are) known.
6. A mãe do rapaz que vai vestir o vestido (os calções) é muito alta.
   The mother of the boy who will wear the dress (the shorts) is very tall.
7. A filha dos fadistas (As filhas do fadista) que vai cantar está (estão) muito ansiosa (s).
   The daughter of the fado singers (The daughters of the fado singer) who will sing is (are) very anxious.
8. O discípulo dos filósofos (Os discípulos do filósofo) que vai ser distinguido está (estão) orgulhoso (s).
   The disciple of the philosopher (The disciples of the philosopher) who will be awarded is (are) proud.
9. O bisavô da menina que vai jogar xadrez (à macaca) está entusiasmado.
   The great-grandfather of the girl who will play chess (hopscotch) is excited.
10. O sócio dos viticultores (Os sócios do viticultor) que vai fazer o vinho é (são) alemão (alemães).
    The partner of the winemakers (the partners of the winemaker) who will make the wine is (are) German.
11. O amigo dos alpinistas (Os amigos do alpinista) que vai subir a montanha está (estão) preocupado (s).
    The friend of the alpinists (The friends of the alpinista) who will climb the mountain is (are) worried.
12. A assistente dos directores (As assistentes do director) que vai presidir à reunião é (são) nova (s).
    The assistant of the directors (the assistants of the director) who will preside the meeting is (are) young.
8  O parceiro dos criminosos (Os parceiros do criminoso) que vai cumprir a pena é (são) inglês (ingleses).
The partner of the criminals (the partners of the criminal) who will do jail time is (are) English.
O apoiante dos candidatos (Os apoiantes do candidato) que vai discursar subiu (subiram) ao palco.
The supporter of the candidates (the supporters of the candidate) who will make the speech rose to stage.
A namorada do rapaz que vai comprar a saia (a mota) está contente.
The girlfriend of the boy who will buy the skirt (the motorbike) is happy.

9  O aluno dos professores (Os alunos do professor) que vai entrar na sala é (são) novo (s) na escola.
The student of the teachers (the students of the teacher) who will enter the room is (are) new in school.
O arquitecto dos investidores (Os arquitectos do investidor) que vai construir o estádio é (são) belga (s).
The architect of the investors (the architects of the investor) who will build the stadium is (are) Belgian.
O marido da costureira que vai arranjar o candeiro (o vestido) está chateado.
The husband of the seamstress who will fix the chandelier (the dress) is angry.

10 O rendeiro dos fazendeiros (Os rendeiros do fazendeiro) que vai plantar a vinha veio (vieram) do Brasil.
The tenant of the farmers (the tenants of the farmer) who will plant the vineyard came from Brazil.
A secretária dos diplomatas (As secretárias do diplomata) que vai receber o prémio é (são) angolana (s).
The secretary of the diplomats (the secretaries of the diplomat) who will receive the award is Angolan.
A amiga do viajante que vai preparar a sobremesa (a bagagem) é alta.
The friend of the traveller who will prepare the dessert (the luggage) is tall.

11 O superior dos militares (Os superiores do militar) que vai denunciar o caso está (estão) assustado (s).
The superior of the soldiers (the superiors of the soldier) who will denounce the case is (are) scared.
O mestre dos judocas (Os mestres do judoca) que vai ser homenageado está (estão) orgulhoso (s).
The master of the judocas (the masters of the judoka) who will be honoured is (are) proud.
A mulher do caseiro que vai alimentar o bebé (o cavalo) está contente.
The wife of the caretaker who will feed the baby (the horse) is happy.

12 O colega dos estudantes (Os colegas do estudante) que vai apresentar o trabalho está (estão) nervoso (s).
The colleague of the students (the colleagues of the student) who will present the work is (are) anxious.
O monitor dos escoteiros (Os monitores do escoteiro) que vai montar a tenda está (estão) contente (s).
The monitor of the scouts (the monitors of the scout) who will put the tent up is (are) happy.
A mulher do carpinteiro que vai fazer a sopa (a cadeira) está triste.
The wife of the carpenter who will make the soup (the chair) is sad.

13 O jurista dos queixosos (Os juristas do queixoso) que vai entrar no tribunal está (estão) confiante (s).
The lawyer of the plaintiffs (The lawyers of the plaintiff) who will enter the court is (are) confident.
O segurança dos políticos (Os seguranças do político) que vai estar na cimeira é (são) americano (s).
The bodyguard of the politicians (The bodyguards of the politician) who will be in the summit is (are) American.
O padrasto da menina que vai montar o móvel (o pónei) está cansado.
The stepfather of the girl who will assemble the furniture (the pony) is tired.

14 O aluno dos cientistas (Os alunos do cientista) que vai fazer a experiência está (estão) expectante (s).
The student of the scientists (The students of the scientist) who will do the experiment is (are) excited.
O preparador dos jogadores (Os preparadores do jogador) que vai entrar em campo está (estão) preocupado (s).
The preparer of the players (The preparers of the player) who will enter the field is (are) concerned.
O padrasto da rapariga que vai provar o vinho (o gelado) está a rir-se.
The stepfather of the girl who will taste the wine/ the ice-cream is (are) laughing.
O assistente dos professores (Os assistentes do professor) que vai dar a aula é (são) inexperiente (s).

The assistant of the professor (the assistants of the professor) who will give the lesson is (are) inexperienced.

O auxiliar dos enfermeiros (Os auxiliares do enfermeiro) que vai suturar a ferida veio (vieram) de Cuba.

The aide to the nurses (the aides to the nurse) who will suture the wound came from Cuba.

A colega do múdo que vai comprar a saia (a consola) está feliz.

The colleague of the child who will buy the skirt (the game-console) is happy.

O protegido dos mafiosos (protegidos do mafioso) que vai entrar no tribunal foi (foram) fotografado (s).

The protégé of the gangsters (the protégés of the gangster) who will enter the court was (were) photographed.

O acólito dos padres (Os acólitos do padre) que vai carregar a cruz é (são) novo (s) na diocese.

The acolyte of the priests (the acolytes of the priest) who will carry the cross is (are) new in the diocese.

A colega do alfaiate que vai cortar o arbusto (o tecido) é algarvio.

The gardener of the tailor who will cut the bush (the cloth) is from Algarve.

O director dos contabilistas (directores do contabilista) que vai ser interrogado está (estão) apreensivo (s).

The director of the accountants (the director of the accountant) who will be interrogated is (are) apprehensive.

O mecenas dos pintores (Os mecenas do pintor) que vai ver a exposição está (estão) satisfeito (s).

The patron of the painters (the patrons of the painter) who will attend the exposition is (are) satisfied.

O cozinheiro da moda que vai cortar o bolo (o bibe) tem um avental.

The cook of the fashion designer who will make the cake (the wedding dress) has an apron.

O chefe dos oficiais (Os chefes do oficial) que vai implementar a operação está (estão) confiante (s).

The chief of the officers (the chiefs of the officer) who will implement the operation is (are) confident.

O empresário dos futebolistas (Os empresários do futebolista) que vai assinar o contrato é (são) novo (s).

The entrepreneur of the soccer players (the entrepreneurs of the soccer player) who will sign the contract is (are) new.

A maquilhadora dos actores (As maquilhadoras do actor) que vai sair do camarim é (são) japonesa (s).

The makeup artist of the actors (the makeup artists of the actor) who will leave the dressing-room is (are) Japanese.

A secretária dos deputados (As secretárias do deputado) que vai redigir a lei está (estão) no gabinete.

The secretary of the deputies (The secretaries of the deputy) who will write the law is (are) in the cabinet.

A criada da costureira que vai cortar a cortina tem um avental.

The maid of the seamstress who will cut the curtain has an apron.

O orientador dos doutorandos (orientadores do doutorando) que vai dar a palestra está (estão) ansioso (s).

The advisor of the PhD students (the advisors of the PhD student) who will give the lecture is (are) anxious.

O editor dos escritores (Os editores do escritor) que vai lançar o livro está (estão) satisfeito (s).

The editor of the writers (the editors of the writer) who will publish the book is (are) satisfied.

A esposa do ciclista que vai cortar o bolo (o leite) tem um lenço.

The wife of the cyclist who will cut the cake (the finish line) has a handkerchief.

O padrinho dos noivos (Os padrinhos do noivo) que vai entrar na igreja é (são) belga (s).

The godfather of the grooms (the godfathers of the groom) who will enter the church is (are) Belgian.

O irmão das freiras (Os irmãos da freira) que vai fazer a peregrinação está (esão) preparado (s).

The brother of the nuns (the brothers of nun) who will do the pilgrimage is (are) prepared.

The wife of the cyclist who will cut the cake (the finish line) is very happy.
O pai das crianças (Os pais da criança) que vai organizar a festa é (são) divorciado (s).
The father of the children (the parents of the child) who will organize the party is (are) divorced.

O senhor do rapazes (Os senhores do rapaz) que vai emigrar está (estão) preocupado (s).
The landlord of the boys (the landlords of the boy) who will emigrate is (are) worried.

A secretária do empreiteiro que vai fazer o café (a ponte) é nova.
The secretary of the contractor who will make the coffee (the bridge) is young.

O ajudante dos padeiros (Os ajudantes do padeiro) que vai distribuir o pão já chegou (chegaram).
The helper of the bakers (the helpers of the baker) who will distribute the bread has (have) arrived.

O irmão dos herdeiros (Os irmãos do herdeiro) que vai ler o testamento veio (vieram) da Suíça.
The brother of the heirs (the brothers of the heir) who will read the will came from Switzerland.

A criada do rapaz que vai lavar a louça (os dentes) está bem disposta.
The maid of the boy who will wash the dishes (the teeth) is in a good mood.

O fornecedor dos merceeiros (Os fornecedores do merceeiro) que vai falir está (estão) desesperado (s).
The supplier of the grocers (the suppliers of the grocer) who will go bankrupt is (are) desperate.

A educadora dos meninos (As educadoras do menino) que vai actuar na peça está (estão) orgulhosa (s).
The educator of the children (the educators of the child) who will take part in the play is (are) proud.

O fotógrafo da modelo que vai mudar o rolo (a roupa) é inglês.
The photographer of the model who will change the film (her clothes) is British.

O amigo dos realizadores (Os amigos do realizador) que vai produzir o novo filme é (são) milionário (s).
The friend of the directors (the friends of the director) who will produce the film is a (are) millionaire (s).

O filho dos imigrantes (Os filhos do imigrante) que vai ser deportado é (são) português (portugueses).
The son of the immigrants (the sons of the immigrant) who will be deported is (are) Portuguese.

O contabilista do carpinteiro que vai recuperar o dinheiro (o móvel) é (são) estrangeiro (s).
The accountant of the carpenter who will recover the Money (the furniture) is foreign.

O docente dos estudantes (Os docentes do estudante) que vai realizar o exame está (estão) exigente (s).
The teacher of the students (the teachers of the student) who will sit the exam is (are) demanding.

O amigo dos manifestantes (Os amigos do manifestante) que vai participar no protesto é (são) espanhol (espanhóis).
The friend of the protesters (the friends of the protester) who will take part in the protest is (are) Spanish.

O pai da bebé que vai comer a lagosta (a papa) está sorridente.
The father of the baby who will eat the lobster (the porridge) is smiling.
O partidário dos deputados (Os partidários do deputado) que vai apresentar a moção é (são) inflexível (inflexíveis).
The supporter of the deputies (the supporters of the deputy) who will present the motion is (are) inflexible.

O negociador dos reféns (Os negociadores do refém) que vai permanecer no terreno é (são) americano (s).
The negotiator for the hostages (the negotiator for the hostage) who will remain on-site is (are) American.

A enfermeira do empresário que vai aplicar o curativo (o dinheiro) é simpática.
The nurse of the businessman who will apply the curative (the money) is nice.

O defensor dos pensionistas (defensores do pensionista) que vai contestar a medida é (são) corajoso (s).
The defender of the pensioners/ the defenders of the pensioner who will appeal the measure is (are) courageous.

O patrocinador dos velejadores (patrocinadores do velejador) que vai investir no barco é (são) árabe (s).
The sponsor of the sailors (the sponsors of the sailor) who will invest in the boat is (are) Arab.

O acompanhante dos cegos (acompanhantes do cego) que vai atravessar a estrada é (são) voluntário (s).
The companion of the blind men (the companions of the blind man) who will cross the street is (are) volunteer (s).

O corretor dos milionários (Os corretores do milionário) que vai comprar as acções é (são) perspicaz (es).
The broker of the millionaires (the brokers of the millionaire) who will buy the shares is (are) smart.

O familiar dos músicos (Os familiares do músico) que vai integrar a orquestra é (são) romeno (s).
The relative of the musician (the relatives of the musician) who will integrate the orchestra is (are) Romanian.

A mãe do bebé que vai fazer o chá (o puzzle) está grávida.
The mother of the child who will make tea (the puzzle) is pregnant.

O amigo da vegetariana que vai comer o hambúrguer (a salada) tem um skate.
The friend of the vegetarian who will eat a steak (a salad) has a skateboard.

A enteada dos italianos (As enteadas do italiano) que vai reclamar a herança é (são) portuguesa (s).
The stepdaughter of the Italians (the stepdaughters of the Italian) who will claim the inheritance is (are) Portuguese.

O filho dos reformados (Os filhos do reformado) que vai comprar a casa está (estão) aliviado (s).
The son of the pensioners (the sons of the pensioner) who will buy the house is (are) relieved.

O intérprete dos oradores (Os intérpretes do orador) que vai entrar no anfiteatro está (estão) atrasado (s).
The interpreter of the orators (the interpreters of the orator) who will enter the amphitheatre is (are) late.

O marido da senhora que vai usar a gravata (o colar) é elegante.
The husband of the lady who will wear a tie (the necklace) is elegant.
O solicitor de clientes (the solicitors of the client) que vai requerer a certidão está (estão) apreensivo (s).
The solicitor of the clients (the solicitors of the client) who will demand the certificate is (are) apprehensive.

O discípulo dos monges (Os discípulos do monge) que vai fazer jejum está (estão) tranquilo (s).
The disciple of the monks (the disciples of the monk) who will fast is (are) calm.

A astróloga da mulher que vai ler o tarot (o jornal) é cigana.
The astrologist of the woman who will read the tarot (the newspaper) is gipsy.

O procurador dos condóminos (procuradores do condómino) que vai fazer a queixa é (são) familiar (es).
The attorney of the joint owners (the attorneys of the joint owner) who will file the complaint is (are) a relative.

O agente dos futebolistas (Os agentes do futebolista) que vai negociar o contrato é (são) inglês (ingleses).
The agent of the soccer players (the agents of the soccer player) who will negotiate the contract is (are) English.

O estilista da actriz que vai fazer o vestido (o filme) veio de França.
The stylist of the actress who will do the dress (the movie) came from France.

O sócio dos proprietários (Os sócios do proprietário) que vai vender as acções está (estão) insatisfeito (s).
The partner of the owners (the partners of the owner) who will sell the shares is (are) unsatisfied.

O conselheiro dos eleitores (conselheiros do eleitor) que vai impugnar o resultado é (sao) competente (s).
The advisor of the voters (the advisors of the voter) who will challenge the result is (are) competent.

O carteiro do padeiro que vai entregar o correio (o pão) está demorado.
The postman of the baker who will deliver the mail (the bread) is late.

O advogado dos estagiários (advogados do estagiário) que vai negociar o contrato é (são) experiente (s).
The lawyer of the interns (the lawyers of the intern) who will negotiate the contract is (are) experienced.

A esposa do homem que vai experimentar o vestido (o fato) é magra.
The wife of the man who will try the dress (the suit) is thin.

O companheiro dos mineiros (Os colegas do mineiro) que vai extrair a pedra é (são) inexperiente (s).
The companion of the fishermen (the companions of the fisherman) who will pull the net is (are) tired.

A adversária das ginastas (As adversárias da ginasta) que vai executar a acrobacia está (estão) nervosa (s).
The rival of the gymnasts (the rivals of the gymnast) who will perform the acrobatics is (are) anxious.

A filha do militar que vai vestir o uniforme escolar (o camuflado) está divertida.
The daughter of the military officer who will wear the school uniform (the camouflage suit) is having fun.

O companheiro dos pescadores (companheiros do pescador) que vai puxar a rede está (estão) cansado (s).
The companion of the fishermen (the companions of the fisherman) who will pull the net is (are) tired.

A cozinheira do engenheiro que vai fazer o frango (o prédio) é loura.
The cook of the engineer who will make the chicken (the building) is blond.
The ally of the rebels (the allies of the rebel) who will integrate the militia is (are) drug trafficker (s).
The brother of the orphans (the brothers of the orphan) who will live with his uncle and aunt is (are) radiant.
The gardener of the doctor who will treat the tree (the patient) is laughing.

The tutor of the minors (the tutors of the minor) who will give the testimony is (are) apprehensive.
The boss of the workers (the bosses of the worker) who will propose the agreement is (are) hesitant.
The farmer of the sculptor who will grow the orchard (make the statue) is from Minho.

The friend of the victims (the friends of the victim) who will make a complaint is (are) furious.
The assistant of the dentists (the assistants of the dentist) who will apply the filling is (are) new.

The art dealer of the painters (the art dealers of the painter) who will hold an exposition came from Paris.
The plumber of the I.T. technician who will install the tap (the software) is experienced.

The partisan of the monarchs (the partisans of the monarch) who will run for elections is (are) from Minho.
The relative of the outcasts (the relatives of the outcast) who will write a book is (are) Russian.

The maid of the surfer who will wax the closet (the board) is Angolan.

The descendant of the counts (the descendants of the count) who will rehabilitate the palace is (are) Austrian.
The kidnapper of the journalists (the kidnappers of the journalist) who will release the video is (are) anxious.

The electrician of the art dealer who will hang the chandelier (the painting) is blond.
B – Images