

Automatic learning of morphology-based associations in Dutch*

Hernán Labbé Grünberg
ACLC, University of Amsterdam

Judith Rispens
ACLC, University of Amsterdam

The aim of this research was to evaluate whether Dutch native speakers process information at the morphological level in an automatic and unconscious way. Participants were presented with stimuli within a masked priming paradigm followed by a lexical decision task. The answer on the lexical decision task could be predicted by the preceding stimulus (presence or absence of past tense morphology). Crucially, only morphological, but not semantic or orthographic information was needed in order to learn the association. Results showed that subjects were indeed able to learn the association between morphological information and the appropriate response. Furthermore, the short presentation time of the stimuli and the masked presentation indicated that the processing of morphological information must have occurred early in word processing, and probably in an automatic and unconscious fashion.

1 Introduction

When we are confronted with a word, the processes by which its meaning is accessed are largely beyond awareness. The study of word processing has revealed that phonological, orthographic, morphological, and semantic aspects of words are activated before the first second after presentation. In the case of morphology, there is no consensus on the specifics of morphological processing during these early stages of word / sentence processing. Some authors claim that morphologically complex words are analyzed just like any other word (Seidenberg & McClelland 1989; Bybee 1995), while others propose specific

* The first author would like to acknowledge Amsterdam Brain and Cognition (ABC) for their support while he was doing his internships at the Brain and Cognitive Science masters. Also, he wants to thank Sible Andringa for his valuable input during the research. He would also like to thank the ACLC, and specially its administrative staff, whose help proved invaluable for conducting this experiment.

mechanisms that handle morphological information, separate from semantic and phonological or orthographic analysis (Pinker 1991; Baayen et al. 1997; Pinker & Ullman 2002). During the last decades, many studies have been carried out investigating morphologically complex words to understand whether and under what conditions these words are decomposed into the separate morphemes upon recognition. The current study also investigates decomposition of morphologically complex words (regular verbs inflected for the past tense) and specifically targeted whether participants recognize the past tense suffix automatically and unconsciously in a masked priming implicit learning paradigm. Our paper is organized as follows. We will first discuss literature on morphological decomposition and masked priming (Section 2) and briefly introduce the paradigm of implicit sequence learning (Section 3). We will then introduce our experimental learning paradigm in which we elicited responses based on the recognition of past tense suffixes within regular verbs. These verbs were presented under masked conditions which enabled us to study whether morphological information was analyzed automatically and unconsciously in native speakers of Dutch. Sections 4 to 7 will discuss the design of this study, the methodology, the data analysis, and results, respectively. The paper finishes with a discussion of how the results contribute to the existing literature on morphological processing.

2 Processing of morphologically complex words

The role of morphological information in word processing has been confirmed in many studies (see Domínguez, Cuetos & Segui (2000) and Rastle & Davis (2008) for reviews). The regularity of morphological forms in words provides a reliable source of information about the word in systematic and predictable ways (Lavric, Clapp & Rastle 2007). In Dutch, the language of the present study, for example, verbs with the suffixes *-te* or *-de* are past tenses. There is a substantial body of literature that has examined whether complex words are stored as lexical units or assembled online via decomposition of its constituent elements (stem + suffix).

A well-known model that assumes that processing of morphology occurs via decomposition is the so-called word and rules model of Pinker (1991). This model is based primarily on evidence from word generation experiments (Prasada & Pinker 1993; Pinker & Prince 1994) and recognition/priming experiments (Rastle et al. 2000), where it was found that processing of regularly inflected words or highly frequent morphologically complex words involved decomposition into its constituent morphemes. The neuropsychological extension of Pinker's model by Ullman (2001, 2004) showed a morpho-functional dissociation between storage and decomposition in the brain (Ullman

et al. 1997, 2005) that distinguished between a declarative or explicit system which handles whole-word storage, and a procedural or implicit system that is responsible for the fast, automatic decompositions of regular morphology. Despite how influential Pinker's model, and Ullman's extension, have become in the theoretical background of word processing studies, the set of conditions that would predict decomposition has not been fully replicated in English (Stockall & Marantz 2006; Feldman et al. 2010 and Morris & Stockall 2012), nor in other languages with different morphological systems (Portin et al. 2007; Gor & Cook 2010). These studies have found just as much evidence for decomposition in irregulars as in regulars, and no differences in processing between native and non-native speakers, thus invalidating the premises under which the Words and Rules model and its neuropsychological extension are based.

Studies carried out in the Dutch language have also offered mixed evidence for decomposition. Baayen et al. (1997, 2003) studied the Dutch plural, which is a highly transparent and reliable inflection, and therefore a promising candidate for automatic decomposition. Nominal stems in Dutch can take either *-s* or *-en* to become plural, with each suffix acting regularly in its own phonological domain. They found strong frequency effects for the *-en* allomorphic variation, suggesting whole-word representations, and a weaker effect for the *-s* allomorph. The authors interpret these findings as evidence of decomposition acting parallel to full-word representations. The authors conclude that the polyfunctionality of the *-en* suffix (which is also an agreement marker in Dutch) explains that it is not automatically decomposed. Indeed, results with the comparative/agentive suffix *-er* in Dutch also show the same pattern of results (Bertram, Baayen & Schreuder 2000). Moreover, in the same study, evidence showed frequency effects for regular past tense verbs, which should, according to most theories, be decomposed into its constituent elements.

These results for the Dutch past tense show that when these complex verbs are processed, the activated representation is sensitive to the frequency of occurrence of the whole word, not of its stem. The authors take this as evidence against decomposition in past tense processing of Dutch verbs. Indeed, many morphologically complex words for which decomposition is predicted because of their structural transparency (such as the past participle) have been found – via surface frequency effects – to be stored as full-form representations in Dutch (De Jong, Schreuder & Baayen 2000; Baayen et al. 2003; Bertram, Baayen & Schreuder 2000), with some marginal effects of frequency counts based on the stem, suggesting that the stems of these words also play a role. The criteria for when words are decomposed vary depending on the authors and the experiment. These include the contextual versus inherent inflection (Booij 2002; Baayen et al. 2003), polyfunctionality of the suffixes (Bertram, Baayen & Schreuder

2000), and inhibitory effects between different types of frequency counts (Baayen et al. 2000). Particularly for Dutch then, there seems to be mixed evidence. Lexical storage appears as the default mechanism for complex words, but marginal effects for (automatic) decomposition are also persistently found. It is worth noting that the studies in Dutch have made repeated use of unprimed lexical decision tasks, much unlike the majority of studies in English and other languages, which make use of the masked priming paradigm. Indeed, this paradigm has been the norm to find effects of early, automatic processing of not only morphology, but also semantics and phonology.

The masked prime paradigm has been used to investigate unconscious aspects of word processing, and is often used in the context of lexical decision or categorization tasks (Van den Bussche, Van den Noortgate & Reynvoet 2009), where participants must categorize the word on the basis of the previous processing of a masked prime word. Masking a word means making its processing occur outside the person's awareness. To this end, the word is presented for a short period of time and is preceded and/or followed by a mask that is meant to interrupt the visual processing of the unconsciously perceived word. Specifically, the masked processing of the prime word is expected to have an impact on the lexical retrieval of the target word presented afterwards, due to activation through a relationship between the prime and the target. Relationships can be for example semantic (*doctor – nurse*), phonological (*candle-candy*), and also morphological (*work-worker*) in nature.

Masked primes, specifically instances where the masked primes are presented very briefly (e.g. 40 ms) are unavailable for conscious report. Thus, the influence of the prime on the response to the target must be ascribed to very early processes. The finding that masked primes that are morphologically related to their targets can influence responses to these targets is evidence that morphological processing occurs very early. The consistency of morphological priming effects stands in contrast with the less reliable and later effect of semantic priming. The robustness of morphological effects in masked priming experiments suggests automatic, unconscious morphological processing occurs earlier (and possibly independent of) semantic processing. Masked priming differs from unmasked priming in the sense that semantic priming effects are smaller and unreliable compared to unmasked priming (Lavric, Clapp, & Rastle 2007; Rastle et al. 2000). The masked prime paradigm thus seems to tap into a stage preceding semantic activation. An important difficulty that studies face that investigate processing of morphological information is its overlap with other, almost simultaneous processes involved in word recognition. These include visual, phonological, semantic and pragmatic aspects, all of which occur close together in time.

Evidence for a distinct role of morphology that is separated from orthography comes from Diependaele et al. (2011). They found native speakers of English to be faster in the recognition of stems primed by their semantically transparent morphological derivations (*worker* priming *work*), compared to recognition of stems primed by opaque derivations (*corner* priming *corn*), where the word ends with the same orthography as a suffixed word, but is in reality a self-standing word with no morphological complexity. This means the presence of an orthographic string with no grammatical function has a different effect than the one caused by the presence of the same form acting as a suffix. Moreover, recognition was the lowest when targets were primed by form controls with endings that are not suffixes in English (e.g. *-el* in *brothel-broth*). This graded priming shows that orthography alone cannot explain priming effects (otherwise the *brothel-broth* condition would have shown a similar priming effect).

Evidence for early, automatic decomposition of complex words, and the importance of using adequate tasks to tap into it, was found by Clahsen & Neubauer (2010). They investigated the highly reliable and transparent German nominalization suffix *-ung* (e.g. *gründ-en* – *Gründ-ung* ‘to found – foundation’) under unprimed and primed conditions in native German speakers. In an unprimed visual lexical decision task, they found that the surface frequency of the derived *-ung* word marginally predicted the speed of recognition of that word for native speakers. Surface frequency effects are interpreted as evidence for the use of whole-word mental representations during lexical access. A marginal effect, therefore, leaves the question open as to whether the morphologically complex word is being decomposed or is activating the lexical representation corresponding to the whole form. However, in a second experiment using the same stimuli but with masked priming (*-ung* nouns priming their infinitive form), native speakers showed similar priming effects between identity priming (a word priming itself) and the derived *-ung* word priming the infinite target. This suggests that the derived word was being decomposed and, as a result, the activation of the stem through decomposition facilitated the recognition of the target word. The fact that evidence for decomposition in morphological processing was found only using masked priming, and was absent in unprimed recognition, shows that the mechanisms involved in automatic morphological processing act early and outside awareness, since masked words are presented subliminally and for very short periods of time. It also shows that masked priming experiments reveal different aspect of morphological processing than unprimed experiments.

From the evidence reviewed, we can conclude that models of morphological processing must be validated across different languages, and even across specific suffixes. Furthermore, the Dutch past tense has been

investigated with methodologies that are not best suited to tap into early, automatic processes. In the current study, early, automatic, and unconscious processing of the regular past tense morphology was studied with a paradigm that is expected to tap early automatic stages of the Dutch past tense. Specifically, this research makes use of an experimental paradigm from outside linguistics (the serial reaction time task) in order to engage implicit learning mechanisms whose existence has been replicated in numerous studies, albeit outside the linguistic domain.

3 Implicit learning

In this study, implicit learning is the means to an end. The purpose is to engage implicit learning mechanisms whose existence has been shown in several studies outside the domain of language, in the context of automatically and unconsciously presented morphological information. In other words, we know implicit learning exists, and we wanted to use it to test whether Dutch native speakers are able to learn an implicit regularity that requires automatic, unconscious processing of past tense suffixes. Procedural learning refers to the ability of perceptual systems to achieve a faster and more accurate processing of incoming stimuli, as long as the stimuli follow systematic patterns. In sequence learning experiments, participants are instructed to respond with motor responses (button press) to the location of stimuli that appear in the screen. Unbeknownst to the participants, there is a regularity in the apparent random position of the stimuli, which results in faster responses to the stimuli that are part of the pattern, compared to stimuli that are truly random. That this learning occurs procedurally means it happens automatically and outside awareness. Shanks & Perruchet (2002) demonstrated that behavioural effects of implicit learning (like faster response times) can be dissociated from the recognition of the learning process itself. That is, participants can learn something and show the results of that learning on their performance, without being aware they learned something. Perruchet, Cleeremans and Destrebecqz (2006) showed that for any two events E1 and E2, where E2 follows E1 systematically, reaction times to the second event will be faster when the link between the two events is not consciously perceived, thus suggesting that this learning mechanism indeed works best under automatic, pre-attentional processing. Indeed, unconscious processing has been shown to positively affect learning in several implicit sequence learning studies (for a review, see Cleeremans, Destrebecqz & Boyer 1998; Destrebecqz & Cleeremans 2001).

A common criticism of early implicit learning evidence was that rather than learning abstract sequences implicitly, subjects were simply mapping visual stimuli to motor responses (usually a button press). However, Howard, Mutter

and Howard (1992) showed that participants can implicitly learn sequences just by visual exposure, meaning that there is more than one medium by which the associations can be learned, and that the nature of the implicit learning is abstract rather than concrete mappings between sensory and motor systems. These results point to fast, unconscious, and abstract learning, but there is a debate on what is exactly learned in these experiments. Important for the present research is whether there can be implicit learning of linguistic information. Hartman, Knopman & Nissen (1989) showed implicit learning of a set of new associations in the verbal domain, where subjects learned implicit associations of whole-word sequences instead of the more common stimulus location-motor response design. Most investigations have looked at learning sequences of consciously perceived stimuli, and the implicit learning that occurs from being exposed to them. So far, there has been no research investigating the implicit learning of unconsciously perceived morphological information. The current experiment investigates implicit learning which involves morphological processing to fill this gap.

4 The present study

This experiment investigates whether native speakers of Dutch are able to process masked words in such a way that the morphological structure of the masked word is used to implicitly learn to predict upcoming target words. Our paradigm is not a priming experiment, since that design assumes that the prime influences processing of the target. In this experiment, “primes” are really predictor words that are masked and shown for a very short period of time. The masked presentation of a word is followed by the presentation of another word that is part of a lexical decision task. The masked words are called predictor words, as they predict the answer of the lexical decision task. For example, in the first half of the experiment, if the masked word contains a past tense suffix, then the presented word of the lexical decision task will be a Dutch word and not a pseudo word. If participants’ implicit learning mechanisms are able to detect the systematicity with which certain suffixes precede certain targets, then we expect implicit learning – manifested through faster response times – to occur.

This experiment, therefore, aims at answering the following questions: Is morphological information, the Dutch past tense specifically, processed automatically at very early (40 ms) stages of word processing? If so, can the knowledge derived from this processing be used to speed responses in a lexical decision task? Confirming these questions would support the idea that morphologically complex words, both allomorphs of the Dutch past tense in this case, are decomposed very early, with its morphological content being analyzed

separately from the stem. This would be in contrast to the evidence gathered by Bertram et al. (2000), where it was concluded that past tense verbs are stored as complete words and not decomposed into stem and suffix. Evidence of an ability to use morphological information to increase performance in an unrelated task would also shed light on the boundaries between linguistic and non-linguistic cognitive processes, showing in this case that the mechanisms responsible for general implicit learning can interact with representations obtained from linguistic processing.

5 Method

5.1 The experiment

In order to study unconscious processing of past tense suffixes, and at the same time safely exclude overlap with any semantic or orthographic processing, a new experimental protocol was designed for this research that was briefly outlined in section 4. Participants were administered a lexical decision task, in which they had to decide whether the target word belonged to the Dutch language. The structure of a masked priming experiment was used. This means each trial consists of the standard stimuli presentation seen in most masked priming studies (see Figure 1).

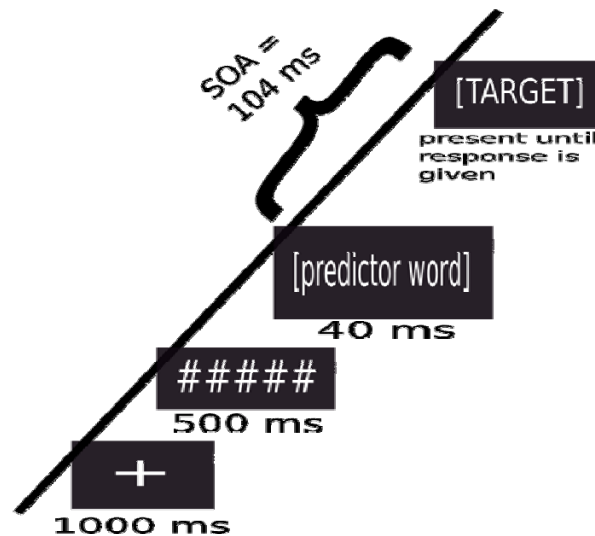


Figure 1: The time course and stimuli present on any given trial. A fixation mark starts the trial, followed by the forward mask, which contains as many hash symbols as letters in the predictor word. Predictors are always presented in small case, and targets are always presented in upper case letters.

The key difference of this design compared to most masked priming experiments is that the masked word did not have any linguistic resemblance, at any level, with the corresponding target word, and therefore it did not prime the target in any way. Instead, this experiment established a systematic but arbitrary relation between predictor and target word: Half of the targets were real Dutch words, and half were phonotactically legal pseudowords. While half of the targets were preceded by a varied mix of inflected words and pseudowords, the other half of the targets were systematically preceded by inflected regular past verbs (stem + past tense allomorph *-de* or *-te*). Thus, the only reliable and systematic cue to predict the response to the target was the information provided by the processing of the regular past tense inflection. Specifically, during the first two experimental blocks, all target words that were real Dutch words were preceded by masked regular past tense verbs. Then, in the last two blocks of the experiment, the same masked past tense predictor words systematically precede non-words, thus inducing a switch in the regularity (see Table 1). The purpose of this switch is to disrupt the learning process, in order to see if the decrease in response times (characteristic of implicit learning) was due to learning or simply to a practice effect.

Table 1: Experimental design of the modified Lexical Decision Task . Transparent trials always have a real past tense (e.g. *wenste*, *kuste*) as a predictor word for either real words (e.g. *rimpel*) in blocks 2 and 3 or pseudowords (e.g. *rokek*) in blocks 4 and 5. Opaque trials have various word classes (except verbs) with *-te* and *-de* endings (e.g. *geuite*, *blote*) preceding pseudowords (e.g. *geralf*) in blocks 2 and 3 or words (e.g. *senaat*) in blocks 4 and 5.

Block 1	Training block
Block 2 and 3	Past Verb (<i>wenste</i>) — Word (<i>rimpel</i>)
	Opaque predictor (<i>geuite</i>) – Pseudoword (<i>geralf</i>)
Block 4 and 5	Past Verb (<i>kuste</i>) — Pseudoword (<i>rokek</i>)
	Opaque predictor (<i>blote</i>) — Word (<i>senaat</i>)

These masked words provided the participant systematic morphological information and on that basis an implicit association between that particular inflection and the response to the lexical decision task. Therefore, these masked words are referred to as transparent predictor words. The other half of the masked words in the first two experimental blocks had the same orthographic ending as the transparent predictor words, but, crucially, they lacked a transparent morphological regularity and therefore did not allow to predict the upcoming target stimuli. Opposite to the transparent predictors, these words were a mix of nouns, adjectives, and pseudowords that ended with the same orthography as the past tense (i.e. *-de* or *-te*) but that presented no systematic morphological regularity that allowed participants to associate these masked words with a specific response. Therefore, for these predictor words, there was no systematic inflectional paradigm that linked them to a target response, as in the case of their transparent counterparts. There was, however, the difficulty of finding words with the same orthographical ending as the transparent predictors, while at the same time making sure there was no semantic, or any other linguistic relation between them that could have had an unwanted effect on the response to the targets. Given that learning an association between target response and the set of grammatical class of these words was still technically possible (only more difficult), these masked word were thus referred to as opaque predictor word, indicating that the regularity that could be learned with these opaque predictors was harder to grasp than the transparent regularity.

5.2 *Participants*

Fifteen native Dutch speaking participants (9 women, 6 men. Mean age = 29) volunteered in this experiment. They were all right-handed and had normal or corrected to normal vision.

5.3 Materials

The stimuli used were taken from the CELEX database of Dutch word forms (Baayen, Piepenbrock & Gulikers 1995). Since it is important for this particular design that there is no facilitation effect between the stimulus acting as predictor word and the one acting as target, the words were selected based on two main criteria. First, there was no semantic, orthographic, or grammatical relation that could cause facilitation or inhibition between the words. Second, the mean logarithmic frequency of words did not differ significantly between words of a list, and between lists of stimuli. Therefore, frequency was also controlled, as the effect of this variable on response times in lexical decision tasks has been extensively documented (for a review, see Yap, Balota, Sibley & Ratcliff 2012). All stimuli occurred only once in the experiment for each participant.

Mean character length for transparent predictor words was 7.24. For opaque predictor words, mean character length was 7.66. For target words, mean character length was 5.97, and 6 for pseudowords. To control that word frequency did not differ significantly within lists of stimuli (targets, opaque and transparent predictors), all words whose frequency deviated more than 3 z-scores from the mean logarithmic frequency were discarded. The same mechanism was used to make sure length of words did not differ significantly: Words with a length that deviated more than 3 z-scores from the mean character length of the list were discarded.

For between-list comparisons, paired t tests were used to control for frequency of the stimuli (see Table 2). In order to correct for multiple comparisons, a 99% confidence interval was used.

Table 2: Mean Logarithmic Frequency for all lists of words used as stimuli.

Stimuli	Mean Logarithmic Frequency
Target Words	0.602
Transparent Predictor Words	0.678
Opaque Predictor Words	1.514

Word frequency between lists of stimuli was controlled as much as possible. Still, given the stringent orthographic control of predictor words, the differences between frequencies did reach significance (all comparisons gave p values of .016 or lower). Ideally, the frequency difference would have been smaller, but for this research to include an orthographic control in the opaque predictor words, items with higher or lower frequencies than expected had to be chosen

from the original CELEX lists. This partly explains why a non-significant difference could not be achieved for between lists comparisons. Still, their respective means was made to be as small as possible with the available stimuli. Moreover, the additional experimental control given by the orthographic ending of the opaque words are expected to provide a robust experimental design to test the hypothesis of this research. Also, the fact that opaque words have an overall higher frequency should, if any, have a facilitation effect on responses, as words with higher frequency are supposed to be recognized faster in lexical decision experiments. Since in these experiments, opaque words are expected to produce slower reaction times, the higher frequency could be even considered as an additional control on these words, which should elicit a slower reaction time to targets than transparent predictors if the hypothesis of the research holds.

In order to create the list of stimuli for each group and each condition, the sampled words from CELEX were ordered in the following lists:

- Target Words: All were bare nouns taken from CELEX
- Target Pseudowords: Generated with WordGen (Duyck, Desmet, Verbeke, & Brysbaert 2004), with 1 lexical neighbor.
- Transparent predictor words: regular verbs inflected for the past tense, half ending in *-te* and half in *-de*.
- Opaque predictor words, Blocks 2 and 3: A mix of adjectives and singular nouns, half ending in *-te* and half in *-de*.
- Opaque predictor word, blocks 4 and 5: A mix of pseudowords and adjectives, half ending in *-te* and half in *-de*.

Crucially, no stimulus was ever repeated twice, neither as predictor word or as target, nor in any of the trials or blocks of the experiment. The only repetition were the two past tense suffixes of the transparent predictor words, which were expected to be the source for the learning effect for half of the trials, and the orthographic ending of all transparent and opaque predictor words (a sequence of the graphemes ‘t’ and ‘e’ and ‘d’ and ‘e’), which were expected to act as control for any orthography effect in the learning of the association.

The change in the regularity of the stimuli after the first two experimental blocks was carried out with the purpose of selectively disrupting the learning process. This interruption should therefore significantly affect those trials where targets are preceded by transparent predictor words, causing an increase in response time. Opposite to this, trials with targets preceded by opaque predictor words should be significantly less affected by the change of regularity, since the response to these target words should be less mediated by predictions as compared to the targets that were preceded by transparent predictors.

The experiment consisted of a lexical decision task with 5 blocks of 100 trials each (see Figure 1). There were three parts to the experiment; The first part consisted of one practice block, followed by two blocks (2 and 3) where target

words were systematically preceded by the same inflectional paradigm (the transparent predictor words) and pseudowords were preceded by opaque predictor words. Finally, there were two more blocks (4 and 5) where the type of target being systematically preceded changed to pseudowords, while words were now preceded by the orthographically controlled, opaque predictor words.

6 Data analysis

No effects were expected in terms of accuracy as all adult participants should be able to carry out the lexical decision task without problems. The speed of their reactions was the dependent variable. A minimum 90% accuracy was established as a cut-off criteria for participants. One participant with an accuracy below this threshold was removed from analysis.

All participants were interviewed after the experiment and were asked whether they had become aware of the masked predictor words. Questions also investigated whether they felt any regularities, increases, or decreases in task difficulty, or repeating patterns. The expected results of these interviews are that participants show no awareness of the masked predictor words, despite these having a significant effect on response times. If this is indeed the case, the processing of these words can be assumed to have occurred unconsciously.

In order to better understand the type of data produced by this experiment, probability density functions of each condition were plotted and examined for normality (see Figure 2). This is important since the normality of distributions is a pre-requisite for using most of the parametric statistical techniques often used in reaction time experiments. However, as is sometimes the case, response-time distributions are not normal, and in that case, non-parametric alternatives become necessary.

7 Results

The 14 participants performed the task with an overall accuracy of 96.7% (SD 2.11%). The lowest accuracy was 91.4% correct and the highest score was 99.2%. The mean reaction time (RT) of the lexical decision task are given in Table 3.

Table 3: Mean reaction time for each type of trial on each block

Block	Type of Trial	
	Opaque	Transparent
Block2	805	711
Block3	748	689
Block4	702	705
Block5	660	701

The characteristics of the RT distributions of the opaque and transparent predictors can be seen in Figure 2. Here we can see that both distributions are not normal, but, as with most RT distribution of learning experiments, are skewed to the left, on the faster end of the response time distribution.

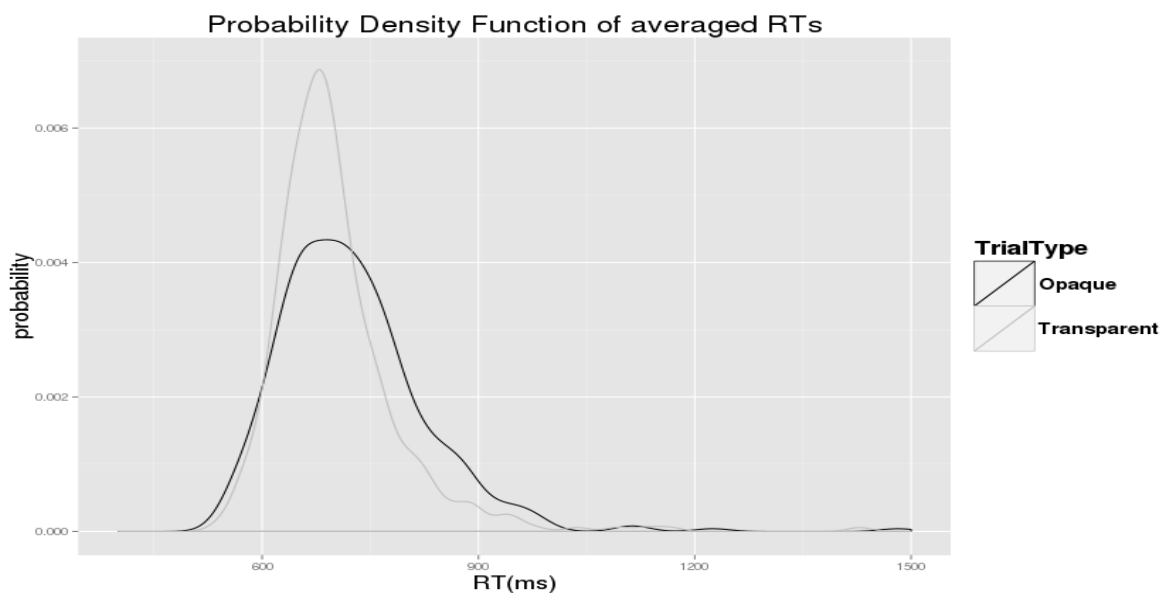


Figure 2: Probability Density Function for each type of trial. The plot shows a clear skewness to the faster end of the distribution.

The skewness seen in the probability density function reflects learning, as it shows that there were trials with longer RTs, but that as trials progressed RTs became shorter. A Locally weighted regression (LOESS, see Cleveland, Devlin & Cleveland 1988) was carried out in order to smooth the RT distribution across trials. A loess model fits a complicated curve through a set of points. In this case, the mean RT across participants for each trial. This technique can be thought of as a complicated moving average, which fits the idiosyncratic nature of RT

distributions. The progression of response times across trials in the four experimental blocks can be seen in Figure 3.

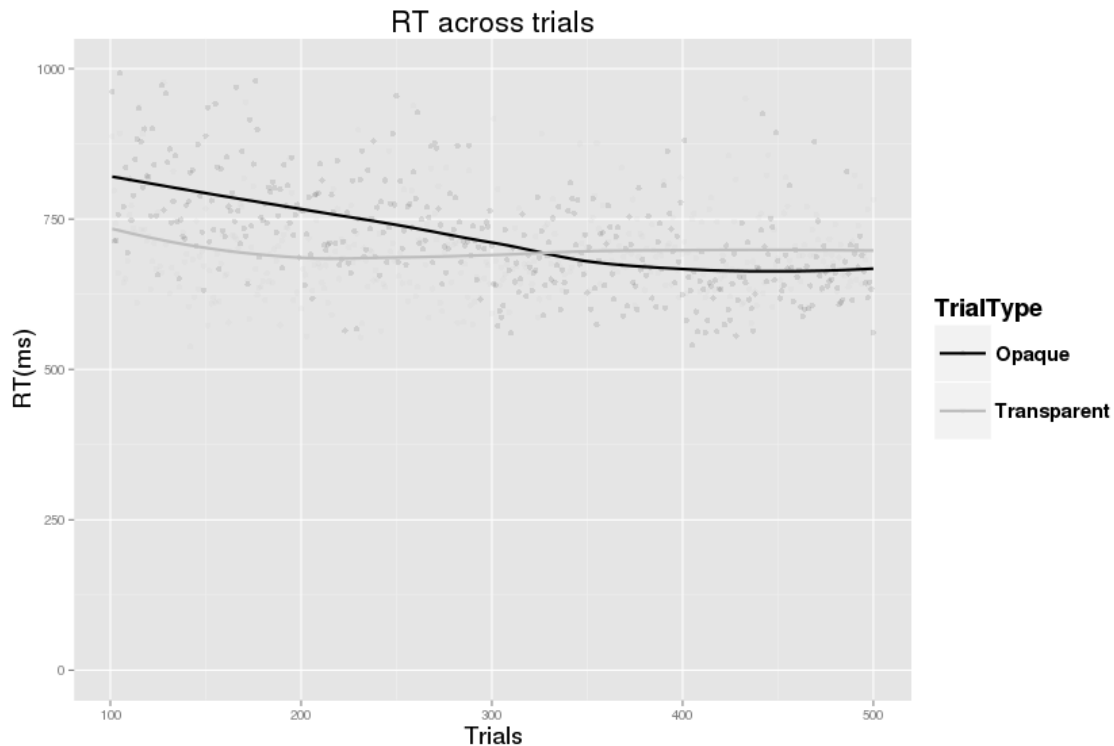


Figure 3: RTs per trial across all trials. The regression line shows the temporal dynamics of the learning process.

Shapiro-Wilk tests carried out on the response time distribution of transparent ($w = .815$, $p < .001$) and opaque ($w = .821$, $p < .001$) trials showed that the distribution was non-normal. Wilcoxon signed rank tests were used to compare transparent and opaque RT distributions. A 99% confidence interval was used to correct for multiple comparisons ($p < .01$). The analysis was first done to successive trials of block 2, to see at which point in time there was a significant learning effect. Results showed that the difference between transparent and opaque trials becomes progressively smaller as block 2 progresses. For example, at trial 10 of block 2, after having gone through a whole training block, the difference between transparent and opaque trials was non-significant, $z = -1.6818$, $p = .114$. At trial 20, the difference becomes larger: $z = -2.7253$, $p = .008$. At trial 30, the difference became closer to significance: $z = -2.7253$, $p = .005$. Only in trial 40, the difference reaches significance at the 99.9% confidence interval: $z = -3.2259$, $p = .001$. The effect of transparent trials keeps increasing as trials progress, as shown in Figure 3. The difference between transparent and opaque trials across all trials in block 2 ends up being highly significant: $z = -6.2474$, $p < .001$. For block 3, the difference remains significant: $z = -5.3844$, $p < .001$. The reaction times to the lexical decision task were

significantly faster for the transparent trials relative to the opaque predictors across block 2 and 3 ($z = -8.1379$, $p < .001$).

In block 4, the RTs between transparent versus opaque predictors were almost equal: $z = 1.1346$, $p = .255$. In block 5, the opaque trials were significantly faster than the transparent ones: $z = 4.3907$, $p < .001$. This is possibly due to participants having been unable to block the previously learned regularity and learn the new regularity based on past verb-pseudoword target associations. This hypothesis gains support when looking at the distributions for each type of answer in Figure 3. It seems to be the case that as transparent trials become slower (towards block 4), opaque trials become faster. Given that learning started very early in block 2, the decrease in RTs reached a ceiling effect which later allowed for some learning to take place with opaque trials. This view is further reinforced when looking at the averages and standard deviations for each trial type across blocks in Figures 3 and 4.

As for subjective reports, 6 of the 14 participants reported being aware of the predictor words, while the rest reported no awareness of the masked words. The participants that were aware of the masked words indicated that even though they recognized they were words, they could not actually report the meaning of any of the masked words. Reports on whether participants noted any regularity were all negative, with no participant noting any repeating pattern across the experiment. These subjective reports indicate that participants were most likely unaware of the masked words, and so the effects these might have on the response to the targets must be due to unconsciously processed information.

8 Discussion

The purpose of this research was to examine whether Dutch native speakers were able to process morphological information automatically and unconsciously. At the same time, we wanted to know whether this information, if processed, could be used by implicit learning mechanisms that have been shown to operate in other non-linguistic domains. Specifically, it was investigated whether a masked prime containing the past verb regular inflection (the allomorphs *-de* or *-te*) would predict the lexical status of a target in a lexical decision task. The results of this research indicate that participants were able to learn this association. The differences between transparent and opaque response times occurred very early in the experiment. This indicates a very early learning effect. The steep decrease in RT that continued in block 3 showed that despite the fact that participants apparently learned the regularity early in the experiment, they continued to improve learning reflected in shorter RTs as blocks progressed. Moreover, the difference between both types of trials appeared early in the experiment. This suggests that learning the association was

easier for participants than expected. This, in turn, possibly facilitated the participants to learn, although to a lesser extent, the opaque association as well.

This pattern of results raises the question whether there was implicit learning based on the prime at all. Instead, it could be the case that participants simply reacted faster to words than to pseudowords, with the predictor words (and their morphology) not making much difference on response times. However, this hypothesis is ruled out by the effect observed in block 4. Once the disruption of the regularity occurred, both types of trial elicited similar reaction times. Also the RTs in the opaque trials showed larger standard deviations than transparent trials. This suggests a different learning pattern compared to that of the transparent trials.

The lack of learning of the second regularity (blocks 4 and 5) was possibly due to participants having been unable to block the previously learned regularity and learn the new one, based on past verb–pseudoword target associations rather than verb–word associations. This hypothesis gains support when looking at the distributions for each type of answer in Figure 3. It seems to be the case that as transparent trials become slower (a slight rise in the graph towards block 4), opaque trials become faster (a move downwards in the graph). Given that learning started very early in block 2, the decrease in RTs reached a ceiling effect which later allowed for some learning to take place with opaque trials. This view is further reinforced when looking at the averages and standard deviations for each trial type across blocks in Figures 3 and 4:

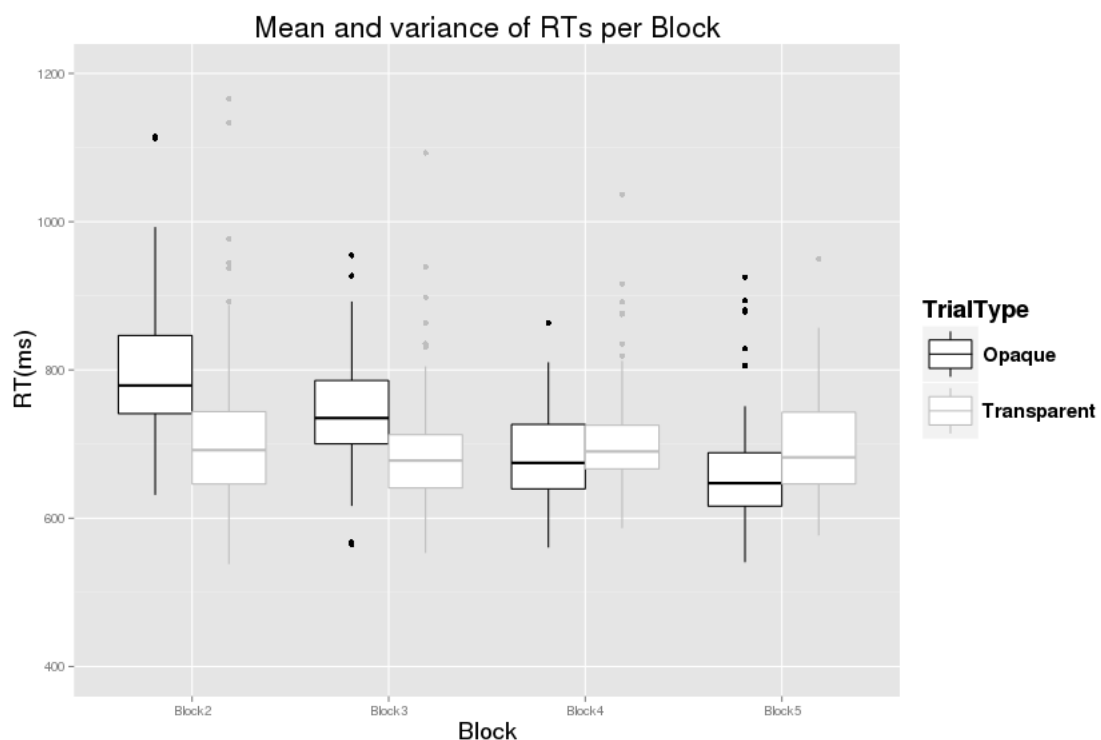


Figure 4: Mean and standard deviation per block for each type of trial.

This figure shows how the average response time for opaque trials (black boxes) decreases linearly, probably due to practice effect, late learning, or a mix of both. Contrary to this tendency, transparent trials (grey boxes) become faster very early. After the disruption takes place, transparent trials slow down and then become slowly faster, but not as fast as opaque trials, which show a continuous decrease of RTs throughout all blocks.

In both transparent and opaque conditions, predictor words ended in the same orthography. Therefore, the observed differences between responses to transparent and opaque trials, with transparent trials being faster until the disruption of the regularity occurred in block 4, should also be interpreted in the light of this control. A key limitation of classical facilitation effects of regularly inflected words is that the priming effect could not be dissociated from orthography, since regularly inflected words share almost all characters with their bare forms. These results, then, provide additional support for the hypothesis that morphological processing is a distinct level in word recognition. Since there is no aspect of semantic or orthographic information that could have made participants anticipate the type of response or the upcoming target, the regularity in morphological inflection of the transparent primes remains the only possibility to explain the observed differences. In future research, less stimuli should be used to allow for a better control of frequency, as using low-frequency words gives a clearer picture of the processing mechanisms used for specific types of words (Keuleers et al. 2010).

Overall, these results show that participants were able to extract the morphological information out of masked words and used that information to answer faster to target words. If the processing of the inflectional morphology of the transparent predictor words is responsible for this effect, it must have occurred very early in word processing (before 40 ms, which was the duration of the masked words) and without participants being aware that they were learning an association. We predict decomposition to be the most likely method under which past tense suffixes were processed. However, since that all past tense predictors were also verbs, a rapid extraction of word class information could also account for these results. Further research is needed to investigate that alternative explanation.

Betram et al. (2000) concluded that Dutch past tense verbs are stored lexically as surface form representations of sound-meaning associations. Our results challenge this hypothesis. Even if word class, and not decomposition, is responsible for the observed learning effect, this still supposes complex lexical representations. However, Bertram et al. seem to have a simpler model in mind where the recognition of the past tense is simply the semantic processing of the whole word.

The data from this experiment thus provides additional support to the theory that morphological information is a necessary part of word processing, and that a model that incorporates information given by morphemes into word processing is better suited to account for empirical data (Dominguez et al. 2000). Also, the lack of awareness shown by participants in the post-experiment interviews is compatible with the hypothesis that regular inflectional morphology is processed by procedural mechanisms that act rapidly and outside awareness (Ferman & Karni 2012).

In order to strengthen our observations, this study should be replicated with a larger sample, but the results also offer several avenues for further research. The inflectional paradigm used in this research could be extended to include others that could also be candidates for fast and automatic processing. Even within a single inflectional paradigm, the role of orthography versus phonology could be studied by using an acoustic stimuli and varying transparent predictor words with allomorphic variations of the same paradigm. L2 speakers with different degrees of proficiency could also be studied to assess a possible link between proficiency and the consolidation of morphological processes. Regarding the type of implicit learning triggered in this experiment, more complex sequences could be used, to test the ways in which automatically and unconsciously processed information can be used on subsequent tasks.

9 References

- Baayen, R.H., R. Piepenbrock & L. Gulikers. 1995. The {CELEX} lexical data base on {CD-ROM}.
- Baayen, R.H. & R. Schreuder. 2000. Towards a psycholinguistic computational model for morphological parsing. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences* 358(1769): 1281-1293.
- Baayen, R.H., J.M. McQueen, T. Dijkstra & R. Schreuder. 2003. Frequency effects in regular inflectional morphology: revisiting Dutch plurals. *Morphological Structure in Language Processing* 151(1): 355-390
- Bertram, R., R.H. Baayen & R. Schreuder. 2000. Effects of family size for complex words. *Journal of Memory and Language* 42(3): 390-405.
- Booij, G. 2002. *The Morphology of Dutch*. Oxford: Oxford University Press.
- Bybee, J. 1995. Regular morphology and the lexicon. *Language and Cognitive Processes*, 10(5): 425-455.
- Clahsen, H. & C. Felser. 2006. Continuity and shallow structures in language processing. *Applied Psycholinguistic* 27(1): 107-126.
- Clahsen, H. 2006. Linguistic perspectives on morphological processing. *Advances in the Theory of the Lexicon* 13(1): 355-388.

- Clahsen, H. & K. Neubauer. 2010. Morphology, frequency, and the processing of derived words in native and non-native speakers. *Lingua* 120(11): 2627-2637.
- Cleeremans, A., A. Destrebecqz & M. Boyer. 1998. Implicit learning: News from the front. *Trends in Cognitive Sciences* 2(10): 406-416.
- Cleveland, W.S & S.J. Devlin. 1988. Locally weighted regression: An approach to regression analysis by local fitting. *Journal of the American Statistical Association* 83(403): 596-610.
- De Jong, N.H., R. Schreuder & R.H. Baayen. 2000. The morphological family size effect and morphology. *Language and Cognitive Processes* 15(4-5): 329-365.
- Destrebecqz, A. & A. Cleeremans. 2001. Can sequence learning be implicit? New evidence with the process dissociation procedure. *Psychonomic Bulletin & Review* 8(2): 343-350.
- Devlin, J.T., H.L. Jamison, P.M. Matthews & L.M. Gonnerman. 2004. Morphology and the internal structure of words. *Proceedings of the National Academy of Sciences of the United States of America* 101(41): 14984-14988.
- Diependaele, K., J.A. Duñabeitia, J. Morris & E. Keuleers. 2011. Fast morphological effects in first and second language word recognition. *Journal of Memory and Language* 64(4): 344-358.
- Domínguez, A., F. Cuetos & J. Seguí. 2000. Morphological processing in word recognition: A review with particular reference to Spanish data. *Psicológica* 21(2): 375-401.
- Duyck, W., T. Desmet, L.P. Verbeke & M. Brysbaert. 2004. WordGen: A tool for word selection and nonword generation in Dutch, English, German, and French. *Behavior Research Methods, Instruments, & Computers* 36(3): 488-499.
- Feldman, L.B., A. Kostić, D.M. Basnight-Brown, D.F. Đurđević & M.J. Pastizzo. 2010. Morphological facilitation for regular and irregular verb formations in native and non-native speakers: Little evidence for two distinct mechanisms. *Bilingualism: Language and Cognition* 13(02): 119-135.
- Ferman, S. & A. Karni. 2012. Procedural and declarative memory in the acquisition of morphological knowledge: A model for second language acquisition in adults. *Current Issues in Bilingualism: Cognitive and Socio-linguistic Perspectives* 5(1): 201-216.
- Gor, K. & S. Cook. 2010. Nonnative processing of verbal morphology: In search of regularity. *Language Learning* 60(1): 88-126.
- Hartman, M., D.S. Knopman & M.J. Nissen. 1989. Implicit learning of new verbal associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 15(6): 1070.
- Howard, J.H., S.A. Mutter & D.V. Howard. 1992. Serial pattern learning by event observation. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 18(5): 1029-1039.
- Keuleers, E., K. Diependaele & M. Brysbaert. 2010. Practice effects in large-scale visual word recognition studies: A lexical decision study on 14,000 Dutch mono- and disyllabic words and nonwords. *Language Sciences* 174(1): 1-15.

- Lavric, A., A. Clapp & K. Rastle. 2007. ERP evidence of morphological analysis from orthography: A masked priming study. *Journal of Cognitive Neuroscience* 19(5): 866-877.
- Morris, J. & L. Stockall. 2012. Early, equivalent ERP masked priming effects for regular and irregular morphology. *Brain and Language* 123(2): 81-93.
- Perruchet, P., A. Cleeremans & A. Destrebecqz. 2006. Dissociating the effects of automatic activation and explicit expectancy on reaction times in a simple associative learning task. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 32(5): 955-965.
- Pinker, S. 1991. Rules of language. *Science* 253(5019): 530-535.
- Pinker, S. & A. Prince. (1994). Regular and irregular morphology and the psychological status of rules of grammar. In S.D. Lima, R.L. Corrigan & G.K. Iverson (eds.), *The reality of linguistic rules*. Amsterdam: John Benjamins, 231-351.
- Pinker, S. & M.T. Ullman. 2002. The past and future of the past tense. *Trends in Cognitive Sciences* 6(11): 456-463.
- Portin, M., M. Lehtonen & M. Laine. 2007. Processing of inflected nouns in late bilinguals. *Applied Psycholinguistics* 28(01): 135-156.
- Prasada, S. & S. Pinker. 1993. Generalisation of regular and irregular morphological patterns. *Language and Cognitive Processes* 8(1): 1-56.
- Rastle, K., M.H. Davis, W.D. Marslen-Wilson & L.K. Tyler. 2000. Morphological and semantic effects in visual word recognition: A time-course study. *Language and Cognitive Processes* 15(4-5): 507-537.
- Rastle, K. & M.H. Davis. 2008. Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes* 23(7-8): 942-971.
- Seidenberg, M.S. & J.L. McClelland. 1989. A distributed, developmental model of word recognition and naming. *Psychological Review* 96(4): 523-568.
- Shanks, D.R. & P. Perruchet. (2002). Dissociation between priming and recognition in the expression of sequential knowledge. *Psychonomic Bulletin & Review* 9(2): 362-367.
- Stockall, L. & A. Marantz. 2006. A single route, full decomposition model of morphological complexity: MEG evidence. *The Mental Lexicon* 1(1): 85-123.
- Ullman, M., S. Corkin, M. Coppola, G. Hickok, J. Growdon, W. Koroshetz & S. Pinker. 1997. A neural dissociation within language: Evidence that the mental dictionary is part of declarative memory, and that grammatical rules are processed by the procedural system. *Journal of Cognitive Neuroscience* 9(2): 266-276.
- Ullman, M.T. 2001. A neurocognitive perspective on language: The declarative/procedural model. *Nature Reviews Neuroscience* 2(10): 717-726.
- Ullman, M.T. 2004. Contributions of memory circuits to language: The declarative/procedural model. *Cognition* 92(1): 231-270.

- Ullman, M.T., R. Pancheva, T. Love, E. Yee, D. Swinney & G. Hickok. 2005. Neural correlates of lexicon and grammar: Evidence from the production, reading, and judgment of inflection in aphasia. *Brain and Language* 93(2): 185-238.
- Van den Bussche, E., W. van den Noortgate & B. Reynvoet. 2009. Mechanisms of masked priming: a meta-analysis. *Psychological Bulletin* 135(3): 452.
- Yap, M.J., D.A. Balota, D.E. Sibley & R. Ratcliff. 2012. Individual differences in visual word recognition: Insights from the English Lexicon Project. *Journal of Experimental Psychology: Human Perception and Performance* 38(1): 53-79

Hernán Labbé Grünberg

H.A.LabbeGrunberg@uva.nl

Judith Rispens

J.E.Rispens@uva.nl