Syntactic Predictability in the Recognition of Carefully and Casually Produced Speech

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Abstract

The present study investigated whether the recognition of spoken words is influenced by how predictable they are given their syntactic context and whether listeners assign more weight to syntactic predictability when acoustic-phonetic information is less reliable. Syntactic predictability was manipulated by varying the word order of past participles and auxiliary verbs in Dutch subordinate clauses. Acoustic-phonetic reliability was manipulated by presenting sentences either in a careful or a casual speaking style. In three eye-tracking experiments, participants recognized past participles more quickly when they occurred after their associated auxiliary verbs than when they preceded them. Response measures tapping into later stages of processing suggested that this effect was stronger for casually than for carefully produced sentences. These findings provide further evidence that syntactic predictability can influence word recognition and that this type of information is particularly useful for coping with acoustic-phonetic reductions in conversational speech. We conclude that listeners dynamically adapt to the different sources of linguistic information available to them.

Keywords: Word recognition, syntax, speech reduction, prediction, conversational speech, Dutch

Introduction

Language comprehension is a complex task. Listeners are confronted with two or three words per second (Levelt, Roelofs, & Meyer, 1999) and have to choose from many thousands words in their mental lexicon. This task is complicated by the fact that the pronunciation of words is often quite variable. In natural conversations, speech is typically produced with a casual speaking style leading to the omission or acoustic weakening of individual phonemes and even whole syllables (Ernestus & Warner, 2011). Johnson (2004) estimated that over 60% of the words uttered in casual speech deviate from their citation forms by at least one phoneme and 28% deviate by two or more phonemes. Despite these facts, listeners are able to recognize casual speech quickly and accurately. One of the reasons for this ability is that listeners can use multiple sources of information from the sentence context in order to predict upcoming words (e.g. Altmann & Kamide, 1999; Arai & Keller, 2013). In the present study, we investigated if listeners can use word-order information in Dutch subordinate clauses in order to predict upcoming past participles. In particular, we explored how this type of information interacts with acoustic-phonetic information by presenting spoken sentences either in a casual or a careful speaking style.

Previous research has demonstrated that listeners are able to use semantic context and discourse-based information in order to anticipate upcoming words (e.g. Altmann & Kamide, 1999; Brouwer, Mitterer, & Huettig, 2013; Chambers, Tanenhaus, Eberhard, Filip, & Carlson, 2002). Using a visual-world eye-tracking task, Altmann and Kamide (1999) showed that participants were more likely to look at a picture of a cake after hearing “The boy will *eat*...”

than after hearing “The boy will *move*...”, demonstrating that listeners can use the semantic content of verbs in order to anticipate subsequent nouns. Semantic context effects have also been found in ERP studies (e.g. van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; Wicha, Moreno, & Kutas, 2004). For example, DeLong, Urbach, and Kutas (2005) presented sentences starting with, for instance, “The day was breezy so the boy went outside to fly...” followed either by a high-probability noun (e.g. “a kite”) or a low-probability noun (e.g. “an airplane”). Crucially, the form of the article preceding the noun (“a” vs. “an”) differed between the high- and low-probability nouns. DeLong et al. found larger N400 components while participants were reading the article matching the low-probability noun (“an”) compared to the article matching the high-probability noun (“a”). This shows that readers had already predicted the high-probability noun when reading its preceding article.

In addition to semantic and discourse-based information, listeners are also able to use syntactic cues for prediction. For example, Kamide, Scheepers, and Altmann (2003) showed that case marking information in German can be used by listeners in order to anticipate nouns. Furthermore, Arai and Keller (2013) showed that whether a verb is transitive or intransitive influences what sentence continuations listeners predict. In a visual-world study, the authors found that listeners were more likely to anticipate upcoming objects (e.g. “the artist”) when the verb in the sentence was transitive (as in “The nun *punished* the artist.”) rather than intransitive (as in “The nun *agreed* and the artist threw the kettle.”).

Although there are many studies that investigated prediction in auditory and visual sentence processing, only few studies have investigated the effect of predictive contextual information on how phonological information is evaluated (e.g. Magnuson, Tanenhaus, & Aslin, 2008; van Alphen & McQueen, 2001). Dahan and Tanenhaus (2004) showed that semantic information can decrease lexical competition among similar sounding words. In a visual-world experiment in Dutch, participants were presented with sentences in which the main verb occurred either before the target noun (as in “Never before climbed a goat so high.”) or after the target noun (as in “Never before has a goat climbed so high.”). It was found that when the main verb occurred after the target noun, there was competition between the noun (“goat”, Dutch: “bok”) and a similar sounding word (“bone”, Dutch: “bot”). However, when the main verb occurred before the noun, evidence for lexical competition disappeared. This result shows that the predictions that listeners make based on the semantic restrictions of verbs influence how phonological information is evaluated during lexical processing. Importantly, Dahan and Tanenhaus also showed that semantic context does not make listeners ignore subsequent acoustic information. When the initial part of the target word was cross-spliced with the phonological competitor (e.g. the “bo” of “bot” spliced onto the “k” of “bok”), competition between the target and the phonological competitor was present even when the main verb preceded the target noun.

In the present study, we were concerned with how the predictability of a syntactic word class can influence word recognition. More specifically, we were interested in the predictability of past participles in Dutch subordinate clauses. We took advantage of the fact that the word order of auxiliary verbs and past participles in Dutch subordinate clauses is free: either the auxiliary can precede the participle, or the participle can precede the auxiliary. Take, for instance, the sentence *I know for sure that he has leaned against the table*. This sentence could be translated into Dutch in two ways:

A) *Ik weet zeker dat hij heeft geleund op de houten tafel*.

B) *Ik weet zeker dat hij geleund heeft op de houten tafel*.

These two translations differ only in the order in which the auxiliary verb (“heeft”, English: “has”) and the past participle (“geleund”, English: “leaned”) occur. In the Dutch linguistics literature, the two word orders have been referred to as the “red” (i.e. auxiliary-first) and the “green” (i.e. participle-first) word orders (e.g. Pardoen, 1991). There are multiple variables that influence when speakers prefer to use one word order over the other (e.g. de Sutter, 2009; Swerts & van Wijk, 2005). Among these are prosodic, morphosyntactic, semantic, and discourse-related factors. Furthermore, there are regional differences between Dutch and Belgian speakers of Dutch. In Flemish (the variant of Dutch spoken in Belgium), the participle-first word order is used almost exclusively whereas in Dutch spoken in the Netherlands there is more variation (Barbiers et al., 2008). Whereas both word orders occur to a similar extent in the central parts of the Netherlands (especially the east), the participle-first word order is more common in the northern and southern parts.

Importantly, the two word orders differ in how predictable the past participle is. In the auxiliary-first construction, the participle is more predictable because the auxiliary indicates that a participle must follow immediately. In our study, we compare the recognition of participles in the more predictable (i.e. auxiliary-first) and the less predictable (i.e. participle-first) syntactic construction. If listeners are sensitive to the predictive information provided by the auxiliary, we expect that the auxiliary-first word order will lead to faster processing of the participle than the participle-first word order.

Whether and how much listeners use syntactic information in order to predict upcoming words may depend on the listening conditions. When listeners attempt to identify spoken words, they rely primarily on the phonological information provided by the speech signal (McQueen, 2007). This information concerns not only the word currently being recognized, but also its acoustic context (e.g. Lieberman, 1963; Pollack & Pickett, 1963, 1964). Especially under conditions in which the speech stream does not provide reliable cues, contextual cues become an important source of information for identifying the words and segments of speech. This has been demonstrated by studies investigating the recognition of acoustically reduced speech (e.g., Brouwer, Mitterer, & Huettig, 2012b; Ernestus, Baayen, & Schreuder, 2002; Janse & Ernestus, 2011; van de Ven, Ernestus, & Schreuder, 2012). For example, Ernestus et al. (2002) presented strongly reduced word forms extracted from a corpus of spontaneous Dutch either in isolation or in context. Listeners' ability to recognize the words was heavily influenced by the amount of context available. Whereas the proportion of correct identifications was only a little more than 50% when words were presented in isolation, it increased to more than 90% when words were presented in full sentence contexts. The strong effect of context suggests that the importance of contextual information depends on the reliability of the acoustic information provided by the words themselves. For reduced speech, in which acoustic information is less reliable, context is therefore more important compared to careful speech.

We investigated the influence of different listening conditions on effects of syntactic predictability by presenting both word orders in a careful and a casual speaking style. A casual speaking style often results in acoustic reductions that can make words more confusable (Brouwer, Mitterer, & Huettig, 2012a). Among the segments that are particularly often reduced in Dutch are schwas, for instance in prefixes of past participles (e.g. Ernestus, 2000; Hanique, Ernestus, & Schuppler, 2013). Dutch past participles such as “geleund” (pronounced as [xəlønt], English: "leaned") consist of a prefix containing a schwa ([xə], [bə] or [fər]), a stem (e.g. [løn]), and a suffix (e.g. [t]). When the schwa in the prefix is reduced or deleted, the participle is more similar to other words which are not past participles. For example, the word "geleund" becomes more similar to the first syllable of the word "gleuven" (English: "grooves"). When confronted with casual speech, listeners can therefore not reliably say if the sequence [xlø] is the onset of the past participle "geleund" or of the noun "gleuven". There is ample evidence in the literature suggesting that phonological overlap among words increases lexical competition (e.g. Allopenna, Magnuson, & Tanenhaus, 1998; Brouwer et al., 2012a; Luce & Pisoni, 1998; McQueen & Viebahn, 2007). We would therefore expect that a casual speaking style should increase lexical competition and slow down word recognition.

There are at least two ways in which a casual speaking style could influence the way in which syntactic information is evaluated. On the one hand, syntactic information may become more important for listeners when they are confronted with casual speech. As there is more phonological ambiguity in casual speech than in careful speech, listeners may benefit more from syntactic predictability. On the other hand, in casual speech the whole utterance is likely to be affected by acoustic reduction. This includes the words that carry syntactic information that could be used in order to predict upcoming words, such as auxiliary verbs. Syntactic information may therefore play less of a role in the processing of casual speech because it is more difficult to extract from the speech signal. A recent study by Van de Ven, Tucker, and Ernestus (2011) using semantic priming suggests that acoustically reduced words only function as effective primes if the time lag between prime and target is relatively long. This suggests that listeners require time in order to recover from acoustic reductions. We may therefore find that listeners are less able to make use of predictive syntactic information when the words that carry it are acoustically reduced because listeners may not have enough time to recover from the reduction of the auxiliary verb before hearing the participle. The idea that the importance of some linguistic cues depends on the availability of other cues is part of both accounts and is consistent with Mattys et al.'s (2005) and Norris et al.'s (1997) frameworks on cue integration in speech segmentation. According to these approaches, listeners use lexical, segmental, and prosodic cues for speech segmentation but the weight that is assigned to each cue depends on its availability in the signal.

In the following experiments we used a printed-word variant of the visual-world eye-tracking paradigm (e.g. Huettig & McQueen, 2007; McQueen & Viebahn, 2007). We presented listeners with carefully and casually produced sentences in which the target word was a past participle that either preceded or followed its associated auxiliary verb. While listening to these utterances, participants looked at visual displays of quadruplets of printed words which included the target participle as well as a non-participle which overlapped with the target word phonologically. The overlap between target and competitor word was larger if the target word was produced in a reduced rather than a careful way. We measured the reaction times (RTs) with which participants identified the target word as well as how much they paid attention to the similar sounding non-participle. If syntactic predictability helps listeners identify spoken words, we expect participants to identify the participle more quickly and to be less distracted by the similar sounding non-participle when the participle follows its auxiliary verb compared to when it precedes it. We also expect participants to identify the participle more quickly in careful than in casual speech because the phonological overlap with the non-participle will be smaller. Furthermore, we may find that the effect of word order is stronger for casual speech than for careful speech because listeners may rely more on syntactic information when the acoustic cues are less reliable. Alternatively, we may find an interaction that goes into the opposite direction. In the casual speaking-style condition, the whole utterance, including the auxiliary, is produced in an acoustically reduced way. Listeners may therefore have difficulties identifying the auxiliary and may consequently not be able to use it in order to predict the upcoming past participle. As a result, the effect of word order may be weaker (or even absent) in the casual speaking-style condition.

Experiment 1

Method

Participants

Forty-eight native speakers of Dutch were recruited from the subject panel of the Max Planck Institute for Psycholinguistics. All were university students. Age ranged from eighteen to twenty-seven years. The participants reported no hearing problems and had normal or corrected-to-normal vision. They were informed about the procedure of the experiment before taking part and were paid for their participation.

Materials

Sixty-four pairs of Dutch participles and non-participles were selected from the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995). The participles had a mean frequency of 191 per million and the non-participles of 347 per million. All words started with the letter <g> (pronounced as /x/). The pairs were chosen such that the two words overlap for the initial three phonemes when the schwa in the past participle is absent. For example, the words of the pair *geleund-gleuven* (*leaned-grooves*) overlap for the initial three phonemes /x/, /l/, and /ø/ when the schwa in *geleund* is absent. All words are listed in the Appendix.

For each pair, two carrier sentences were constructed, one that contained the participle and one that contained the non-participle. The sentences that contained the participle were used in the experimental trials. On these trials, the participle was the target word and the non-participle was the competitor. The sentences that contained the non-participle served as filler trials. On these trials, the non-participle was the target word. The sentences were identical up until the onset of each target word (see Table 1 for an example). The target words were positioned approximately in the centre of their carrier sentences. For the experimental sentences, two versions were constructed: in one version, the auxiliary preceded the participle and in the other version, the auxiliary followed the participle (see Table 1). For each version, a carefully and a casually produced recording was made. In the casually produced recording, the target word (but also other words in the sentence) were produced in an acoustically reduced way. For the experimental sentences, this resulted in four different versions of each sentence: an auxiliary-first version that was carefully produced, an auxiliary-first version that was casually produced, a participle-first version that was carefully produced, and a participle-first version that was casually produced. For the filler sentences, this resulted in two different versions: one that was carefully and one that was casually produced. In addition, eight practice sentences were created. Four of these sentences contained a participle and four did not. In half of the sentences containing a participle, the auxiliary preceded the participle and in the other half the auxiliary followed the participle.

(Table 1 about here)

In order to investigate whether there was a preference for one of the two word orders, we conducted a rating experiment. Twelve participants (native speakers of Dutch) who did not participate in the other experiments were simultaneously presented with visual representations of both syntactic versions of each sentence. We asked the participants to indicate which version they preferred by using a scale from 1 (auxiliary-first) to 6 (participle-first). The mean rating was 3.39. Independent-samples t tests showed that subject and item means did not differ significantly from 3.5 ($t_1(11) = -0.52$, $p = 0.62$; $t_2(63) = -1.81$, $p = 0.08$), indicating that there was no preference for either word order.

For the construction of the visual displays, the sixty-four participle-non-participle pairs were combined into 32 quadruplets (see the Appendix). For example, the pair *geleund-gleuven* [leaned-grooves] and the pair *gelift-glimlachte* [lifted-smiled] were combined into a quadruplet. Each visual display consisted of one quadruplet. On a given trial, the words from one participle-non-participle pair served as target and competitor, respectively, while the words from the other pair served as distractors. The words across the two pairs shared the second consonant but differed in the following vowel. For instance, all four words in the example quadruplet contain the consonant /l/ but only the words in the same target-competitor pair share the same vowel following the /l/ (*geleund* and *gleuven* share the /ø/ whereas *gelift* and *glimlachte* share the /I/). Each visual display was presented four times such that each word was the target once. As a result, there were 128 trials and eight practice trials. The words of a given quadruplet were presented pseudo-randomly across the four positions on the screen such that the words occurred in different positions each time a quadruplet was repeated.

Three pseudo-randomized running orders were created such that each presentation of a given quadruplet was separated by at least three trials. For each running order, experimental sentences were randomly assigned to one of the four conditions with an equal number of sentences per condition. Each running order was then rotated through the remaining three conditions resulting in twelve different experimental lists. An equal number of participants was assigned to each list. For the practice sentences, the quadruplets were not repeated. Each practice trial consisted of a unique quadruplet and a unique target sentence.

Recordings and acoustic analyses

The sentences were recorded in a sound-proof booth by a female native speaker of Dutch. For the casual sentences, the speaker was instructed to speak in a fast and casual way. It was explicitly stated that acoustic reductions were desirable. For the careful sentences, the speaker was instructed to speak in a clear and careful manner and to avoid acoustic reductions. We investigated if the different speaking styles influenced the acoustic properties of the stimuli by analyzing sentence duration, target word duration, auxiliary verb duration, schwa presence, schwa duration, initial /x/ duration, speaking rate until target word onset, and the divergence point between the target and the other words in its quadruplet. We defined the divergence point as the earliest point in time, measured from the beginning of the word, at which a word differs phonologically from the other words in the quadruplet. A schwa was judged to be present if there was a detectable portion of vocalic energy of at least one pitch period. Note that this does not mean that there were absolutely no cues to schwa in the tokens labelled in this analysis as having no schwa; nevertheless, such tokens are more reduced than those with an identifiable schwa. All of these acoustic measures are listed in Table 2 for the experimental and the filler items.

(Table 2 about here)

In order to determine if speaking style and word order influenced the acoustic properties of the stimuli, we employed linear mixed-effects models. Word order and speaking style were entered as fixed effects and random intercepts were included for each participle. For durations and speaking rate we used linear mixed-effects models and for schwa presence we used generalized mixed-effects models with a binomial link function. For the linear mixed-effects models, data points with standardized residuals of two and a half or more were considered outliers and removed from the analysis. All measures except for the divergence points suggested that the casually produced sentences were acoustically more reduced than the carefully produced ones. A casual speaking style resulted in a higher speaking rate and shorter sentence, participle, and critical schwa durations. Furthermore, the probability that a past participle contained a schwa was smaller for casually than for carefully produced sentences (all $|t| > 2.00$ and $p < 0.01$). The absence of an effect for the divergence points suggests that the increase in segmental overlap for casual words in which the schwa was absent (82.8% of the cases) is traded against shorter word durations. As casual words tended to have no detectable schwa in the prefix, the phonological overlap with the competitor increases. However, because they are produced more quickly, the overlapping phonemes are squeezed together temporally such that their divergence points do not differ from those of the carefully produced words.

In addition to the effects of speaking style, we also found effects of word order (all $|t| > 2.00$ and $p < 0.05$). Participles in the auxiliary-first word order had shorter /x/ durations and earlier divergence points while having longer schwas and sentences. Furthermore, target words in casual sentences were longer in participle-first than in auxiliary-first sentences. These results are consistent with studies showing that words that are more predictable have shorter durations and more reduced prefixes (Bell, Brenier, Gregory, Girand, & Jurafsky, 2009; Lieberman, 1963; Pluymaekers, Ernestus, & Baayen, 2005). The shorter /x/ durations might be due to the fact that participles are more predictable when following an auxiliary verb than when preceding it. The slightly longer schwa durations (mean: 6 ms) might be a small compensatory effect. However, because the increase in the schwa duration does not fully absorb the decrease in the /x/ duration, the divergence points occur earlier than in the participle-first word order. One may speculate that the fact that participle word durations were affected by word order only when produced casually indicates that predictability effects are stronger in casual than in careful speech production.

In summary, the acoustic measures confirmed that our casually produced stimuli were acoustically more reduced than our carefully produced stimuli. Furthermore, we found evidence suggesting that participles in the auxiliary-first word order are more reduced than participles in the participle-first word order. This finding is consistent with previous studies suggesting that words that are more predictable are more likely to be produced in a reduced way.

At first sight the fact that participles are more reduced in the auxiliary-first word order than in the participle-first word order might appear to be a confound. Differences in how listeners respond to the two word orders could either be due to the different word orders or due to differences in word duration. But the acoustic differences do not pose a problem for the validity of our argument because they work against our hypothesis. To reiterate, we expect participles in the auxiliary-first word order to be easier to recognize than in the participle-first word order. However, the words in the auxiliary-first word order are more reduced which means that, on signal-based grounds alone, they should be harder to recognize. Therefore, if we do find the expected effect of word order, it cannot be due to differences in reduction because the effect of reduction goes into the opposite direction to the effect of word order.

Procedure

Participants were seated approximately 70 cm from a 47.5 x 30 cm LCD computer screen running at 120 Hz. Monocular eye movements were recorded with a remote desktop-mounted SR-Research Eyelink 1000 system at a sampling rate of 500 Hz. Participants were told that they would hear spoken sentences and see four words on a screen. Their task was to click as quickly as possible on the word that they heard in the spoken sentence. The experiment was preceded by a brief calibration session.

(Figure 1 about here)

On each trial, participants saw a fixation cross for 500 milliseconds followed by a quadruplet of printed words. All words were presented in lower-case Lucida Sans Typewriter font size 20. The horizontal distance between the centres of the words was 512 pixels and the vertical distance was 385 pixels. An example of the type of visual display that participants saw is depicted in Figure 1. The spoken sentences were presented through headphones at a comfortable listening level. The time between the visual onset of the printed words and the onset of the spoken sentence was fixed at two seconds. After 72 trials, participants could take a break. A drift check was carried out before the experiment was resumed. The complete experimental session took approximately twenty minutes.

Results

For all of the following analyses we employed mixed-effects modeling with word order and speaking style as fixed factors and past participle and subject as random factors. Model fitting was performed in a stepwise fashion. In order to determine the fixed-effects structure of the model, we started by including word order, speaking style and interaction terms and subsequently removed terms if they were not significant. Once the fixed-effects structure was determined, we included random slopes for all significant fixed effects and tested whether the inclusion of a random slope improved the model fit using a chi-square test (Baayen, 2008). If a random slope did not improve the model, we removed it. We estimated p values by using the standard normal distribution (Baayen, Davidson, & Bates, 2008). For the statistical analyses of the Reaction Times (RTs), the data were log-transformed and RTs that differed more than two standard deviations from a given participant's mean were discarded as outliers. During the modeling procedure, data points with standardized residuals larger than 2.5 were removed. For the analysis of the accuracy data, generalized mixed-effects models with a binomial link function were used. In all of the following analyses only significant fixed and random effects are reported.

Accuracy

Trials with RTs smaller than 200 or larger than 4,000 milliseconds, as measured from the onset of the participle, were regarded as extreme values and were not included in the analyses (<0.8%). Trials on which participants clicked on the word that was actually mentioned in the sentence were scored as correct and trials on which other words were clicked on were scored as incorrect. Table 3 shows the mean accuracy values for each of the four experimental conditions. Accuracy was very high (all means are higher than 98%). The statistical analyses suggest that there was a small but significant difference between carefully and casually produced stimuli with the latter ones being responded to slightly less accurately (β_{casual}=-1.57, z=-2.23, $p<0.05$; SD of random intercepts for participants: 0.65, SD of random intercepts for words: 5.73). There was no effect of word order and no interaction between speaking style and word order.

(Table 3 about here)

RTs

Only correct trials were included in the analyses. RTs were measured from target word onset. The average RTs are displayed in Table 3. In order to account for differences in duration among the words, we included past participle duration as a control variable. The analyses showed a main effect of word order ($\beta_{participle\text{-}first}=0.06$, $t=6.9$, $p<0.001$; SD of random intercepts for participants: 0.11, SD of random intercepts for words: 0.07), indicating that participles in sentences with the participle-first word order were responded to more slowly than participles in sentences with the auxiliary-first word order. The same model indicated also a main effect of speaking style ($\beta_{casual}=0.02$, $t=2.1$, $p<0.05$), indicating that RTs for casually produced stimuli were longer than for carefully produced ones. The interaction between word order and speaking style was not significant and neither was the effect of word duration.

Gaze probability

Only correct trials were included in the fixation analyses. Fixations were scored as having landed on a particular word when the fixation fell within a rectangular area of 300 by 200 pixels around the centre of that word. We coded whether or not a fixation fell on a given word on the display for one hundred 10-ms time intervals ranging from 200 ms before the onset of the target word until 1,400 ms later. Fixation proportions are shown in Figures 2A and 2B. Before conducting linear mixed-effects modeling, fixation proportions were transformed to empirical logits (Barr, 2008). In order to investigate the time course of the fixation behavior, we tested the effects of word order and speaking style across four time windows. The purpose of the first time window analysis was to determine whether listeners use word order information before the onset of the target word. This window ranged from the average onset of the auxiliary verb in the auxiliary-first condition (159 ms before participle onset), offset by a further 200 ms, until the onset of the following past participle (plus the same 200 ms offset). Note that the same time window was used for sentences with the auxiliary-first and the participle-first word order. The additional 200 milliseconds were added to these and all other window boundaries in order to account for the fact that it takes approximately this amount of time to program and launch a saccade (Matin, Shao, & Boff, 1993). Therefore, time window 1 ranged from 41 ms after participle onset until 200 ms after participle onset. If listeners use the information provided by the auxiliary verb in order to predict the upcoming past participle, we would expect to find an effect of word order in this time window. The second time window ranged from the onset of the past participle (plus 200 ms) until the average offset of the past participles (plus 200 ms). This window thus ranged from 200 ms until 579 ms measured from the average past participle onset. This time window covers the period during which the acoustic information of the past participle unfolds. If speaking style and word order influence the efficiency with which listeners access the past participle while acoustic information becomes available, we would expect to find differences in fixation probability across conditions in this window. The remaining two time windows covered the time period (again with the 200 ms offset) from the average offset of the past participle until the time the average RT was recorded. These time windows were of the same length as the second time window (379 ms). We kept the time windows identical in size in order to compare the same amount of data (i.e. samples) across analyses. Therefore, the window boundaries are as follows. Time window 1 ranged from 41 milliseconds (ms) after word onset until 200 ms, window 2 ranged from 200 ms until 579 ms, window 3 from 579 ms until 958 ms, and window 4 ranged from 958 until 1337 ms. The vertical lines in Figures 2 and 3 illustrate these time windows.

(Figure 2 about here)

In time window 1 there were no effects of word order or speaking style for either the fixations to the target or those to the competitor. These results indicate that participants were equally likely to look at the past participle and the competitor across all conditions. In time window 2, a different pattern of results emerges. For target fixations, we found significantly fewer fixations to the target word for sentences with the participle-first compared to the auxiliary-first word order ($\beta_{participle\text{-}first}$=-0.14, t=-2.60, $p<0.01$; SD of random intercepts for words: 0.10). There was no significant difference between casually and carefully articulated words and no interaction. This pattern was also reflected in the competitor fixations. We find significantly more fixations to the competitor word in the participle-first condition than in the auxiliary-first condition ($\beta_{participle\text{-}first}$=0.15, t=2.50, $p<0.05$; SD of random intercepts for participants: 0.09, SD of random intercepts for words: 0.12). There was no effect of speaking style and no interaction.

(Table 4 about here)

In window 3, the identical pattern of results was found. There were fewer looks to the target in the participle-first than the auxiliary-first word order ($\beta_{participle\text{-}first}$=-0.15, t=-2.50, $p<0.05$; SD of random intercepts for words: 0.19), no effect of speaking style and no interaction. For the competitor, however, we found a significant interaction between word order and speaking style. Table 4 summarizes the parameters of the model. An analysis of the simple effects indicated that for carefully produced sentences there was no effect of word order. For casually produced sentences there were more fixations towards the competitor in the participle-first condition than the auxiliary-first condition ($\beta_{participle\text{-}first \mid casual} = 0.26$, $t=2.77$, $p<0.01$; SD of random intercepts for participants: 0.32, SD of random intercepts for words: 0.57). For sentences with the auxiliary-first word order, there was no effect of speaking style. For sentences with the participle-first word order, there were more fixations towards the competitor when the past participle was produced casually than when it was produced carefully ($\beta_{casual \mid participle\text{-}first} = 0.30$, $t=2.06$, $p<0.05$; SD of random intercepts for participants: 0.35; SD of random slopes of the factor speaking style for participants: 0.53; SD of random intercepts for words: 0.59; SD of random slopes of the factor speaking style for words: 0.66). In time window 4 there were no effects of word order or speaking style for either the fixations to the target or those to the competitor.

Discussion

The results of Experiment 1 show that both word order and speaking style can have an influence on how quickly listeners are able to identify words uttered in a sentence context. Participants responded more quickly and were more likely to pay overt visual attention to target words that were syntactically predictable. Similar to the fixations on the target word, fixations on the competitor were influenced by the syntactic predictability of the target word. If the target word was not syntactically predictable, listeners were more likely to consider the competitor as a potential target. In contrast, when the target word was syntactically predictable, listeners were more likely to rule out the competitor because it belonged to a syntactic category that cannot occur after an auxiliary verb.

Furthermore, the analysis of the RTs and the accuracy of the mouse clicks suggest that the speaking style in which the sentences were produced also influenced the listeners' ability to recognize the past participles. In the majority of cases, casually produced target words did not contain a schwa in the prefix, which increased the initial phonological overlap between the targets and the competitors (see Table 2). The fact that listeners paid more overt attention to the competitor when hearing casually produced targets reflects that they were sensitive to the increase in phonological overlap. The lack of an interaction between word order and speaking style for target fixations suggests that listeners make use of syntactic information irrespectively of how reliable the acoustic cues in the speech input are. It also shows that the auxiliary verbs were intelligible enough so that listeners could extract syntactic cues from the signal. However, the interaction between word order and speaking style for competitor fixations (in window 3) showed that participants were more likely to look at the competitor if the participle was less predictable, but only if the sentences were produced in a casual manner. This result supports the hypothesis that syntactic information is more useful if acoustic-phonetic information is less reliable. But the fact that the interaction only emerged for the competitor fixations and not the target fixations is somewhat puzzling. We will return to this issue later.

In sum, the results of Experiment 1 support the notion that syntactic predictability can influence word recognition. However, the effect of word order could also be driven by the information given by the following sentence context. It has previously been shown that listeners not only use preceding context in order to recognize words but also following context (e.g. Connine, Blasko, & Hall, 1991; Pollack & Pickett, 1964; van de Ven et al., 2012). If the listeners in our study used the following context in order to identify the target participle, they could have done so more quickly in the auxiliary-first than the participle-first condition. As in the auxiliary-first word order the auxiliary verb is positioned to the left of the participle, the distance between the participle and the following noun is exactly one word shorter than in the participle-first condition. It is therefore logically possible that the processing advantage for sentences in which the auxiliary precedes the participle is actually due to the quicker arrival of the following noun. In order to investigate this possibility we conducted Experiment 2. We presented the stimulus sentences only until the offset of the target word and its associated auxiliary verb (see Table 1). If the effect of word order that we found in Experiment 1 is still present in Experiment 2, we can exclude the possibility that it was entirely due to information from the following context becoming available more quickly.

Experiment 2

Method

Participants

Another forty-eight native speakers of Dutch were recruited from the subject panel of the Max Planck Institute for Psycholinguistics. Age ranged from eighteen to twenty-six years. The participants reported no hearing problems and had normal or corrected-to-normal vision. They were paid for their participation.

Materials

The materials were based on the stimuli from Experiment 1. New versions were created by removing the portion of the speech signal that followed the target word and its associated auxiliary verb (see Table 1). In order to keep the amount of information carried by the sentence fragments constant across conditions, the auxiliary verb was included for both word order conditions (i.e. even when it followed the participle).

Procedure

The procedure was the same as in Experiment 1.

Results

Accuracy

The mean values for the four experimental conditions are shown in Table 3. Generally, accuracy was very high (all means are above 98%). There was no effect of speaking style, word order, or an interaction.

RTs

The average RTs are displayed in Table 3. As for Experiment 1, we included past participle duration as a control variable in order to account for differences in word durations. The analyses showed a main effect of word order ($\beta_{participle\text{-}first}$ = 0.07, t=8.1, p<0.001; SD of random intercepts for participants: 0.10, SD of random intercepts for words: 0.06), indicating that participles in sentences with the participle-first word order were responded to more slowly than participles in sentences with the auxiliary-first word order. There was also a main effect of speaking style (β_{casual} =0.03, t=2.9, p<0.01), indicating that RTs for casually produced stimuli were longer than for carefully produced ones. As in Experiment 1, the interaction between word order and speaking style was not significant and neither was the effect of word duration.

Gaze probability

As in Experiment 1, we analyzed the effects of word order and speaking style for each of the four time windows individually. Fixation proportions are shown in Figures 2C and 2D. In time window 1, there were no effects of word order or speaking style for the fixations to the target. In contrast, for the fixations to the competitor we found an interaction between word order and speaking style. The parameters of this model are summarized in Table 5. An analysis of the simple effects indicated that for carefully produced sentences there was no effect of word order. For casually produced sentences there were more fixations towards the competitor when the participle preceded the auxiliary than when it followed it ($\beta_{participle\text{-}first \mid casual} = 0.23$, $t=2.06$, $p<0.05$; SD of random intercepts for participants: 0.25, SD of random intercepts for words: 0.05). There was no effect of speaking style for sentences with the participle-first or the auxiliary-first word order.

(Table 5 about here)

In time window 2, there were fewer fixations to the target for sentences with the participle-first word order than the auxiliary-first word order ($\beta_{participle\text{-}first} = -0.14$, $t=-2.70$, $p<0.01$; SD of random intercepts for participants: 0.03; SD of random intercepts for words: 0.09). There was no significant difference between casually and carefully articulated sentences and no interaction. This pattern was also reflected in the competitor fixations. There were more fixations to the competitor in sentences with the participle-first word order than the auxiliary-first word order ($\beta_{participle\text{-}first} = 0.24$, $t=4.57$, $p<0.001$; SD of random intercepts for participants: 0.06, SD of random intercepts for words: 0.18). There was no effect of speaking style and no interaction.

In time window 3, there were also fewer fixations to the target for sentences with the participle-first word order than the auxiliary-first word order ($\beta_{participle\text{-}first} = -0.13$, $t=-2.20$,

$p<0.05$; SD of random intercepts for participants: 0.05; SD of random intercepts for words: 0.10). There was also no effect of speaking style and no interaction. For the competitor, we found no significant effects of word order, speaking style, or the interaction.

In time window 4, there were fewer fixations to the target when the past participle was produced casually than when it was produced carefully ($\beta_{casual} = -0.52$, $t=-3.98$, $p<0.001$; SD of random intercepts for participants: 0.57; SD of random slopes of the factor speaking style for participants: 0.56; SD of random intercepts for words: 0.48; SD of random slopes of the factor speaking style for participants: 0.58). For competitor fixations, neither the effect of word order nor of speaking style was significant.

Discussion

The purpose of Experiment 2 was to investigate if the effect of word order that we found in Experiment 1 was due to information that the participants extracted from the following context. The results suggest that this was not the case. Even when the following context was removed, target words embedded in sentences with the participle-first word order were responded to more slowly and fixated less often compared to targets in sentences with the auxiliary-first word order. Similarly, casually produced targets were responded to more slowly compared to targets in carefully produced sentences.

Both Experiments 1 and 2 suggest that listeners are sensitive to both syntactic predictability and changes in phonological overlap as a result of acoustic reductions. Furthermore, the RTs and target fixations suggest that these factors influence word recognition independently from each other. Listeners appear to make use of syntactic information to the same extent when listening to casually produced speech as they do when listening to carefully produced speech. This finding is contrary to the idea that listeners adapt dynamically to the demands of different listening situations (Brouwer et al., 2012b; McQueen & Huettig, 2012). From such a perspective, one might expect that as information from the speech signal becomes less reliable due to phonetic reductions, listeners rely more on other sources of information such as syntactic predictability. The influence of word order should then be stronger for sentences produced in a casually speaking style because under these circumstances phonological information is less reliable. However, as in Experiment 1, we found an interaction between word order and speaking style for the competitor fixations. This interaction suggests that word order information is more useful for casually than for carefully produced sentences. But the fact that we find this interaction only for competitor and not target fixations as well as the fact that it occurs in different time windows across Experiments 1 and 2 remains puzzling. It is possible that this is a spurious effect, a possibility that we will investigate in a combined analysis later.

How could the lack of an interaction between speaking style and word order for target fixations and RTs be explained? One potential explanation might be that although the phonetic information in the casual speech signal was less reliable it was nevertheless sufficient when there was enough time for listeners to make a decision. When facing an acoustically ambiguous stimulus, there are (at least) two ways in which one can respond. First, one can wait until more acoustic information becomes available. Second, one can use other sources of information in order to compensate for the lack of unambiguous acoustic information. As there was no time limit in the previous experiments, participants could take as much time as they needed in order to process the reduced speech signal. However, when put under time pressure, listeners need to find another way to compensate for the lack of acoustic information. We may therefore find that under time pressure, syntactic predictability has a stronger effect when listening to casual speech than when listening to careful speech. In order to investigate this hypothesis, we conducted Experiment 3 in which we limited the amount of time listeners had in order to respond.

Experiment 3

Method

Participants

Another forty-eight native speakers of Dutch were recruited from the subject panel of the Max Planck Institute for Psycholinguistics. Age ranged from eighteen to twenty-nine years. The participants reported no hearing problems and had normal or corrected-to-normal vision. They were paid for their participation.

Materials

The materials were the same as in Experiment 1.

Procedure

The procedure was identical to that of Experiment 1 with one crucial exception. Participants had only a limited amount of time in order to respond. Based on informal piloting, we used a time limit of 1,400 milliseconds after the offset of the target word. If participants had not responded within this time period, the trial ended and the words “Te langzaam” (“too slow”) were displayed in the centre of the screen in large red letters. Participants were told about the time limit before the start of the experiment.

Results

Accuracy

For the accuracy analyses, trials during which participants clicked on the wrong word or failed to make a response within the given time limit were scored as incorrect. The mean accuracy values are shown in Table 3. The statistical analyses showed that there was a main effect of word order ($\beta_{participle\text{-}first}=-0.33$, $z=-2.73$, $p<0.01$; SD of random intercepts for participants: 0.57, SD of random intercepts for words: 0.68), showing that participants were less accurate when responding to sentences with the participle-first word order than vice versa. Furthermore, there was a main effect of speaking style ($\beta_{casual}=-0.85$, $z=-6.82$, $p<0.001$), indicating that performance was better for items spoken with a careful compared to a casual speaking style. The interaction between word order and speaking style was not significant.

RTs

Average reaction times for each experimental condition are listed in Table 3. There was a significant main effect of word order showing that participants took longer to click on the past participle if it preceded the auxiliary verb compared to when it followed it ($\beta_{participle\text{-}first}=0.07$, $t=7.7$, $p<0.001$; SD of random intercepts for participants: 0.07, SD of random intercepts for words: 0.05). There were no significant effects of speaking style and participle duration. The interaction between word order and speaking style was also not significant.

Gaze probability

As in the previous two experiments, we analyzed the effects of word order and speaking style individually for each of the four time windows. Fixation proportions are shown in Figures

2E and 2F. In time window 1, there were no effects of word order or speaking style on the fixations to the target or the competitor. In time window 2, there were significantly fewer fixations to the target in sentences with the participle-first word order than the auxiliary-first word order ($\beta_{participle\text{-}first}$ = -0.20, t=-3.83, p<0.001; SD of random intercepts for words: 0.10). There were no effects of speaking style and no interaction. For the fixations to the competitor, we found an interaction between word order and speaking style. The results of this model is summarized in Table 6.

(Table 6 about here)

An analysis of the simple effects indicated that for carefully produced sentences, there were more fixations towards the competitor if the participle preceded the auxiliary than when it followed it ($\beta_{participle\text{-}first \mid careful}$ = 0.31, t=3.74, p<0.001; SD of random intercepts for words: 0.23). For casually produced sentences there was no effect of word order. For sentences with the auxiliary-first word order, there were more fixations to the competitor if the participle was produced casually than when it was produced carefully ($\beta_{casual \mid auxiliary\text{-}first}$ = 0.23, 2.81, p<0.01; SD of random intercepts for words: 0.34). For sentences with the participle-first word order there was no effect of speaking style.

In time window 3, there were fewer fixations to the target in sentences with the participle-first word order than the auxiliary-first word order ($\beta_{participle\text{-}first}$ = -0.24, t=-4.01, p<0.001; SD of random intercepts for words: 0.12). There were no effects of speaking style and no interaction. For the fixations to the competitor, there were no significant effects either. In time window 4, there were no effects of word order or speaking style for the fixations to the target or the competitor.

Discussion

The purpose of Experiment 3 was to investigate how time pressure influences the degree to which listeners make use of syntactic information when confronted with carefully and casually produced speech. Neither the accuracy data, nor the RT data, nor the gaze probability data support the hypothesis that listeners rely more on syntactic information if the speaking style is casual rather than careful. The target fixations and RTs replicated the main effect of word order that we found in the previous two experiments but did not provide any evidence suggesting that word order is more important when listening to casual speech than when listening to careful speech. As in the previous two experiments, there was an interaction between word order and speaking style for the competitor fixations. Whereas in Experiments 1 and 2 this interaction suggested a more important role for syntactic information in casual than in careful speech, the interaction that appeared in Experiment 3 suggested the opposite. Taken together, these findings suggest the possibility that the effect is spurious and not reliable. We therefore compared all three experiments in a combined analysis.

Comparison of Experiments 1, 2, and 3

Accuracy

The analyses show that participants made fewer correct responses in the participle-first than in the auxiliary-first condition ($\beta_{participle\text{-}first}$=-0.27, z=-2.35, $p<0.05$; SD of random intercepts for participants: 0.58, SD of random intercepts for words: 0.68; SD of random slopes for Experiments 1 vs. 3 for words: 2.31; SD of random slopes for Experiments 2 vs. 3 for words: 0.94). Furthermore, they made fewer correct responses when being presented with casual compared to careful stimuli (β_{casual}=-0.83, z=-6.88, p<0.001). The interaction between word order and speaking style was not significant. In addition, accuracy in Experiment 1 was higher than in Experiment 3 ($\beta_{Exp1\ vs.\ Exp3}$=6.02, z=4.81, p<0.001) and higher in Experiment 2 than in Experiment 3 ($\beta_{Exp2\ vs.\ Exp3}$=3.76, z=7.87, p<0.001). There was no significant difference between Experiments 1 and 2 and no significant interactions.

RTs

The results of the model fitted to the RTs is shown in Table 7. Responses in Experiment 1 and 2 were slower than in Experiment 3. Furthermore, responses in Experiment 2 were faster than in Experiment 1. These differences reflect a speed-accuracy trade-off: while RTs became faster from Experiment 1 to 3, accuracy decreased. Furthermore, there was a significant effect of target word duration: longer past participles were responded to more slowly than shorter participles. Importantly, there was a significant two-way interaction between word order and speaking style. An analysis of the simple effects showed that participants responded more slowly to sentences with the participle-first word order than the auxiliary-first word order for both speaking styles. However, as shown by the beta weights, this effect was stronger for casual speech ($\beta_{participle\text{-}first\ |\ casual}$=0.08, t=8.8, p<0.001; SD of random intercepts for participants: 0.10, SD of random intercepts for words: 0.08) than for careful speech ($\beta_{participle\text{-}first\ |\ careful}$=0.05, t=7.4, p<0.001; SD of random intercepts for participants: 0.10, SD of random intercepts for words: 0.06). Furthermore, in sentences with the participle-first word order casually produced past participles were responded to more slowly than carefully produced past participles ($\beta_{casual\ |\ participle\text{-}first}$=0.03, t=4.5, p<0.001; SD of random intercepts for participants: 0.09, SD of random intercepts for words: 0.06). In contrast, for the auxiliary-first condition, there was no significant effect of speaking style. There were no two- or three-way interactions of experiment with word order or speaking style.

(Table 7 about here)

Gaze probability

The averaged fixation proportions are shown in Figures 3A and 3B. In time window 1, there were no effects of word order or speaking style for either target or competitor fixations. In time window 2, there were significantly fewer fixations to the target if it occurred in sentences with the participle-first word order compared with the auxiliary-first word order ($\beta_{participle\text{-}first}$= 0.16, t=-5.33, p<0.001; SD of random intercepts for words: 0.15). There was no significant difference between casually and carefully articulated words and no interaction. Furthermore, there were significantly fewer fixations in Experiment 1 compared to Experiment 3 ($\beta_{Exp1\ vs.\ Exp3}$=-0.08, t=-2.03, p<0.05). There were no significant differences in fixation proportions between Experiments 2 and 3 or Experiments 1 and 2 and no interactions. For the fixations to the competitor, we also found a main effect of word order. There were significantly more fixations to the competitor in the participle-first condition than in the auxiliary-first condition ($\beta_{participle\text{-}first}$=0.20, t=5.99, p<0.001; SD of random intercepts for participants: 0.07, SD of random intercepts for words: 0.19). Furthermore, there were more competitor fixations when the sentences were produced in a casual speaking style than when they were produced in a careful speaking style (β_{casual} = 0.08, t=2.54, p<0.05). The interaction between word order and speaking style was not significant and there were no main or interaction effects with experiment.

In time window 3, a similar pattern of results emerged. There were significantly fewer fixations to the target if it occurred in sentences with the participle-first word order compared with the auxiliary-first word order ($\beta_{participle\text{-}first}$=-0.17, t=-5.09, $p<0.001$; SD of random intercepts for participants: 0.01, SD of random intercepts for words: 0.17). There was no significant difference between the careful and casual conditions and no significant interaction between word order and speaking style. Furthermore, there were fewer fixations to the target in Experiment 1 than in Experiment 3 ($\beta_{Exp1\ vs.\ Exp3}$=-0.11, t=-2.53, $p<0.05$) and more in Experiment 2 than in Experiment 1 ($\beta_{Exp2\ vs.\ Exp1}$=0.08, t=1.99, $p<0.05$). There was no difference in target fixations between Experiments 2 and 3 and none of the two- or three-way interactions with experiment were significant. The pattern of results for the target fixations matches almost perfectly with the results for the fixations to the competitor. There were more fixations to the competitor for sentences with the participle-first than the auxiliary-first word order ($\beta_{participle\text{-}first}$=0.15, t=2.16, $p<0.05$; SD of random intercepts for participants: 0.40, SD of random intercepts for words: 0.17; SD of random slopes of the factor word order for participants: 0.53; SD of random slopes of the factor word order for words: 0.26). There was no difference in the number of competitor fixations between the casual and careful conditions and no significant interaction between speaking style and word order. The same model also indicated that participants were more likely to fixate the competitor in Experiment 1 compared to Experiment 3 ($\beta_{Exp1\ vs\ 3}$ = 0.22, t=2.75, $p<0.01$) but there were no differences between Experiments 2 and 3 or Experiments 2 and 1. None of the two- or three-way interactions between experiment and speaking style or word order were significant.

In window 4, the fixations to the target revealed a significant interaction between word order and speaking style. The parameters of this model are summarized in Table 8. An analysis of the simple effects showed that for careful sentences, there was no effect of word order. When the sentences were produced casually, there were fewer fixations towards the target word for sentences with the participle-first word order than with the auxiliary-first word order ($\beta_{participle\text{-}first \mid casual}$ = -0.19, t=-2.02, p<0.05; SD of random intercepts for participants: 0.47; SD of random intercepts for words: 0.22; SD of random slopes of the factor word order for words: 0.47). Furthermore, for sentences with the auxiliary-first word order, there was no effect of speaking style. In contrast, for sentences with the participle-first word order, there were fewer target fixations for casually compared to carefully produced sentences ($\beta_{casual \mid participle\text{-}first}$ = -0.42, t=-3.65, p<0.001; SD of random intercepts for participants: 0.71; SD of random slopes of the factor speaking style for participants: 0.79; SD of random intercepts for words: 0.47; SD of random slopes of the factor speaking style for words: 0.58).

(Table 8 about here)

For the fixations to the competitor, there was no effect of word order, speaking style, and no interaction. However, there was a main effect of experiment showing that there were more competitor fixations in Experiment 1 than in Experiment 3 ($\beta_{Exp1\ vs\ Exp3}$ = 0.65, t=4.85, p<0.001; SD of random intercepts for participants: 0.60, SD of random intercepts for words: 0.60) and more fixations to the competitor in Experiment 2 than in Experiment 3 ($\beta_{Exp2\ vs\ Exp3}$ = 0.50, t=3.67, p<0.001).

Control analyses

It remains possible that the effect of word order could be due to other factors: the duration of the sentence after the participle, the participants' preference for one order over the other, or bigram frequency. More specifically, bigram frequency refers here to the frequency with which a given past participle occurs together with its preceding word (be that an auxiliary verb or other types of words). We tested whether the effect of word order remained statistically significant after controlling for these factors by conducting additional analyses for each dependent measure (i.e. accuracy, RT, and gaze probability) based on the combined data from all three experiments. We defined sentence remainder duration as the time from the offset of the past participle until the end on the sentence. We used the data from the rating experiment (mean ratings per item) as estimates of preference for one or the other word order for each sentence. For bigram frequency, we used estimates based on the Dutch internet search engine IxQuick (https://www.ixquick.com). The log-transformed bigram frequencies ranged from 1.10 to 11.74 with a mean of 5.89 and a median of 5.37. For each analysis, we first fitted a control model using linear regression in which we regressed the respective dependent variable on the control variables. Subsequently, we used the residuals of this model as the dependent variable in the original models. Correlations between the experimental and control variables are shown in Table 9.

(Table 9 about here)

For the accuracy scores, the control model suggests that the higher the bigram frequency was, the more accurately participants responded (β_{bigram}=0.08, z=4.0, p<0.001). The effect of word order, which we had found earlier, disappeared. For the RTs, the control model indicated increasing RTs with increasing sentence remainder durations ($\beta_{remainder}$<0.001, t=6.12, p<0.001). Furthermore, RTs were slower for sentences with higher ratings (β_{rating}=0.01, t=2.14, p<0.05) reflecting that responses were slower when the preference was for the participle-first word order. In addition, participants were faster for stimuli with higher bigram frequencies than lower bigram frequencies (β_{bigram}=-0.01, t=-7.29, p<0.001).Importantly, despite the significant influence of the control variables, the interaction effect between word order and speaking style remained significant ($\beta_{participle\text{-}first*casual}$=0.03, t=2.29, p<0.05; SD of random intercepts for participants: 0.1; SD of random intercepts for words: 0.06; SD of random slopes of the interaction between the factors speaking style and word order for words: 0.02).

For gaze probability, we analyzed time windows 2, 3, and 4 because these are the windows in which we had found an effect of word order in the previous analyses. In windows 2 and 3, the control models indicated a lower gaze probability for longer sentence remainders than for shorter ones (window 2: $\beta_{remainder}$>-0.001, t=-4.15, p<0.001; window 3: $\beta_{remainder}$=-0.001, t=-4.06, p<0.001) and a higher gaze probability for higher bigram frequencies than lower ones (window 2: β_{bigram}=0.05, t=4.35, p<0.001; window 3: β_{bigram}=0.04, t=3.72 p<0.001). Importantly, when taking the control variables into account, the effect of word order disappeared. However, finding an effect of sentence remainder duration in the early time window is quite puzzling because participants ought not to be able to anticipate the end of the sentence so early. We therefore investigated if the effect of sentence remainder duration is actually due to its correlation with word order (r=0.27, t=4.49, p<0.001). When entering sentence remainder and word order simultaneously into the original LMER for time window 2, sentence remainder is not significant whereas word order is ($\beta_{participle\text{-}first}$=-0.15, t=-4.43, p<0.001; SD of random intercepts for words: 0.15). We therefore fitted a second control model without sentence remainder duration (i.e. only bigram frequency and ratings). For these residuals, word order was still a significant predictor ($\beta_{participle\text{-}first}$=-0.08, t=-2.49, p<0.05; SD of random intercepts for participants: < 0.001; SD of random intercepts for words: 0.18). An analysis for time window 3 yielded the same pattern of results. When entering sentence remainder and word order simultaneously into the original LMER, sentence remainder was not significant whereas word order still was ($\beta_{participle\text{-}first}$=-0.17, t=-4.58, p<0.001; SD of random intercepts for participants: 0.01; SD of random intercepts for words: 0.17). As for time window 2, for the residuals of a control model without sentence duration remainder, word order was a significant predictor ($\beta_{participle\text{-}first}$=-0.10, t=-2.90, p<0.01; SD of random intercepts for participants: <0.001; SD of random intercepts for words: 0.2). These results suggest that word order exerted a significant influence on gaze probability above and beyond sentence duration remainder and bigram frequency. In window 4, the control models did not show effects of sentence remainder, rating, or bigram frequency. Not surprisingly, when entering the residuals of the control model into the original LMER, the critical interaction between word order and speaking style remained significant as shown in Table 10.

(Table 10 about here)

Taken together, the control analyses suggest that the word order effects remain significant after controlling for potential effects of the duration of the sentence remainder, the preference ratings, and bigram frequency. This does not mean, of course, that bigram frequency does not influence predictive language processing. However, it appears that the present effect of word order cannot be reduced to an effect of bigram frequency.

Discussion

The comparison of the three experiments confirmed that listeners performed better at recognizing the target past participle when it occurred in sentences with the auxiliary-first word order than in sentences with the participle-first word order. Furthermore, the analysis of the different time windows showed that the influence of word order occurred after the onset of the past participle. The fact that the effect did not appear before the onset of the past participle (i.e. in time window 1) suggests that listeners did not start to predict the past participle as soon as they heard the auxiliary and instead benefited from word order information only as the target word started to unfold. Furthermore, the analysis of the combined data from all three experiments revealed a finding that did not come out in the individual analyses of the experiments. Both the reaction times and the late target fixations showed an interaction between word order and speaking style, suggesting that the effect of word order was stronger for casual speech than for careful speech. In addition, the interaction effects between word order and speaking style for the competitor fixations that we found in the individual analyses of the experiments disappeared in the overall analyses. This suggests that it is not reliable and that the effect is probably a type one error. In contrast, the interaction between word order and speaking style for the target fixations seems to be robust because it occurs in both the late gaze probabilities as well as the reaction times. As the interaction effect emerges only in the combined analysis, it appears to be rather small and requires a relatively large amount of data in order to be detected. The interaction suggests that listeners rely more on syntactic information when the speech input is produced in a casual manner than when it is produced carefully. The fact that we observed the interaction in the RTs and the late time window but not in the earlier time windows suggests that the increased benefit of syntactic information for casual speech manifests itself relatively late in lexical processing.

Furthermore, the comparison of the three experiments sheds light on the question of whether the effect of word order might be at least partially due to the quicker arrival of information from the following context. If so, word order should have had a weaker effect in

Experiment 2 compared to Experiments 1 and 3. However, our analyses indicate no interaction between word order and Experiment suggesting that the word order effect is not dependent on information from the following context.

General Discussion

This study investigated how syntactic predictability influences the recognition of words embedded in carefully and casually spoken sentence contexts. We manipulated syntactic predictability by swapping the order of past participles and their associated auxiliary verbs in Dutch subordinate clauses, where word order is not fixed. The participle is more predictable in the auxiliary-first word order than in the participle-first word order because the auxiliary indicates that a participle must follow immediately. Moreover, we explored whether the influence of syntactic predictability differs depending on whether the sentences were produced in a careful or a casual manner. In a casual speaking style, words typically undergo acoustic reductions, which potentially decreases the amount of information conveyed by the speech signal. We hypothesized that there are two possible ways in which a reduced speaking style could influence the way in which word order information is used. First, listeners might make more use of syntactic cues in order to compensate for the decrease in acoustic-phonetic information that results from a casual speaking style. Alternatively, listeners may be less able to benefit from syntactic information because it is more difficult to extract it from an acoustically reduced speech input.

We conducted three eye-tracking experiments using a printed-word variant of the visual world paradigm (e.g. McQueen & Viebahn, 2007), in which careful and casual variants of sentences with either the auxiliary-first or the participle-first word order were presented while listeners had to identify the participle on a screen. In addition to the target participle, the display contained a phonological competitor for which phonological overlap with the target word was larger when the target was produced in a reduced way compared to an unreduced way. In Experiment 1, complete sentences were presented and the participants were under no time pressure to respond. In Experiment 2, the sentence context following the target word and its associated auxiliary verb was removed in order to control for following semantic context effects. Experiment 3 was like Experiment 1 but a time limit was imposed on the responses in order to put participants under time pressure.

Our first finding is that in all three experiments, participles were recognized more easily when they followed their associated auxiliary verbs compared to when they preceded them. This result provides further evidence for the hypothesis that syntactic predictability can influence the speed with which listeners recognize words (Arai & Keller, 2013; Kamide et al., 2003). Our results extend these findings by showing that listeners can use auxiliary verbs in order to facilitate the recognition of following past participles. Auxiliary verbs do not contain any semantic information; they merely signal that a participle is more likely to come up than a non-participle. In other words, they provide information about the word class that the following word is likely to belong to.

Interestingly, the analyses of the separate time windows suggest that although syntactic predictability facilitated the recognition of the past participle, listeners did not actually *predict* its occurrence. That is, participants did not start looking at the target word before its acoustic onset. Predictability means that a certain input is, in principle, predictable based on previously occurring information. The predicting information has the potential to be used. However, just because there is information that *could* be used in order to predict upcoming input does not necessarily mean that it *will* or *can* be used by the listener. Given that previous research has shown that listeners are able to predict upcoming words (e.g. Altmann & Kamide, 1999; Arai & Keller, 2013; Kamide et al., 2003), the question arises as to why participants were not predicting the target word in the present study. One difference between our study and previous work is the time that listeners had in order to develop a prediction about the upcoming input. In our study, there were no words between the predictive word (i.e. the auxiliary verb) and the target word (i.e. the past participle). In previous studies that found target fixations before the target's acoustic onset, there was at least one word in between the predictive precursor and the target. For example, Altmann and Kamide (1999) presented sentences such as "The boy will eat the cake" in which the word "eat" is predictive of the word "cake". Thus, in their study, the two words do not follow each other but are separated by the definite article "the". It is possible that this intervening word was long enough to allow the listeners to predict the upcoming noun. In Dahan and Tanenhaus (2004), the two critical words were also separated by an article. For example, in the sentence "Never before climbed a goat so high", the predictive verb "climbed" and the target word "goat" are separated by the indefinite article "a". The results of our study suggest that at least one intermediate word is necessary for predictive eye movements to occur. Unfortunately, this hypothesis cannot be tested with these materials because the syntactic structure that we used does not allow for the insertion of words between auxiliary verbs and past participles.

Another reason participants did not execute anticipatory eye movements in our study could be related to the type of visual display that we used. Finding the target word among the distractors was a quite difficult task. Whereas previous studies investigating predictive processing used mostly displays containing pictures (e.g. Altmann & Kamide, 1999; Arai & Keller, 2013; Dahan & Tanenhaus, 2004), we used printed words. Printed words look more similar to each other than the pictures of existing objects used in the other studies, which makes them more difficult to distinguish from one another. Furthermore, the words that we presented on the screen were spelled in a similar way (they all start with <gel>, <gl>, <ger>, or <gr>), making it even more difficult to find the target word among the distractors. The difficulty of finding the target object on the visual display may have delayed the execution of eye movements to the target. Participants might have needed more time in order to find the target or they might have been more conservative in their search behavior and waited for more information to appear before starting to look for the target.

The fact that syntactic predictability also improved the recognition of casually produced words contributes to our understanding of how listeners process conversational speech, which often contains acoustically reduced word forms. Previous studies have demonstrated that listeners have difficulty recognizing reduced word forms when these are presented in isolation. Listeners' performance on reduced words when they are embedded in context is almost as good as when recognizing unreduced word forms (Ernestus et al., 2002). This is consistent with the observation that naive listeners are hardly aware of the presence of acoustic reductions (Kemps, Ernestus, Schreuder, & Baayen, 2004) despite the fact that they are ubiquitous in everyday conversations (e.g. Ernestus, 2000; Johnson, 2004). There are several contextual cues that have been proposed to facilitate the recognition of reduced word forms. Among these are acoustic (Janse & Ernestus, 2011), semantic (van de Ven et al., 2012) and discourse-based (Brouwer et al., 2012b) information. Our results suggest that syntactic information can also be added to this list of cues: Reduced words that are syntactically more predictable are easier to recognize.

Finally, the effect of syntactic predictability also points to the significance of word order variability in Dutch subordinate clauses. Previous studies have investigated the circumstances under which speakers of Dutch prefer either the auxiliary-first or the participle-first word order (e.g. Swerts & van Wijk, 2005). Our study has demonstrated that this choice has consequences for the listener. The auxiliary-first word order leads to faster recognition of the past participle. Crucially, this advantage in recognition performance does not influence the preference for one word order over the other, as was shown in our rating study. Apparently, factors other than the listener's ease of recognition are more important when it comes to the usage of syntactic structures.

The second finding of our study is that participles were recognized more easily when they were produced carefully rather than casually. This result is consistent with previous findings reported by Brouwer et al. (2012a) who showed that massive acoustic reductions that increase the acoustic similarity among words can change the pattern of lexical competition. Our results extend Brouwer et al.'s findings by showing that lexical processing is also influenced by a relatively mild form of acoustic reduction (i.e., schwa reduction).

Our third finding is that the effect of syntactic predictability was stronger when the participle was produced in an acoustically reduced way compared to when it was produced in a careful way. This suggests that listeners make more use of syntactic information when acoustic cues are less reliable. The fact that this interaction effect emerged in the RT data and the late time window of the eye-tracking data suggests that it is due to processes that take time to act. At first, acoustic reduction and syntactic predictability influence the processing of the target participle independently from each other. Lsteners then appear to recover from acoustic reduction more quickly when the participle is more predictable. This suggests that both syntactic and phonological information are processed in parallel and are integrated not immediately but after a short processing delay. Note that this does not mean that syntactic and phonological processing are themselves delayed (as indeed the main effects in the RTs and fixation analyses show), only that their integration takes some time.

The finding that the integration of syntactic and phonological information occurs relatively late does not contradict previous research that has found an early influence of syntax on phonetic processing (e.g. van Alphen & McQueen, 2001). Syntactic information may influence language processing in different ways. Van Alphen and McQueen (2001) investigated the effects of syntactic information on phonemic decision-making. This type of process does not necessarily tap into the same kinds of representations and processes that are involved in on-line word recognition (which is what our study is focussing on). In fact, van Alphen and McQueen assume that phonemic decision making is located in a post-lexical phonemic decision module, as proposed in the Merge model (Norris, McQueen, & Cutler, 2000). Furthermore, their design involved multiple repetitions of a small number of highly similar sentence frames. In contrast, in our study, listeners were exposed to a different sentence on each trial making the experimental stimuli much more variable. As the experimental situations between van Alphen and McQueen's study and our own differ quite substantially, comparisons referring to the time course of effects are hard to make. It is thus very well possible that knowledge about syntactic structures can bias early judgments about phonological categories on the one hand and influence on-line lexical processing at later stages on the other hand. The fact that we observe the interaction effect later than the main effects suggests that phonological and syntactic information are processed on independent pathways during early stages of processing (such as lexical access). During later stages in which lexical units are integrated into larger structures such as sentences and discourse contexts, both streams are combined.

The fact that the interaction of speaking style and word order was only present in the overall analysis in which we combined the data from the three experiments suggests that it is a relatively small effect. One explanation for why the interaction effect is small is that listeners exploit syntactic cues as much as possible even if the acoustic cues are perfectly reliable. The effect of word order has therefore almost no room to increase when the speech input becomes less reliable. A second possibility is that the acoustic reductions induced by the casual speaking style were not severe enough for listeners to need to rely on the word order cue. Although our results show that the reduced speaking style did decrease recognition performance, this effect may simply not have been strong enough for the listeners to substantially change the way in which they weigh acoustic and syntactic sources of information. A third reason for the small magnitude of the interaction effect may be that listeners could not make much more use of syntactic predictability in the casual speech condition because the auxiliary verbs themselves were acoustically reduced, which made it harder for listeners to process them. While on the one hand listeners may want to rely more on syntactic information when acoustic cues are less reliable, on the other hand, accessing syntactic information may be harder because the words providing that type of information are themselves acoustically reduced.

So far, no theory of spoken word recognition has explicitly implemented a mechanism that could explain the influence of syntactic predictability on spoken word recognition. However, several theories could be extended in order to account for the present results. There are at least two possible mechanisms. First, listeners might access representations that contain information about the syntactic category that a word belongs to and use this knowledge in order to predict upcoming word classes. Depending on which word class is likely to follow (e.g. after an auxiliary verb), words that belong to this word class will be favoured whereas words that do not belong to this word class are less likely to be considered. A second mechanism is based on bigram frequencies: Instead of accessing knowledge about word class, listeners might predict upcoming words based on how often two words have occurred together in the past. Our control analyses suggest that bigram frequencies could explain part of the effect of word order that we found but not all of it. This suggests that the word order effect that we found is at least to some extent based on abstract knowledge about the relationships among syntactic categories.

Activation-based models such as TRACE (McClelland & Elman, 1986; Mirman, McClelland, & Holt, 2006) could learn about word-order based predictability by encoding the bigram frequencies among words in connection weights. After these connection weights have been established, auxiliary verbs that have become activated would send activation to associated participles and consequently boost their activation levels. More plausibly, given the current results, a connectionist model could include a layer of processing units that represent syntactic classes (such as auxiliary verbs and past participles). Activated auxiliary verb units would send activation to past participle nodes which in turn would activate word forms that belong to the past participle class. These past participles would become pre-activated, which would in turn facilitate their recognition. A different framework in which effects of syntactic predictability could be implemented is offered by Bayesian models such as Shortlist B (Norris & McQueen, 2008). In this model, the recognition of words is based on probabilities rather than levels of activation. For the calculation of the (posterior) probability with which a word is recognized, the model combines the word's prior probability with the probability of the acoustic signal given that the word was uttered. Shortlist B allows word priors to be influenced by several factors such as lexical frequency and could in principle include effects of semantic and syntactic context. According to this account, syntactic predictability could increase the posterior probability of a word by increasing the word's prior probability. Both types of model could be adapted in order to explain effects of syntactic predictability. However, neither of them specifically predicts that the integration of syntactic and phonological information occurs relatively late. Both types of models would need to address this result.

In conclusion, the results of the present study provide further evidence for the hypothesis that syntactic information facilitates the recognition of words in sentential contexts. Syntactic information becomes even more useful when acoustic cues are less reliable as when listening to casual speech, suggesting that syntactic context provides useful cues that can help listeners to cope with speech reductions in conversational speech. This supports the notion that listeners dynamically adapt to the different sources of linguistic information that are available to them.

Acknowledgements

We would like to thank Corine Baayen and Martijn Bentum for help with the construction and recording of the stimuli, Jens Frielink for help with the acoustic analyses, and Ilse Pit for help with data collection. This study was partly funded by an IMPRS fellowship to the first author and an ERC starting grant (284108) to the second author. We would like to thank Philip Monahan and two anonymous reviewers for valuable feedback.

Appendix

Quadruplets (words that were presented together on the screen) used in all three experiments.

Quadruplet	Participle	Non-participle	Participle	Non-participle
1	geroosterd *(roasted)*	grootschalig *(large-scale)*	geroerd *(stirred)*	groette *(greeted)*
2	gerold *(rolled)*	gromde *(growled)*	geroepen *(called)*	groene *(green)*
3	geraspt *(grated)*	grappig *(funny)*	gericht *(aimed)*	grind *(gravel)*
4	gerot *(rotted)*	grotten *(caves)*	geroest *(rusted)*	groeven *(grooves)*
5	gered *(saved)*	grendeltje *(lock)*	geregeld *(organized)*	grenen *(pine)*
6	gelopen *(run)*	glooiend *(declining)*	geluwd *(abated)*	glurende *(peeking)*
7	geraadpleegd *(consulted)*	gracieus *(gracefully)*	gereikt *(reached)*	grijpkranen *(cranes)*
8	gelapt *(patched)*	glanzend *(glossy)*	gelikt *(licked)*	glitters *(glitter)*
9	geloofd *(believed)*	glorie *(glory)*	gelaveerd *(maneuvered)*	glazuur *(gloss/icing)*
10	gerangeerd *(shunted)*	graffiti *(graffiti)*	geriskeerd *(risked)*	griffierschap *(clerkship)*
11	gereisd *(traveled)*	grijpgrage *(grabby)*	geruimd *(cleared)*	gruiskolen *(coal dust)*
12	gelaagd *(layered)*	glazig *(glassy)*	gelijmd *(glued)*	glijbanen *(slides)*
13	geranseld *(whipped)*	grassprieten *(blades of grass)*	gerinkeld *(jingled)*	grimmig *(grim)*
14	geluisterd *(listened)*	gluiperds *(weaselly)*	gelicht *(shined)*	glibberig *(slippery)*
15	geleid *(led)*	glijdend *(sliding)*	gelogen *(lied)*	globes *(globes)*
16	geremd *(inhibited)*	greppels *(ditches)*	gerammeld *(rattled)*	grabbeltonnen *(grab bags)*
17	gelost *(unloaded)*	glommen *(shine)*	geloeid *(mooed)*	gloeiende *(glowing)*

18	gerezen *(raised)*	gretig *(eagerly)*	gerafeld *(frayed)*	grafisch *(graphic)*
19	geraapt *(picked)*	graaide *(snatched)*	geringd *(ringed)*	grilde *(grilled)*
20	geleund *(leaned)*	gleuven *(grooves)*	gelift *(hitchhiked)*	glimlachte *(smiled)*
21	gerimpeld *(wrinkled)*	grinnikend *(chuckling)*	geramd *(rammed)*	grandioos *(magnificently)*
22	gerond *(circumnavigated)*	grofweg *(roughly)*	geroemd *(praised)*	groepen *(groups)*
23	gerouwd *(mourned)*	grauwe *(gray)*	gerommeld *(rummaged)*	grondig *(thoroughly)*
24	gerept *(rushed)*	grenzen *(limits)*	geraakt *(hit)*	gratis *(cost-free)*
25	gerangschikt *(arranged)*	grammen *(grams)*	geritseld *(managed)*	grillige *(bizarre)*
26	gelucht *(aired)*	glunderen *(smile)*	gelaten *(let)*	glaasjes *(glasses)*
27	gerild *(trembled)*	griffels *(pencils)*	geraamd *(estimated)*	graag *(gladly)*
28	geraasd *(raged)*	graanvelden *(cornfields)*	gereinigd *(cleaned)*	grijnzend *(smiling)*
29	gelogeerd *(stayed/lodged)*	globale *(global)*	geloerd *(lurked)*	gloednieuwe *(brand new)*
30	gerekend *(counted)*	grepen *(holds)*	geraden *(guessed)*	graatmager *(skinny)*
31	geragd *(stuck out)*	grafurnen *(urns)*	gerijpt *(matured)*	grijs *(gray)*
32	geronseld *(recruited)*	grove *(coarse)*	geroeid *(rowed)*	groeiende *(growing)*

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Table 1. Example stimuli for the two word order conditions in Experiments 1 to 3.

Experiment	Example stimulus	Condition
1 & 3	Ik weet zeker dat hij heeft geleund op de houten tafel. (*I know for sure that he has leaned against the wooden table.*)	Auxiliary-first
	Ik weet zeker dat hij geleund heeft op de houten tafel. (*I know for sure that he leaned has against the wooden table.*)	Participle-first
	Ik weet zeker dat hij gleuven maakte in de houten tafel. (*I know for sure that he made grooves into the wooden table.*)	Filler
2	Ik weet zeker dat hij heeft geleund (*I know for sure that he has leaned*)	Auxiliary-first
	Ik weet zeker dat hij geleund heeft (*I know for sure that he leaned has*)	Participle-first
	Ik weet zeker dat hij gleuven (*I know for sure that he grooves*)	Filler

Table 2. Acoustic properties of the stimuli used in the three experiments.

	Auxiliary-first		Participle-first		Filler items	
	Careful	Casual	Careful	Casual	Careful	Casual
Sentence duration	2,678	2,365	2,642	2,350	2,661	2,435
Target duration	429	325	425	338	381	343
Auxiliary duration	170	148	141	127	n/a	n/a
Schwa presence	100	15.62	98.44	18.75	n/a	n/a
Schwa duration	50	14	44	13	n/a	n/a
/x/ duration	81	77	97	90	86	86
Speaking rate	6.59	7.45	6.68	7.54	6.88	7.69
Divergence point	187	190	195	201	101	97

Note. Durations and divergence points are given in milliseconds. For the calculation of the average schwa durations, only participles with a schwa duration larger than zero were included. Schwa presence is expressed as a percentage and speaking rate is expressed as number of syllables per second.

Table 3. Accuracy and reaction times for Experiments 1, 2, and 3.

Experiment		Accuracy		Reaction times	
		Auxiliary-first	Participle-first	Auxiliary-first	Participle-first
1	Careful	99.87	99.74	1,331	1,403
	Casual	98.82	99.61	1,364	1,466
2	Careful	99.35	99.48	1,252	1,343
	Casual	98.48	98.96	1,290	1,391
3	Careful	94.27 (0.39, 5.34)	91.41 (1.3, 7.29)	1,122	1,179
	Casual	87.11 (1.95, 10.94)	84.24 (1.95, 13.8)	1,106	1,200

Note. Accuracy values are given in percentages and reaction times in milliseconds. For Experiment 3, the values in parentheses indicate the percentages of incorrectly selected words (first value) and the percentage of trials on which participants did not respond within the time limit.

Table 4. Linear-mixed effects model for competitor fixations in Window 3 of Experiment 1.

Fixed effects	β	t	p
Intercept	-1.30	-13.43	
Word order (participle-first)	-0.12	-1.02	> 0.1
Speaking style (casual)	-0.12	-0.99	> 0.1
Word order * speaking style	0.45	2.64	< 0.01
Random effects		SD	
Participant	Intercept	0.27	
Word	Intercept	0.45	
	Word order (participle-first)	0.60	
	Speaking style (casual)	0.58	
	Word order * speaking style	0.88	

Table 5. Linear-mixed effects model for competitor fixations in Window 1 of Experiment 2.

Fixed effects	β	t	p
Intercept	-1.01	-11.25	
Word order (participle-first)	-0.11	-0.98	> 0.1
Speaking style (casual)	-0.16	-1.39	> 0.1
Word order * speaking style	0.34	2.15	< 0.05
Random effects		SD	
Participant	Intercept	0.15	
Word	Intercept	0.25	

Table 6. Linear-mixed effects model for competitor fixations in Window 2 of Experiment 3.

Fixed effects	β	t	p
Intercept	-0.84	-12.73	
Word order (participle-first)	0.32	3.85	< 0.001
Speaking style (casual)	0.22	2.61	< 0.01
Word order * speaking style	-0.26	-2.27	< 0.05
Random effects		SD	
Word	Intercept	0.22	

Table 7. Linear-mixed effects model for reaction times in the combined analysis of Experiments 1, 2, and 3.

Fixed effects	β	t	p
Intercept	6.89	159.77	
Word order (participle-first)	0.06	7.11	<0.001
Speaking style (casual)	0.03	2.29	<0.05
Experiment 1 vs. 3	0.16	7.67	<0.001
Experiment 2 vs. 3	0.11	5.36	<0.001
Experiment 2 vs. 1	-0.05	-2.32	<0.05
Target duration	0.0003	2.77	<0.01
Word order * speaking style	0.02	2.14	<0.05
Random effects		SD	
Participant	Intercept	0.10	
Word	Intercept	0.06	
	Word order (participle-first)	0.02	
	Speaking style (casual)	0.04	
	Word order * speaking style	0.02	

Table 8. Linear-mixed effects model for target fixations in Window 4 of the combined analysis of Experiments 1, 2, and 3.

Fixed effects	β	t	p
Intercept	1.72	14.02	
Word order (participle-first)	0.08	0.80	> 0.1
Speaking style (casual)	0.06	0.39	> 0.1
Experiment 1 vs. 3	-0.37	-2.38	< 0.05
Experiment 2 vs. 3	-0.20	-1.27	> 0.1
Experiment 2 vs. 1	0.17	1.15	> 0.1
Word order * speaking style	-0.27	-2.01	< 0.05
Experiment 1 vs. 3 * speaking style	-0.14	-0.80	> 0.1
Experiment 2 vs. 3 * speaking style	-0.42	-2.38	< 0.05
Experiment 2 vs. 1 * speaking style	-0.28	-1.70	> 0.05
Random effects		SD	
Participant	Intercept	0.62	
	Word order (participle-first)	0.64	
	Speaking style (casual)	0.75	
	Word order * speaking style	0.84	
Word	Intercept	0.38	
	Word order (participle-first)	0.49	
	Speaking style (casual)	0.36	
	Experiment 1 vs. 3	0.48	
	Experiment 2 vs. 3	0.55	
	Experiment 2 vs. 1	0.30	
	Word order * speaking style	0.56	

Note. During the model fitting procedure it was not possible to include both random slopes for both interaction terms without R returning an error message. We chose to report the model with random slopes for the interaction between word order and speaking style because our primary interest is in this interaction rather than the interaction between experiment and speaking style. Furthermore, the AIC value for the model with random slopes for the interaction between speaking style and word order is lower than for the other model (33,522 vs. 33,602) indicating a better model fit.

Table 9. Correlations between the main dependent measures and the control variables.

	Sentence remainder	Ratings	Bigram frequency	Word order	Speaking style
Accuracy	-0.04	-0.03	0.18	-0.10	-0.29
RTs	0.24	0.10	-0.29	0.38	0.13
Target gaze probability in window 1	-0.11	-0.07	0.08	-0.12	0.11
Target gaze probability in window 2	-0.18	0.01	0.19	-0.30	-0.01
Target gaze probability in window 3	-0.17	0.02	0.17	-0.28	-0.12
Target gaze probability in window 4	-0.05	0.03	0.11	-0.06	-0.19

Note. Bigram frequencies are based on the Dutch internet search engine IxQuick. Higher ratings reflect a preference for the participle-first word order. Word order is coded as follows: auxiliary-first = 0, participle-first = 1. Speaking style is coded with careful = 0 and casual = 1.

Table 10. Control model for target fixations in Window 4 of the combined analysis of Experiments 1, 2, and 3.

Fixed effects	β	t	p
Intercept	-1.02	-8.46	
Word order (participle-first)	0.12	1.14	> 0.1
Speaking style (casual)	0.08	0.50	> 0.1
E1 vs. E3	-0.38	-2.58	< 0.01
E2 vs. E3	-0.22	-1.51	> 0.1
E2 vs. E1	0.15	1.08	> 0.1
Word order * speaking style	-0.28	-2.12	< 0.05
E1 vs. E3 * speaking style	-0.17	-0.97	> 0.1
E2 vs. E3 * speaking style	-0.43	-2.41	< 0.05
E2 vs. E1 * speaking style	-0.26	-1.53	> 0.1
Random effects		SD	
Participant	Intercept	0.64	
	Word order (participle-first)	0.64	
	Speaking style (casual)	0.77	
	Word order * speaking style	0.86	
Word	Intercept	0.33	
	Word order (participle-first)	0.47	
	Speaking style (casual)	0.37	
	Word order * speaking style	0.53	

Figure captions

Figure 1. Example of a visual display containing one of the quadruplets of words presented to participants in Experiments 1, 2, and 3. In this example, the target word is the past participle “geleund” (“leaned”) and the competitor is the noun “gleuven” (“grooves”). The two other words (“gelift” meaning “lifted” and “glimlachte” meaning “smiled”) serve as distractors and occur as targets and competitors during other trials. (Note that the picture is not drawn to scale.)

Figure 2. Gaze probability over time for target words (i.e. past participles) and competitors in Experiments 1, 2, and 3. Time 0 is aligned to the onset of the target word. An example for a target word is “geleund” (“leaned”) and an example for a competitor is “gleuven” (“grooves”). W1 = analysis window 1, W2 = analysis window 2, W3 = analysis window 3, and W4 = analysis window 4.

Figure 3. Gaze probability over time for target words (i.e. past participles) and competitors collapsed across Experiments 1, 2, and 3. Time 0 is aligned to the onset of the target word. An example for a target word is “geleund” (“leaned”) and an example for a competitor is “gleuven” (“grooves”). W1 = analysis window 1, W2 = analysis window 2, W3 = analysis window 3, and W4 = analysis window 4.

Figure 1

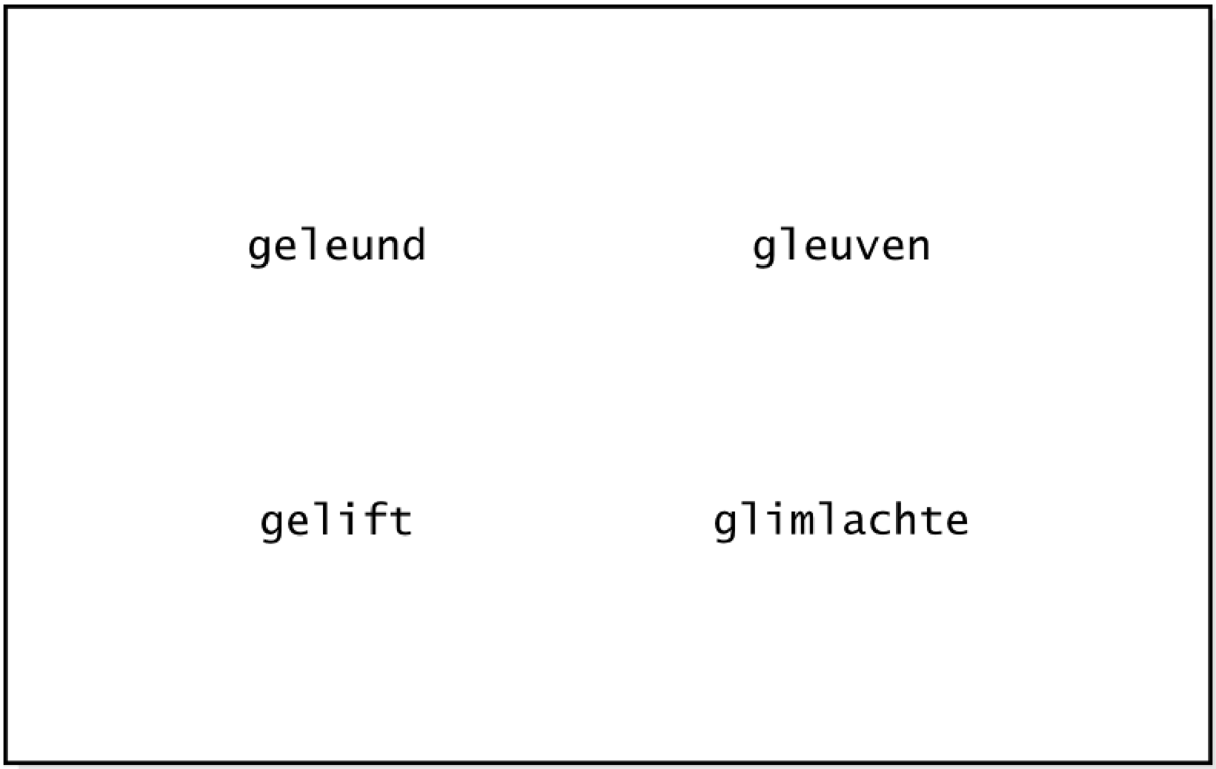


Figure 2

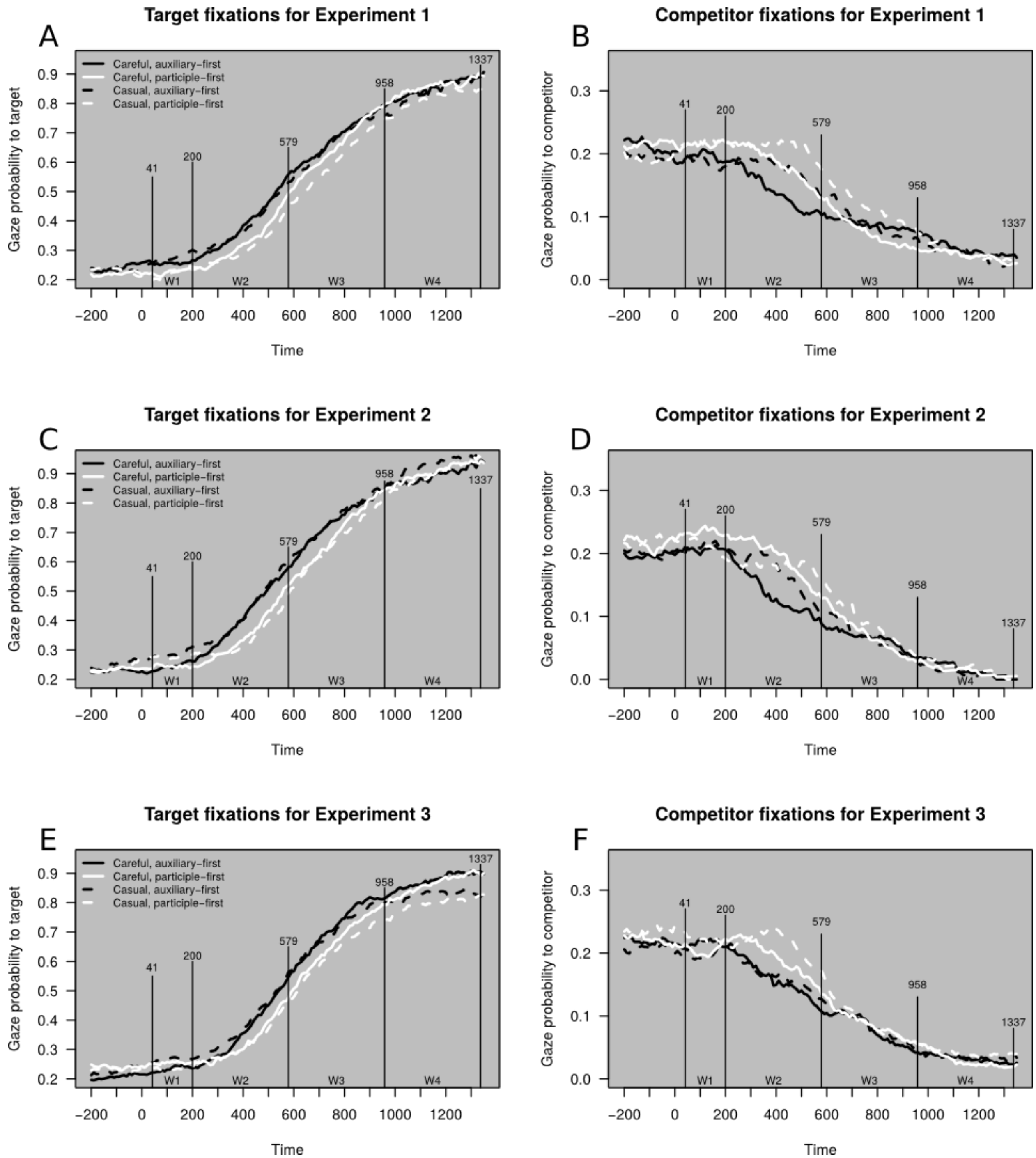
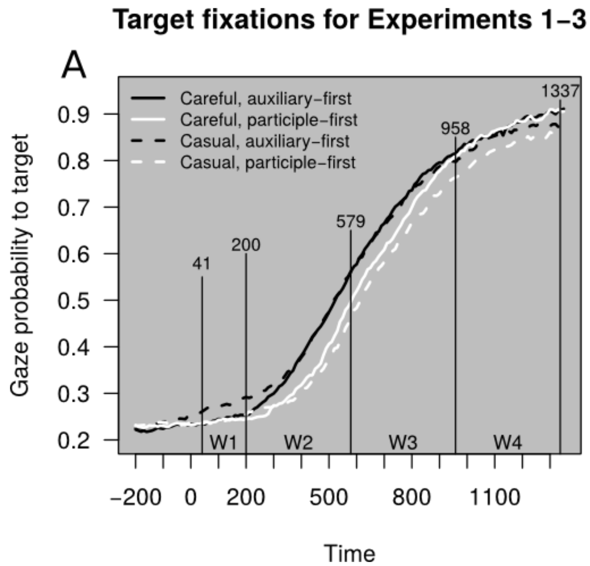
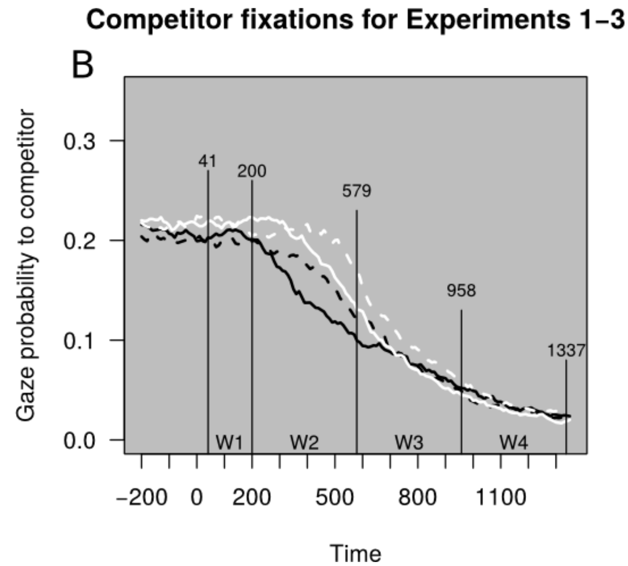

Target fixations for Experiment 1
A
Careful, auxiliary−first
Careful, participle−first
Casual, auxiliary−first
Casual, participle−first
Gaze probability to target
Time
Competitor fixations for Experiment 1
B
Gaze probability to competitor
Time
Target fixations for Experiment 2
C
Competitor fixations for Experiment 2
D
Target fixations for Experiment 3
E
Competitor fixations for Experiment 3
F
W1
W2
W3
W4
41
200
579
958
1337

Figure 3


Target fixations for Experiments 1–3
A
Careful, auxiliary–first
Careful, participle–first
Casual, auxiliary–first
Casual, participle–first
Gaze probability to target
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
41
200
579
958
1337
W1
W2
W3
W4
–200
0
200
500
800
1100
Time


Competitor fixations for Experiments 1–3
B
Gaze probability to competitor
0.3
0.2
0.1
0.0
41
200
579
958
1337
W1
W2
W3
W4
–200
0
200
500
800
1100
Time