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Pairing up networks

Phonological and graphemic networks in interaction

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Pairing up networks

Phonological and graphemic networks in interaction

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Abstract
This study looks at the interaction between phonological and graphemic priming, since previous literature (Meyer et al., 1974, Shulman et al., 1978, Hillinger, 1980, Evett & Humphreys, 1981) has been inconclusive and conflicting. In order to give new insights, Dutch participants were tested with word pairs, by means of a Lexical Decision task. These pairs where graphemically and phonologically related, only graphemically related, only phonologically related, or unrelated. This experiment was carried out in order to investigate whether phonological and graphemic priming combined is stronger than only phonological priming or graphemic priming. The results partially confirmed our predictions, with as main outcome the increased facilitation of both phonological and graphemic priming, compared to the other types of priming that were taken into consideration. Furthermore, this study found that graphemic priming has an inhibitory effect on the participant's responsiveness.

1. Introduction[1]

Since the 1980s, great importance has been given to the field of modularity with regard to cognitive networks. Previous studies have assumed the existence of demarcated systems in the human brain that serve a particular purpose or operation (see Fodor, 1983, for a detailed description), also known as cognitive modules. In the domain of linguistics, parsing processes of lexical items are thought to be driven by different modules, such as the visual and the semantic module, among others. The question is whether and to what extent these modules interact with each other.

In this paper, we will explore the interaction of the phonological and graphemic networks. By means of a lexical decision task we measured the response time of 19 Dutch participants, who were presented with different types of word-word pairs and word-non-word pairs. The first word in a pair is the prime, the second word the target. We tested the unconscious influence of the prime on the recognition of the target word (also called 'priming effect') by means of three categories of related pairs: phonologically related, graphemically related, and phonologically + graphemically related. The control condition consists of unrelated pairs.

Concretely, we will formulate an answer to the following research question: To what extent is the priming effect different, in terms of response time, for phonologically related words

1 Special thanks to Judith Brinksma and Jim Teasdale for their help on working out the theoretical issues.

or graphemically related words, compared to the case in which words are both phonologically and graphemically related? Formally, we propose the following null hypothesis: the reaction time to stimuli that are graphemically and phonologically related does not differ from stimuli that are either graphemically or phonologically related. Furthermore, we propose as alternative hypothesis that the reaction time to stimuli that are graphemically and phonologically related differs from stimuli that are either graphemically or phonologically related.

We predict that the interaction of the phonological component and the graphemic component will lead to a cumulative effect. Concretely, this would mean a lower response time for the graphemic + phonological category compared to both of the two components taken alone. Below, we present a series of expectations for the individual categories as compared to the baseline condition and to each other:

(1) Response times for phonological priming are lower than for no priming (cf. Swin ney, 1979).

(2) Response times for graphemic priming are different than for no priming: there is no evidence for a precise direction in which graphemic priming would differ from the baseline condition, but we do believe that there is 'some' difference.

(3) Response times for phonological + graphemic priming is lower than phonological priming: as the words in a pair are rhyming and visually similar, we believe that the target word should be recognized faster.

(4) Response times for phonological + graphemic priming is lower than graphemic priming: the same reason as for phonological priming in prediction (3) is adopted.

Hence, we expect that, when words are both phonologically and graphemically related, there indeed is a facilitating effect. From this, the prediction follows that there is no ceiling effect when the words are only graphemically or only phonologically related. This implication argues against a modular approach, given that in a modular approach the combination of two modules would be just as fast as one module alone.

This study might give further insight in the interaction between phonological and graphemic priming, as well as the availability of both types of priming. From a broader point of view, this study might give additional evidence in favor of either the modular or the interactive approach, and which one should be taken when examining neural networks.

The present paper is divided into four parts. Section 2 offers an overview of the literature in the domain of phonological, graphemic, and semantic networks that are thought to be active in the human brain. In section 3, we will explain the methodology that has been used to test the relevant population and to analyze the outcomes of the trials. The results and analysis are reported in section 4. Finally, a conclusion will be presented in section 5.

2. Theoretical background

As mentioned before, modularity issues in the field of neural networks have been object of discussion since the early 1980s. It was the publication of *The Modularity of Mind* (Fodor, 1983), that first drew attention to this matter. Throughout the years, a distinction between two main approaches on modularity has been set: a modular approach versus an interactive approach.

In early psycholinguistic literature, the modular approach to the different networks in the human brain was the dominant hypothesis (Forster, 1981; Tanenhaus, Carlson, & Seidenberg, 1985). This idea implies that the brain functions by using several modules that work independently. For instance, there is a visual module, which processes visual stimuli. However, there is a lot of evidence against this approach (cf. Zwitserlood, 1989; Bülthoff & Yuille, 1996). Alternatively, an interactive approach has been proposed. This approach implies that the assumed cognitive modules interact with each other, which means, for example, that the activation of meaning occurs simultaneously with word-form activation. More in general terms, semantic and phonological networks are believed to be interrelated and activated in parallel in the human brain. According to Marslen-Wilson (1987), however, the coexistence of different cognitive modules can also lead to partial interaction, a situation in which certain modules are of a strictly autonomous nature, whereas others interact.

Apart from the phonological and semantic networks, research has been done on the graphemic network (Shulman, Hornak, & Sanders, 1978; Meyer, Schvaneveldt, & Ruddy, 1974; Hillinger, 1980). However, the results of previous research are conflicting. Meyer et al. (1974) found no evidence of graphemic priming, while Shulman et al. (1978) did find evidence. Hillinger (1980) showed that there was no difference between phonological priming and graphemic priming, although this lack of difference might be due to a ceiling effect. Finally, Evett & Humphreys (1981) found evidence for graphemic priming, but report no additional benefit for phonologic and graphemic priming at the same time. These findings provide sufficient motivation for us to cautiously assume that graphemic priming and a related cognitive module do exist. The question remains whether the graphemic and phonological systems interact with each other and what the effect might be, if there is any. In the following section, we describe the methodology of the experiment that will test for the relevant interaction mentioned above.

3. Methodology

In this section, we will report the methodology of this experiment. Section 3.1 will describe the participants we tested; in section 3.2 we will refer to the materials used. Section 3.3 outlines the procedure of the lexical decision task adopted, and 3.4 explains what tools we used to analyze the collected data.

3.1 Participants

For this experiment, 20 participants were tested in total. The mean age of the participants was 21;3 years. The participants were all native speakers of Dutch. They were not dyslexic and had normal or corrected to normal vision. The participants were recruited with caution at Utrecht University, so that the participants had little to no experience with the lexical decision task. All but one participant were right-handed. Furthermore, all but one participant were monolingual. There was no control for gender, since we had no reason to think this would make a difference.

The experiment was written for right-handed participants, specifically. Given that the participant's dominant hand is generally faster than the non-dominant hand, a left-handed person could possibly react faster to nonwords (left button) than to words (right button). After comparing the reaction times of the only left-handed participant with the mean reaction times of the right-handed population of our sample, the left-handed participant was excluded from the analysis based on their performance. As for bilingual participants, there was only one. This participant was not excluded, since their performance did not differ from the monolinguals among the sample.

3.2 Materials

The stimuli were created in four different categories: phonologically related and graphemically related (PHAF), only phonologically related (PHON), only graphemically related (GRAF), and unrelated (UN). For every category, there were two levels: word-word and word-nonword. The nonwords were designed in such a manner, that they would satisfy the category they are in. We decided to use relatively short stimuli with a length of minimally three letters and a maximum of seven letters. The stimuli were both monosyllabic and disyllabic words. This specific choice has been made so that different word lengths would not result in different reading times, and different response times as a consequence. In the categories PHON and GRAF, multiple English and French loanwords were used as a prime in order to create the desired contrast or likelihood. Loanwords were never used as a target to avoid misinterpretations. In fact, a loanword could be (erroneously) interpreted as a nonauthentic Dutch word and therefore be considered as a nonword in the lexical decision task. Examples of the stimuli can be observed in Appendix 1[2].

There were 22 word-word pairs and 22 word-nonword pairs per category, adding up to a total of 176 word pairs. These word pairs were randomized and presented to all the participants, resulting in a within-subject experiment design. By doing so, the participants would not develop a strategy effect.

The experiment was coded in ZEP (Veenker, 2017) and performed on a Linux operating system. The ZEP script of this experiment is an adaptation of a template file. This template file was retrieved from the Beexy website[3]. The default template is made for a visual lexical decision task with visual priming. The default experiment is auto-paced and returns the response time and correctness as output. In the template modules, we adapted the following settings: the duration of visual elements (e.g. the fixation cross, the intertrial interval, etc.), the stimuli (prime-target pairs and categories), the instructions, and minor aspects of the general layout.

3.3 Procedure

The participants were asked to come to the UiL-OTS research facility in Utrecht, where

2 Appendices are included in this digital copy of LingUU.

3 https://www.beexy.nl/download/zep/templates/latest/vislexdec_vp.zip

they were received by the experimenters. Each subject was instructed to enter a soundproof booth, to sit down on a chair in front of a computer monitor and to lay the index finger of each hand on the left and right button of a BeexyBox, that was placed in front of them on a desk. Then, the experiment was started from a computer outside the booth. First, the instructions screen was run, followed by the practice trial in which 10 non-related word pairs were presented to the subject. The instructions can be consulted in Appendix 2.

During the practice trials, the participant received feedback (✓ or ✗) to their choices, contrary to the experimental trials, where no feedback was provided. If the participant showed that they did not understand the task by returning a relatively high rate of wrong answers during the practice trials, the experiment was started again. When they completed the practice trial in a manner that showed that the task was understood, the experiment was started.

A trial starts with a fixation cross (1000 ms), which gets replaced with the prime for 750 ms. When the target disappears, the target appears after 300 ms. The target disappears after 2000 ms, which is also the time the participants have to answer. After the trial, there is an intertrial interval of 1000 ms. This is repeated until the participant has answered to all stimuli once. When the participant gives the wrong answer, the trial will not be repeated later in the experiment. Repetition could interfere with the priming effect we are investigating. A (Beexy) button box was used to collect the responses, and response labels matching the buttons were presented on the screen.

3.4 Analysis

The analysis was performed using RStudio (RStudio Team, 2016), version 1.1.383. To analyze the data, we used lme4 (Bates, Bolker, & Walker, 2015) and lmerTest (Kuznetsova, Brockhoff, & Christensen, 2017).[4] The latter package is an extension on the summary function, which adds a significance level to the performed t-tests. We created a model taking into account both fixed and random effects in order to fit the data.

All missed targets, i.e. answers that were given after the maximum response time limit of 2000 ms (see section 3.3), were excluded from the datafile. Additionally, when checking the amount of mistakes made per item, three items scored around or below chance (50% wrong). These items were also removed from the dataset. Furthermore, there were outliers with a too low response time (between 0 and 250 ms) on some of the items, for instance a response time of 13 milliseconds. These were deleted, because they were considered to be too fast to represent a conscious response time. Lastly, we excluded all items that were answered wrong.

A critical step of our analysis has been the decision to formally divide each category into a phonological (phon) and a graphemic (graph) component, i.e. in numeric terms. In other words, each word pair has two components that are activated or unactivated based on the relatedness between the prime and the target. Following this formalization, the components of each category can be observed in Table 1.

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4 Data visualisations were made using *sjPlot* (Lüdecke, 2016), *Lattice* (Sarkar, 2008), *ggplot2* (Wickham, 2009), and *dplyr* (Wickham, Francois, Hendry, & Müller, 2017).

Table 1

Components per category

	Component	
Category	**phon**	**graph**
PHAF	1	1
PHON	1	0
GRAF	0	1
UN	0	0

In this manner, we were able to analyze the interaction between the components that represent the two cognitive modules we are interested in, rather than a mere comparison between the means of each of the four categories.

4. Results and analysis

In this section, we will provide the results collected from the lexical decision task and provide an analysis of this data. This section will mainly focus on the Mixed Linear model that we created to fit our data.

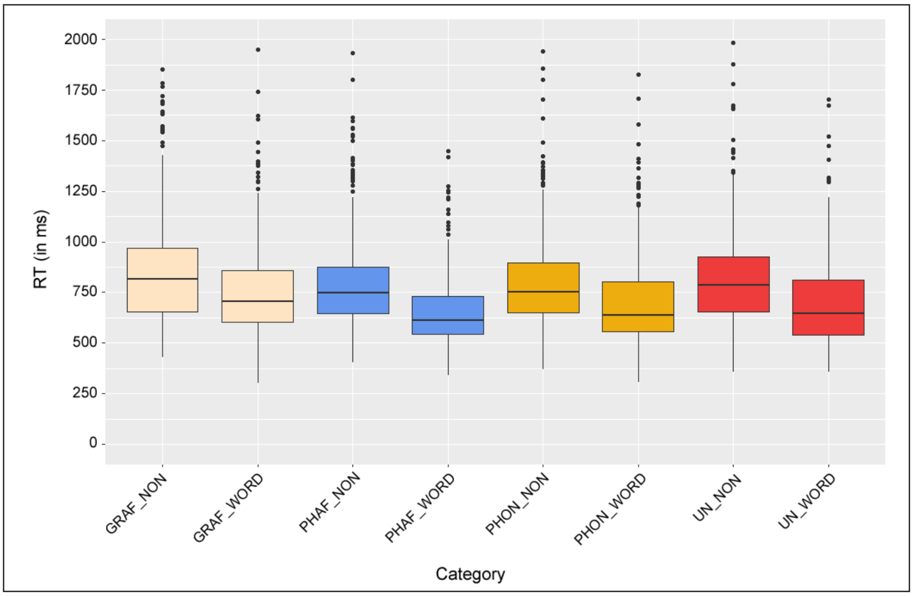

Figure 1. Response time per category.

In Figure 1, the four categories are represented with different colors, each of them with two levels: words and nonwords. The figure shows that the 75% of response times for each category is placed roughly between 500 ms and 1000 ms, with minima and maxima of around 250 ms and 1500 ms, respectively. Importantly, the boxplots again show slower response times for nonword (_NON) categories (i.e. the median and IQR are lower on the y-axis), than for word categories. Among the word (_WORD) categories, it looks like word pairs that are phonologically + graphemically related (PHAF_WORD) are recognized the fastest by our participants. At the top of each boxplot, there are data points that are named outliers by R. However, since the participants only have two seconds to answer, this is still within the time frame and we do not consider these data points to be proper outliers. Other major conclusions cannot be drawn about differences between the categories from this graph.

In order to analyze the data, a linear mixed effects analysis (Bates et al., 2015) of the relationship between response time and word category was performed. Since there are missing values in the data set (such as missed targets, or wrongly answered targets), a mixed linear effects analysis seemed most fitting. This type of analysis takes into account both fixed and random effects. We constructed this model using only the word-word pairs, leaving out the word-nonword pairs.

As fixed effects, we took into account whether a word has a phonological component and whether it has a graphemic component, as was previously shown in Table 1. We entered these components into the model with an interaction term. We excluded gender from our model, since it did not improve the fit of our model ($\chi2(1) = 0.2432$, $p = 0.6219$). We included random intercepts for participant id and item id, and we included by-participant random slopes for the effect of type.

The *lmerTest* (Kuznetsova, Brockhoff, & Christensen, 2017) showed that, when the priming was both phonological and graphemic, the participants process the word pairs significantly faster than unrelated word pairs ($t(56.48)= -3.624$, $p < 0.001$). Additionally, it showed that when the priming was only graphemic, the word pairs get processed significantly slower than unrelated words ($t(72.20)= 2.710$, $p < 0.01$). There was no significant difference found between unrelated word pairs and phonologically related word pairs ($t(53.93)= 0.487$, $p = 0.628$). This means that when there is both phonological and graphemic priming, there is a facilitation. When there is only graphemic priming, there is an inhibition effect.

The fixed effects are visualized in Figure 2, which shows the best linear unbiased prediction (BLUP). This means that in this figure the different components are plotted relative to the intercept, which are the unrelated word pairs. The intercept was estimated at 696 ms, which is represented as the 0 on the x-axis. The overlap of PHON with 0 shows that it does not differ from the unrelated words. The BLUP also shows that PHON*GRAPH (*i.e.* the interaction of the two components) is processed 118 ms faster than the unrelated words and that GRAPH is processed 60 ms slower.

When plotting the random slopes, an interesting observation can be made. Figure 3 shows that the difference between random slopes per participant are very similar for PHON and UN, as well as for PHAF. Interestingly, for the category GRAF we observe that the random slopes are very different per participant, with the biggest difference between two participants being about 500 ms. This implies that the inhibitory effect is stronger for some participants than for others.

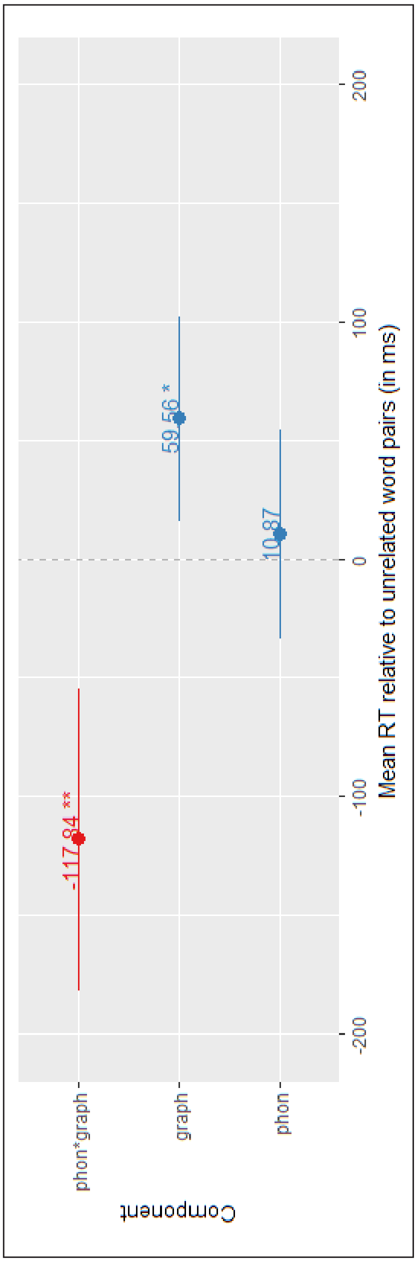

Figure 2. Fixed effects. Mean RT relative to unrelated word pairs (in ms) .

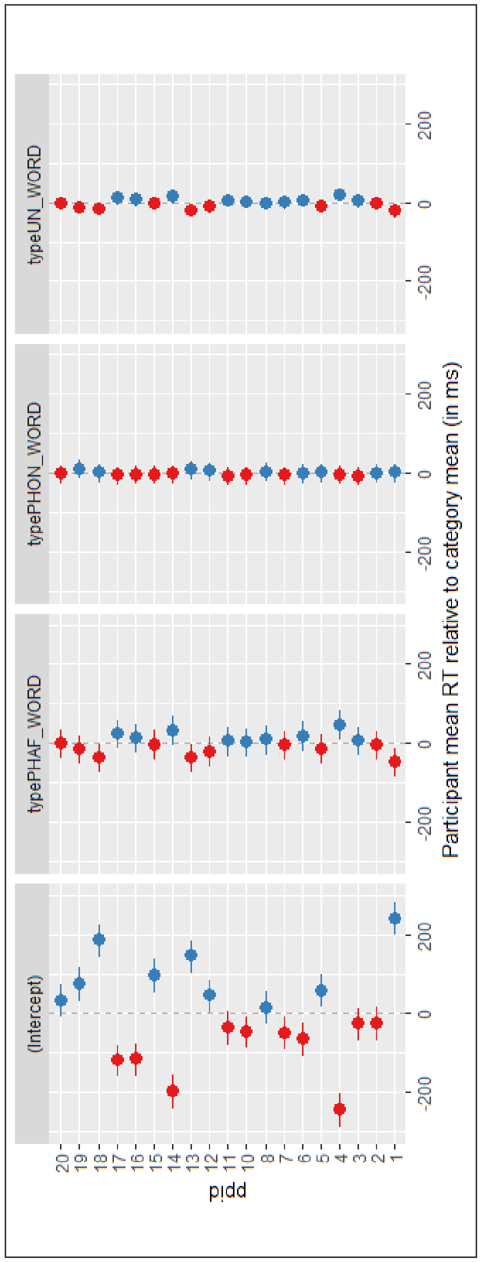

Figure 3. Random slopes per category.

In summary, we have found that the combination of phonological and graphemic priming leads to a facilitation. Additionally, we have found that graphemic priming without phonological priming leads to an inhibition effect. When assessing the random slopes, we found that this effect is not equally large for all participants.

5. Conclusion

In this paper we argued that the research on graphemic priming has been inconclusive. We designed a visual lexical decision in order to give answer to the following question: To what extent is the priming effect different, in terms of response time, for phonologically related words or graphemically related words, compared to the case in which words are both phonologically and graphemically related?

The results show that the interaction of both phonological and graphemic priming leads to a facilitation with respect to the other categories, which means that the response time is lower for this category than for the others. This means that the H0 is not borne out and thus the H0 can be rejected, in favor of the alternative hypothesis. Concretely, predictions (3) and (4) are confirmed. Additionally, we have found that graphemic priming taken alone leads to an inhibition effect, which is of a different extent among the participants. This result confirms prediction (2). Furthermore, we found no difference between only phonological priming and the unrelated word pairs, contrary to prediction (1).

Projecting to a higher level, these results are compatible with an interactive approach. If the brain was modular, we would have found that the combined effect of phonological and graphemic priming was equal to the effect of either phonological or graphemic priming. However, this was not the case. On top of that, graphemic priming alone even gave an inhibitory effect on the participant's responsiveness. We conclude that these results can only be accounted for if we take an interactive approach to the function of the brain.

Several aspects of the experiment might have been dealt with differently. The experiment could be done with a higher number of participants to see if the significance between the categories holds. Also, we could have balanced the numbers of men and women among the participants better; sex was ruled out as a fixed effect now, since this factor was not balanced. Besides, we could have asked a fair amount of left-handed subjects to participate, since we are now basing our results exclusively on a right-handed sample. The results of the only left-handed person lead to their removal, because of different response times between words (right button) and non-words (left button) compared to the right-handed in general. Since we did not know for sure if this difference was due to her being left-handed or to other factors, we excluded them from the model. It is necessary to mention that we did not control for word frequency. In order to statistically exclude the possible effect of word frequency, this should be taken into account in future studies. Lastly, we did not control for Dutch words that resembled an English lexical entry. This turned out to be a problem for just one of the stimuli (which was 'tree', meaning 'step' in Dutch).

However, we expect that these differences may only strengthen the results we found. We conclude that, indeed, phonologically and graphemically related words are processed faster than only phonologically and only graphemically related word.

This study has shown that there is an effect for graphemic and phonological relations, however it is limited to lexical decision with short words. Further research may look at whether this effect also holds for longer words or even sentences that look or sound similar to a certain extent. In addition, the semantic module could be taken into play, in order to precisely define their influence and interactions within the human neural networks.

6. Acknowledgments

The design of this experiment has been developed in professor Sergey Avrutin's course *Brain, Language and Cognition*. Thanks to fellow students Judith Brinksma and James Teasdale for their contribution in this process. We conducted the experiment and wrote this paper within the course *Experimental Design and Data Analysis*. Thanks to professor Iris Mulders for her remarks. Finally, thanks to the anonymous participants who took part in this study. ■

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Appendices

Appendix 1. Examples of stimuli

Overview of stimuli (examples)

Phon + Graph				**Phon**			
Word		**Non-word**		**Word**		**Non-word**	
Prime	**Target**	**Prime**	**Tar=get**	**Prime**	**Target**	**Prime**	**Target**
kucht	lucht	trein	slein	touw	pauw	hacker	zekker
merel	kerel	vaart	laart	shawl	schaal	yoghurt	locherd
ark	park	winter	rinter	chic	ziek	kou	sau
vloer	voer	roer	doer	toilet	ballet	sushi	roeshi

Graph				Un			
Word		Non-word		Word		Non-word	
Prime	Target	Prime	Target	Prime	Target	Prime	Target
cool	zool	reünie	reumie	tand	bier	zender	podem
clan	plan	geïnd	geints	stekker	vrouw	brug	jolk
jus	mus	poëzie	woezie	appel	fiets	paard	beurk
ruïne	bruine	shag	sag	snel	riet	gum	kach

Appendix 2. Instruction to the participant

Beste participant,

Bedankt voor het deelnemen aan dit onderzoek.

Je zult gedurende het experiment telkens twee woorden te zien krijgen. Jouw taak is om bij het tweede woord van ieder koppel te bepalen of het een bestaand Nederlands woord is of niet.

Als je denkt dat het woord bestaat, druk dan op de rechterknop; denk je van niet, druk dan op de linkerknop.

Het is belangrijk dat je snel en zo nauwkeurig mogelijk kiest: blijf daarom geconcentreerd.

Voordat het echte experiment begint, krijg je een oefenronde. Het doel hiervan is je te laten zien wat de opdracht inhoudt.

Druk op een knop om door te gaan naar de oefenronde.

Einde van de oefenronde.

Een van de proefleiders zal nu naar binnen komen om te vragen of alles duidelijk is.

Druk op een knop om door te gaan naar het experiment.

Einde van het experiment.

Dank je wel voor het meedoen!