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The effect of rhyme and cohort priming on spoken word recognition

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The effect of rhyme and cohort priming on spoken word recognition

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phonological priming
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Abstract
In this experiment, we examined the effect of phonological priming by means of an auditory lexical decision task. There is evidence for competition at word activation level during spoken word recognition. Two spoken word recognition models will be discussed and compared: the Cohort model (Marslen-Wilson & Tyler, 1980) and the TRACE model (McClelland & Elman, 1986). Both argue that bottom-up activation occurs, which means that phonemes activate lexical access. However, the TRACE model accounts for top-down expectations and the non-linear direction of activation. We will test both models by means of Dutch stimuli that are either matching in rhyme (pin-zin), matching in cohort (zit-zin) or unrelated (tas-deur). We obtained a significant difference between the response time to cohort- and to rhyme-related targets. Participants responded on average 48 ms faster (SE = 15 ms) to rhyme-related targets than to cohort-related targets. The conclusion is, therefore, that the results support the TRACE model because this model allows for continuous mapping. Contrarily, a stronger rhyme priming effect is not explained by the Cohort model.

1. Introduction

1.1 Aging and cognitive decline

To understand spoken language, listeners have to segment words from continuous speech. However, people do not make full breaks after each spoken word and articulation is influenced by a lot of processes like co-articulation, assimilation and phoneme-deletion. Therefore, the acoustic information in speech is quite diverse. Nevertheless, our brains receive the acoustic information via our ears, process it and recognize words. How this process of word recognition exactly works is still unknown and more research is required to collect more pieces to this puzzle. One way of doing this is by monitoring the effects that different priming conditions have on the speed of spoken word recognition. As quite some research has been done on this subject, it is interesting to compare the possible differences phonological priming may have depending on the language of the listener. The current paper examines the effects of rhyme priming and cohort priming on spoken word recognition of monosyllabic Dutch words in a lexical decision task.

2. Theoretical background

2.1 Spoken word recognition

The core of research on spoken word recognition is finding out how strings of sounds get mapped onto meanings. In other words, a string of sounds, like /dɔːg/ for example, reaches one's ears, then the sounds are processed and one's brain finds an entry in the lexicon that matches the sounds of the string. However, research has found that not just this particular entry, dog, will be activated, but that words similar to *dog* will be co-activated as well (e.g. Neely, 1977). There is evidence that words are recognized faster if the word pairs are phonologically or semantically related (e.g. Neely, 1977). So, /dɔːg/ also activates cat (semantically) and fog (phonologically) for instance. This very phenomenon can tell us more about what happens during word recognition and is often utilized in experiments through priming. One direct way of testing the speech recognition speed is via an auditory lexical decision task, which is the method used in the current study. The task of the participants is to decide whether the second word of each pair is an existing word or not. The first word of the pair, also referred to as the prime word, can have effects on the speed of recognition of the second word of the pair, the target word. For example, if the two words of a pair are semantically related, response time to the second word will be faster than if the words were semantically unrelated (e.g. Ferrand & New, 2003). To illustrate this, the pair dog - cat will give faster response times than the pair dog - key.

Using the data gathered from research, multiple attempts to describe the process of spoken word recognition using models have been made (e.g Marslen-Wilson & Tyler, 1980; McClelland & Elman, 1986). As this paper will focus on phonetic priming, we will compare two models that specifically attempt to explain (co)activation of a word in chunks based on phonological input: the Cohort model and the TRACE model.

2.2 Cohort model

According to the Cohort model (Marslen-Wilson & Tyler, 1980), the brain makes selections of possible words, named cohorts, while it receives auditory input. First, the initial phoneme of a word is received and processed. Based on the phonemes that are processed through time, a set of words (also referred to as cohort) is activated. For example, the phoneme cluster /kæn/ activates *candle*, *can*, *cancel* and other words starting with the same phonemes. Then, the following phoneme /d/ inhibits the activation of can and cancel. Out of these three wordcandidates, candle remains.

In short, the three stages of this model are Access, Selection and Integration. First, during the Access stage, the auditory input of phonemes reaches the ear of the hearer. Then secondly, depending on the phonemes the hearer has heard, the mental lexicon gives a cohort of candidates that start with the same phonemes. The more phonemes one hears of a word, the smaller this cohort becomes. This is called the selection stage. Finally, when one has heard the entire word, only one word option remains. The semantic and syntactic properties of this word are then integrated into the high-level representation of the context.

Marslen-Wilson and Zwitserlood (1989) performed a Dutch cross-modal lexical decision task in which visual target words were primed by auditory stimuli. All prime words were similar in rhymes with words that were semantically associated with the visual targets. For example, the participants heard *woning* (*house*) before seeing the word *bij* (*bee*), which is semantically related to *honing* (*honey*). So there is a phonological association between the auditory word and the semantically associated word to the visual target. In another study by Marlsen-Wilson, Brown and Zwitserlood (1989, in Marlsen-Wilson & Zwitserlood, 1989) the same experiment was done with prime words that were similar in word onsets; participants heard *kapitein* (*captain*) before seeing the word *geld* (*money*), which is semantically related to *kapitaal* (*capital*). They found that words with the same onset were effective cross-modal primes. Marlsen-Wilson and Zwitserlood compared their results with the results of that study. They found that word rhymes did not result in faster recognition of the visual probes. Therefore, they conclude that word onsets have a special status in word recognition, which is in favor of the Cohort model.

2.3 TRACE model

Contrary to the Cohort model, the TRACE model (McClelland & Elman, 1986) does not look for exact matches of phonemes specifically in a forward sequence. It allows continuous mapping and tries to account for variability of phoneme quality. In the TRACE model, multiple words are activated depending on similarity and frequency and activated words compete for recognition, similar to the Cohort model. The TRACE model has three layers of speech, namely the feature, phoneme and word layers. These layers pass information between each other and, within each layer, units compete for recognition.

Figure 1 shows a diagram of the TRACE model. First, acoustic input of a spoken word enters the feature layer and is processed. Second, the acoustic information is passed to the phoneme layer, in which the phoneme is amongst competitors. Third, when a phoneme is recognized, the phoneme information is passed onto the word layer. In this layer, possible words compete for recognition. This manner of initial activation is called bottom-up or feedforward activation. In addition, the TRACE model also contains a top-down or feedback manner of activation. For instance, due to interference from background noise, it is possible to miss the first phonemes of a spoken word, but the word can still be understood due to the context of the word. The Cohort model does not include this top-down activation and, therefore, has no explanation for recognition by final phonemes.

Evidence for continuous mapping was given by Allopenna, Magnuson and Tanenhaus (1998) through an eye-tracking experiment in a spoken-word recognition task. The participants heard a word, while they were looking at pictures. The authors found that the participants made a considerable number of fixations on phonological competitors (cohort and rhyme) of the target image. This revealed that not only cohort-related but also rhyming words provide interference. Bottom-up information from the visual cues interacts, thus, with top-down information from the auditory word, which is in line with the TRACE model.

Those results are supported by Norris, McQueen and Cutler (2002), who did a series of four experiments on the facilitation effect related to rhyming words. They argue that the advantage of rhyming primes and targets on cohort-related pairs in an auditory task is due to a mechanism of pre-lexical activation. It is generally assumed, according to Norris and colleagues, that spoken word recognition happens in two phases: first, the raw phonological information is extracted to allow lexical access and second, the competition between all candidates happens. The automatic process linked to a rhyming relation between both items is a manifestation of the first stage (pre-lexical activation). If the activation of the first word resonates until the start of the second word, the reactivation of the features will reach a critical level of activation faster, which is visible in words as well as in non-words (Norris et al., 2002). Although this effect also occurs in cohort-related stimuli pairs, it is compensated for by the inhibitory effect of lexical competition occurring earlier. At the beginning of word recognition, the second word in a cohort-related stimuli pair could be the same as the first word. For instance, the prime word leg and the target word let both start with /lɛ/. However, when it becomes clear that these two are not the same word, the activation of the prime word has to be inhibited. Since it is already clear in a rhyme-related pair that the second word is not the same as the first word (e.g. *lake* and *take*), this inhibitory effect does not occur as rhyme-based co-activation only happens when the rhyme is processed (i.e. at the end of the word in question). As a result, co-activation through rhyme priming would bring less inhibition of competition than co-activation from cohort priming, allowing faster recognition.

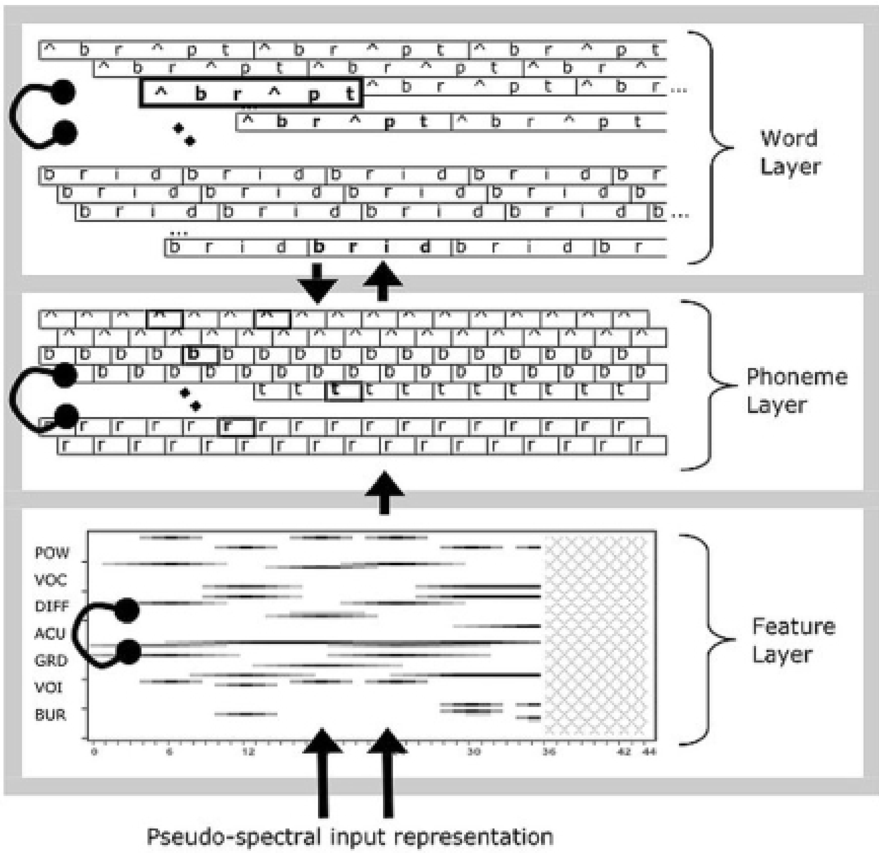

Figure 1. A scheme of the TRACE from Strauss, Harris and Magnuson (2007). The arrows show bottom-up and top-down interactions between the three layers. Units within each layer show inhibition and compete with each other.

3. Current study

The current study aims to examine the priming effect of cohorts and rhymes in a lexical decision task. There is around the fact that continuous mapping models, such as TRACE, are better suited for describing the brain activation processes during word recognition. TRACE indeed accounts for top-down activation as well as bottom-up, including the impact of the context. The Cohort model, however, does not include top-down feedback. In support of this model, the study by Marlsen-Wilson and Zwitserlood (1989) did not find a priming effect for word rhymes; only for word onsets.

The current study largely replicates the study by Marlsen-Wilson and Zwitserlood (1989) in terms of comparing the priming effects of onsets and rhymes, with the difference that only auditory phonologically related targets are used to examine whether similar results can be found. We intend to test both models by means of rhyming and cohort-related monosyllabic Dutch stimuli pairs and look at the alleged effects of activation and inhibition mentioned by Norris et al. (2002). Our research question is how spoken words are processed by the brain: in a forward sequence (Cohort) or with feedback (TRACE)? In addition, the subquestion of this paper is whether priming with a matching rhyme (rhyme prime) results in faster response times to the target word than priming with a matching onset and nucleus (cohort prime).

The results of the study by Marlsen-Wilson and Zwitserlood (1989) suggest that word onsets have a stronger priming effect than word rhymes. However, the study by Norris et al. (2002) found an inhibitory effect in word pairs that have the same onset, but not in word pairs with the same rhyme. It could be that this inhibitory effect does not occur in a cross-modal priming task, as was used in the study by Marlsen-Wilson and Zwitserlood (1989). Therefore, in the current study an auditive priming task is used to see whether similar or different results will be found. In addition, the TRACE model is more backed-up by research than the cohort model. Therefore, our hypothesis is that the TRACE model gives a better account of online lexical processing and we expect, thus, a delay in the response time to cohort-related targets compared to rhyme-related targets. In other words, we expect that a rhyme has a stronger priming effect than the cohort. If we indeed find this outcome, this would contradict the findings of Marlsen-Wilson and Zwitserlood (1989), which would suggest that cross-modal priming could lead to different effects than uni-modal priming. Therefore, this result would contribute to the field of psycholinguistics by providing evidence that different modality combinations could lead to different priming effects.

4. Method

4.1 Participants

A total of 29 participants were recruited from family members and friends of the experimenters aged between 19 and 59 years old (17 females, 12 males, M = 31;6, SD = 14). They were all native Dutch speakers, all but one were right-handed and none of them had reported being dyslexic. There was no for participating in the study. The procedure was approved by the UiL-OTS Ethical Committee (ETCL).

Dutch is chosen as experimental language, because the experiment was run in the UiL-OTS lab in Utrecht, the Netherlands. It was, therefore, most convenient to recruit native

Dutch participants. In addition, this study largely replicates Marslen-Wilson and Zwitserlood (1989) which contained Dutch stimuli and tested Dutch native speakers as well.

4.2 Material

All the stimuli were monosyllables with a CVC structure that were recorded by an adult female Dutch speaker. The prime was always an existing word and the target was either a word or a non-word. Each participant received four practice pairs before the real trials began with 160 word pairs (320 words in total). There were three types of relations between the prime and the target: unrelated, cohort-related and rhyme-related. Cohort-related targets shared the CV structure (e.g. *hok - hol*) and rhyme-related targets shared the VC structure (e.g. *hok - mok*). No semantic relation occurred within the pairs and no non-word was an existing word in English. The words could come from different lexical categories and could be inflected verbs. Table 1 gives an overview of stimuli examples for each condition. The whole list of stimuli can be found in Appendix 1[1].

Table 1

Stimuli examples for each condition

	Cohort related	**Rhyme related**	**Unrelated**
Word	zit (sit) - zin (sentence)	pin (pin) - zin (sentence)	tas (bag) - deur (door)
Non-word	neer (down) - neek	deeg (dough) - beeg	room (cream) - wuus

All words were selected by the researchers themselves. From these words, the experimental stimuli were derived: 20 rhyme related words and 20 cohort related word pairs. There were 40 filler unrelated word targets. The filler non-words stimuli were derived from 20 cohort related non-words, 20 rhyme related non-words and 40 unrelated non-words. We used a Latin-square design to generate two different experimental stimuli lists presented to the participants, in such a way that the participants were either presented with the cohort-related prime or the rhyme-related prime of a target word. Because the target words were the same for all participants, there was no frequency effect of the target words. In addition to that, we used a pseudo-randomization for the order of the pairs, with a maximum of three subsequent non-filler items and two subsequent non-filler items of the same type. Per item the screen showed the question: "Is the second word an existing word in Dutch?" Two versions of the experimental screen were created with the position of the yes and no button inverted to counter-balance for an effect of a dominant-hand bias. The participants were distributed equally into each group and each version.

A fixation cross appeared one second before the start of each trial, and feedback appeared during one second after each response from the participants only during the practice trials. Each stimulus item onset was preceded by a 30 ms silence interval, the stimulus onset asynchrony was of 300 ms, and participants had three seconds to make a decision. The intertrial interval was of one second.

1 Appendices are included in this digital copy of LingUU.

4.3 Procedure

The stimuli were recorded in a soundproof booth using the version 2.0.0 of Audacity(R) audio recording and editing software[2]. Participants were either tested in a soundproof booth or in a quiet room. The stimuli were presented to participants via loudspeakers in the former condition or via headphones in the latter condition. The reaction times were recorded from the onset of the target stimulus. Each session consisted of four practice trials after which participants could still ask questions, before the 160 experimental trials. They were instructed to decide as quickly as possible whether each second word of the pair they heard was an existing word in Dutch, and to press the button labelled *yes* on a button box if the item was a word and the button labelled *no* if it was a non-word. They had to use both hands, one per button.

4.4 Data Analysis

We used the *lme4* package (Bates, Maechler, Bolker & Walker, 2015) in R (R Core Team, 2016) to perform a linear mixed effects analysis of the relation between response time, and cohort priming and rhyme priming. As fixed effects, we used priming type and trial number, without interaction term. Trial number is only part of the model, because more data is explained when this factor is part of the model. As random effects, we had intercepts for subjects and items, as well as by-subject and by-item random slopes for the effect of priming type. The model was performed on the data of the correct responses to the cohort and rhyme pairs.

A linear mixed effects analysis was performed to see the effect of word type (word versus non-word) on the response time. This was done to see whether the lexical decision task in this study leads to similar results as lexical decision tasks in the previous literature. There should, namely, be an effect of word type in a lexical decision task; existing words should have shorter response times than non-existing words. In other words, participants have to check their entire mental lexicon to be sure that a non-word does not exist in a mental lexicon, which takes time. As fixed effects in the model, we used word type and trial number. As random effects, we had intercepts for subjects and items, as well as by-subject random slopes for the effect of word type. This model was performed on the data of the correct responses to all stimulus types.

The models were compared using the likelihood ratio test. So, p-values were obtained by comparing models stepwise by doing ANOVAs between two models each time. Two models were compared, one of which contained the examined factor and the other did not. Based on the significance of the p-value in the output of the ANOVA it was decided whether the factor had a significant effect on the response time and, thus, whether the factor should be part of the model.

To examine the research question, the correct responses to the experimental stimuli were analyzed. We did not exclude any of the participants, because no participant

2 Audacity(R) software is copyright (c) 1999-2014 Audacity Team. Website: http://audacity.sourceforge.net/. It is a free software distributed under the terms of the GNU General Public License. The name Audacity(R) is a registered trademark of Dominic Mazzoni.

showed abnormalities compared to the group. We did exclude the response times of the trials in which participants did not respond (value -9999), and response times that were below 400 ms. When the percentage of correct responses to a target item was below 60%, that item was excluded as well. This was done for five target non-words: *bir, vir, don*, *pem*, and *tan*. These words were probably too similar to existing words in Dutch. For example, *bir* (/bɪr/), which is a non-existing word in Dutch, sounded almost the same as *beer* (/bɪ:r/), which is an existing word in Dutch. The total percentage of excluded data was approximately 4%.

5. Results and Discussion

In this section, the results are explained and interpreted. First, the raw data is described to see the distribution of the responses. After that, the data of the cohort and prime pairs is described and compared.

5.1 Data exploration

Figure 2 shows a histogram of the response times of all trials of the experiment. The bell curve indicates that the distribution of the response times is a normal distribution with a mean response time of approximately 1050 ms. The mean response time per stimulus type is presented in Figure 3 with boxplots.

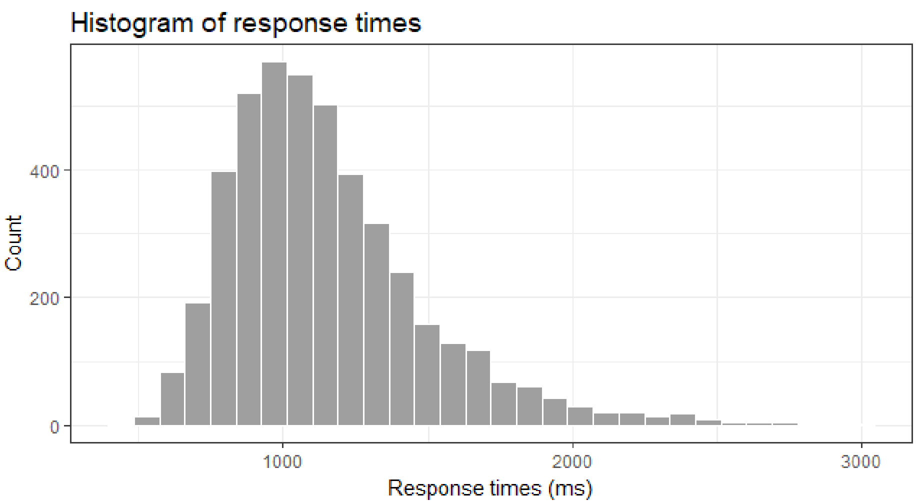

Figure 2. Histogram of response times in milliseconds of all trials in the experiments.

As can be seen from the boxplots in Figure 3, the mean response times of the existing words with either the cohort prime or rhyme prime are lower than the mean response times of the other (filler) stimulus types. In addition, the existing word with a rhyme prime has the lowest mean response time. The mean response times of the experimental stimuli (word cohort and word rhyme) are around 1000 ms. The mean response times of the filler stimuli are all around 1100 ms. However, as can be seen in the figure, there are a lot of outliers. Most outliers were not excluded, because the mixed model controls for this.

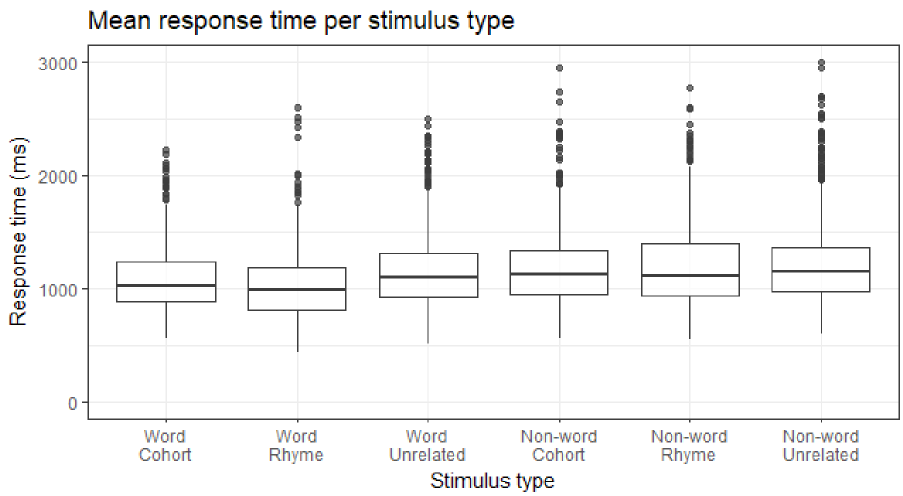

Figure 3. Boxplots of mean response time in milliseconds per stimulus type.

The linear mixed effects analysis of the correct responses to all stimulus types showed that there was a significant effect of word type ($\chi^2(1) = 7.80$, $p = 0.0052$). The mean response time of the existing words was 104 ms (SE = 36 ms) faster than the mean response time of the non-existing words. This result indicates that the auditory lexical decision task worked properly.

In the next section, the results of the linear mixed effects analysis are described. In this analysis, only the data of the correct responses to the cohort and rhyme priming stimuli are taken into account.

5.2 Rhyme versus cohort priming

The linear mixed effects analysis of correct responses to the phonologically primed stimuli indicated that there were significant effects of priming type ($\chi^2(1) = 8.41$, $p = 0.0037$) and trial number ($\chi^2(1) = 13.33$, $p = 0.00026$) on the response times. The results suggest that the participants were 48 ms (SE = 15 ms) faster on average when the prime word had the same rhyme as the target word than when the prime and target words had the same cohort. The boxplots of the mean response time per stimulus type in Figure 3 is in line with this finding, because the mean response time for existing words with a rhyme prime was the lowest.

The outcome of the analysis showed that there was, except for a significant effect of priming type, also a significant effect of trial number. The mean response time decreased with 0.6 ms (SE = 0.2 ms) per trial number on average. So, participants responded faster in the course of the experiment. It could be that this result reflects a learning effect or habituation effect.

The significant positive effect of rhyme priming is in favour of the TRACE model. According to this model, the auditory stimulus is divided into phonemes but instead of looking for exact matches, even approximate matches in phoneme sequences anywhere in the target word are allowed to be activated. So, the results reflect continuous mapping. The mean response times to target words with a cohort prime word were lower than the response times of words with a rhyme prime word. This could be due to an effect of lexical access that inhibits word activation of the target word in the cohort condition (Norris et al., 2002).

6. Conclusion

In conclusion, this study examined the effect of cohort and rhyme priming on the word recognition of monosyllabic Dutch words. The research question was whether priming with a matching rhyme (rhyme prime) results in faster response times to the target word than priming with a matching onset and nucleus (cohort prime). Based on the literature, we expected that the effect of rhyme priming was stronger than the effect of cohort priming. To examine this, an auditory lexical decision task was performed. The results of a linear mixed effects analysis showed that the participants responded on average 48 ms (SE = 15 ms) faster when the target word was primed with a rhyme word than when it was primed with a cohort word. Therefore, the results indicate that the rhyme of a prime word has a stronger positive effect on the activation of a target word than the cohort of a prime word. This result is in line with the TRACE model and the literature described in Section 2, because it reflects bottom-up as well as top-down activation.

In contrast, this result cannot be explained by the Cohort model and contradicts the results found by Marslen-Wilson and Zwitserlood (1989). This may be caused by the methodological differences between the current study and Marslen-Wilson and Zwitserlood (1989). The latter study used auditory primes and visual targets, which may affect word recognition in a different way than purely auditory stimuli pairs. This then implies that there are differences in how words are recognized and co-activated depending on how stimuli are presented. This finding contributes to the field of psycholinguistics by showing that different modalities lead to different priming effects. More research is needed to explain these differences in priming effects. However, based on our results, we conclude that the TRACE model is more complete than the Cohort model. This suggests that the brain processes spoken words in a bottom-up and top-down fashion.

The stimulus items used in the current study were only monosyllabic words. Further research could be done to see whether the effect of rhyme priming is still stronger in words that contain more syllables. The effect of rhyme priming could also be investigated in different modalities, or even in cross-modalities. It could be that a rhyme priming effect in written words is dependent on the transparency of the orthography of a language. So, for instance, the rhyme priming effect on written words could be stronger in Dutch than in English.

The current study has given evidence for feedback or top-down activation of spoken word recognition. Out of this follows that the TRACE model is more complete than the Cohort model in terms of explaining phonological priming effects. ■

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Appendices

Appendix 1. Stimuli

Gemiddelden (en standaarddeviaties) per conditie en per variabele

Type	Target	Prime
Word rhyme	ruis	buis
Word unrelated	dam	rug
Non-word cohort	neuf	neus
Non-word unrelated	gop	dier

Experimental trials

	Target Word	Cohort Prime	Rhyme Prime
1	bot	bol	lot
2	bal	bar	val
3	sip	sik	wip
4	had	ham	mat
5	feit	fijn	geit
6	gat	gas	pad
7	dom	dop	bom
8	cel	set	bel
9	boos	boom	poos
10	duik	duim	buik
11	vos	vol	los
12	man	map	kan
13	pan	pak	van
14	kat	kar	lat
15	kaas	kaal	baas
16	vat	vak	nat
17	zoen	zoek	doen
18	zaal	zaak	baal
19	boon	boot	toon
20	wijn	wijk	zijn
21	zin	zit	pin
22	haan	haak	baan
23	hak	hal	bak
24	dak	dan	zak
25	hok	hol	mok
26	hoek	hoes	doek
27	maan	maak	gaan
28	naam	naar	raam
29	kop	kok	mop

30	laag	laan	vaag
31	vijf	vijl	lijf
32	min	mik	kin
33	haas	haat	vaas
34	ram	rat	nam
35	dus	dun	lus
36	weg	wel	pech
37	wol	won	lol
38	zes	zet	bes
39	paal	paar	taal
40	ruig	tuin[1]	huig

Experimental trials

	Target	Prime	Stimulus type
1	biet	zout	Word unrelated
2	bon	hek	Word unrelated
3	dip	koor	Word unrelated
4	doos	jat	Word unrelated
5	fop	mak	Word unrelated
6	geen	luis	Word unrelated
7	goed	heb	Word unrelated
8	goud	rood	Word unrelated
9	haal	zot	Word unrelated
10	hijs	god	Word unrelated
11	kip	lijn	Word unrelated
12	kom	put	Word unrelated
13	koos	puin	Word unrelated
14	lam	keus	Word unrelated
15	nul	hap	Word unrelated
16	meel	sap	Word unrelated
17	muis	kot	Word unrelated
18	noot	maf	Word unrelated
19	pad	nek	Word unrelated
20	peer	net	Word unrelated
21	pijn	koek	Word unrelated
22	raad	ziek	Word unrelated
23	ras	tot	Word unrelated
24	rem	sok	Word unrelated
25	ril	loep	Word unrelated

1 *Tuin* is of course not a cohort prime word of the target word *ruig*. We accidentally made a mistake here. Since this was only one item, we do not think that this influenced the results.

26	rok	pen	Word unrelated
27	som	win	Word unrelated
28	toen	lip	Word unrelated
29	vel	wat	Word unrelated
30	wit	zus	Word unrelated
31	buur	luik	Word unrelated
32	duin	reis	Word unrelated
33	duif	zoon	Word unrelated
34	mis	pop	Word unrelated
35	vis	lak	Word unrelated
36	jas	peil	Word unrelated
37	hip	rot	Word unrelated
38	roem	wijs	Word unrelated
39	zoem	pit	Word unrelated
40	deur	tas	Word unrelated
41	zik	tik	Non-word rhyme
42	jaal	maal	Non-word rhyme
43	pes	les	Non-word rhyme
44	juur	kuur	Non-word rhyme
45	zam	tam	Non-word rhyme
46	jaak	kaak	Non-word rhyme
47	tag	dag	Non-word rhyme
48	git	dit	Non-word rhyme
49	poem	noem	Non-word rhyme
50	hog	nog	Non-word rhyme
51	pum	gum	Non-word rhyme
52	mel	fel	Non-word rhyme
53	tul	gul	Non-word rhyme
54	gol	mol	Non-word rhyme
55	sut	nut	Non-word rhyme
56	lon	non	Non-word rhyme
57	tep	nep	Non-word rhyme
58	res	mes	Non-word rhyme
59	zos	mos	Non-word rhyme
60	beeg	deeg	Non-word rhyme
61	baaf	koop	Non-word unrelated
62	maap	wis	Non-word unrelated
63	bir	raaf	Non-word unrelated
64	vir	maat	Non-word unrelated
65	zil	lap	Non-word unrelated
66	kes	maag	Non-word unrelated
67	din	wal	Non-word unrelated

68	mip	rus	Non-word unrelated
69	ler	roer	Non-word unrelated
70	ker	rol	Non-word unrelated
71	lar	woon	Non-word unrelated
72	koom	raap	Non-word unrelated
73	laar	kook	Non-word unrelated
74	lim	zag	Non-word unrelated
75	wap	loop	Non-word unrelated
76	mief	waar	Non-word unrelated
77	pem	lood	Non-word unrelated
78	beup	lied	Non-word unrelated
79	lep	pool	Non-word unrelated
80	zeet	lach	Non-word unrelated
81	nof	met	Non-word unrelated
82	mieg	rek	Non-word unrelated
83	leup	jaar	Non-word unrelated
84	wug	toch	Non-word unrelated
85	rup	tol	Non-word unrelated
86	jit	haar	Non-word unrelated
87	beep	maar	Non-word unrelated
88	nof	lik	Non-word unrelated
89	joek	heus	Non-word unrelated
90	toes	reus	Non-word unrelated
91	paaf	loog	Non-word unrelated
92	zaap	tuig	Non-word unrelated
93	reen	hoog	Non-word unrelated
94	hig	zuig	Non-word unrelated
95	goef	lijk	Non-word unrelated
96	soel	rijm	Non-word unrelated
97	nijk	roes	Non-word unrelated
98	moon	rap	Non-word unrelated
99	taap	rein	Non-word unrelated
100	wuus	room	Non-word unrelated
101	mup	mus	Non-word cohort
102	mef	mep	Non-word cohort
103	deg	dek	Non-word cohort
104	dap	das	Non-word cohort
105	sup	suf	Non-word cohort
106	boep	boen	Non-word cohort
107	bijm	bijl	Non-word cohort
108	book	boog	Non-word cohort
109	tef	tel	Non-word cohort

110	tan	tak	Non-word cohort
111	kaaf	kaap	Non-word cohort
112	keuf	keur	Non-word cohort
113	kijp	kijk	Non-word cohort
114	neel	neem	Non-word cohort
115	nief	niet	Non-word cohort
116	neek	neer	Non-word cohort
117	don	dol	Non-word cohort
118	dif	dik	Non-word cohort
119	lan	laf	Non-word cohort
120	bip	bil	Non-word cohort

Appendix 2. R output effect word type

```
Linear mixed model fit by maximum likelihood t-tests use Satterthwaite approximations
to degrees of freedom [lmerMod]
Formula: rt ~ WordNonword + trialnum + (1 + WordNonword | ppid) + (1 |id)
  Data: AllDataCorrect

    AIC     BIC  logLik deviance df.resid
59001.2 59052.0 -29492.6 58985.2     4234

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.0254 -0.6045 -0.1757  0.3730  5.9504

Random effects:
 Groups   Name            Variance Std.Dev. Corr
 id       (Intercept)     22875    151.2
 ppid     (Intercept)     43015    207.4
          WordNonwordWord 19315    139.0    -0.76
 Residual                 55960    236.6
Number of obs: 4242, groups:  id, 155; ppid, 29

Fixed effects:
                  Estimate Std. Error         df t value Pr(>|t|)
(Intercept)     1267.45116   43.10824   43.00000  29.402  < 2e-16 ***
WordNonwordWord -103.69689   36.19937   83.00000  -2.865  0.00529 **
trialnum          -0.84470    0.08104 4050.00000 -10.423  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) WrdNnW
WrdNnwrdWrd -0.698
trialnum    -0.152  0.002
```

Appendix 3. R output priming effect

```
Linear mixed model fit by maximum likelihood t-tests use Satterthwaite approximations
to degrees of freedom [lmerMod]
Formula: rt ~ type + trialnum + (1 + type | ppid) + (1 + type | id)
  Data: TargetsCorrect

  AIC       BIC    logLik deviance  df.resid
14787.7 14837.5 -7383.8 14767.7        1068

Scaled residuals:
   Min       1Q  Median      3Q      Max
-2.0489 -0.6075 -0.1743  0.3630  5.2444

Random effects:
Groups   Name        Variance Std.Dev. Corr
id       (Intercept) 19328    139.02
         typeW_RH     2227     47.19   0.38
ppid     (Intercept) 15335    123.84
         typeW_RH      157     12.53   1.00
Residual             43539    208.66
Number of obs: 1078, groups:  id, 40; ppid, 29

Fixed effects:
             Estimate Std. Error        df  t value  Pr(>|t|)
(Intercept) 1117.7470    35.4270   74.8000  31.551  < 2e-16 ***
typeW_RH     -47.6454    14.9875   36.1000  -3.179 0.003030 **
trialnum      -0.5540     0.1506 1017.8000  -3.678 0.000248 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
         (Intr)  tyW_RH
typeW_RH  0.056
trialnum -0.358  0.020
```