The Effect of High Head-Frequency in Position-Specific Letter Recognition in (Non)Words

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Abstract

Letter recognition in high frequency (non)words will be studied by means of the conceptual network. Previous studies examining this, found an unexpected peak in performance in the third position of non-words, instead of the expected hook shape for positions one to five. The current study builds on these previous studies by providing an explanation for the peak. This is done by partial replication of the previous studies and adding a new variable, head-frequency. This experiment uses high frequency Dutch (non)words and distributed and centered warning signals. The centered warning signal is thought to cause the peak in the third position, but it is expected that the effect of the high head frequency will overrule this effect. The current study found that high head frequency does provide an explanation for the peak in position three, as the hook-shape was found, and therefore the notion that head frequency has a larger effect on letter recognition than warning signal.

Keywords: Letter Recall, Word Recognition, Conceptual Network, Head-Frequency, Warning Signal

The Effect of Head-Frequency in Position-Specific Letter Recognition in (Non)Words

When we are little children, we all must learn how to recognize letters and spell words. When we get older, the reading will become more fluently and more easily. By the time adulthood is reached, most of us are fully fluent in our native language, and maybe also in different languages. It takes no effort for us to read, it seems like it is an automatic skill. But how come we read so easily? When reading, the words are recognized as a whole, instead as a sequence of separate letters. The core of this process is the recognition of letters and linking this to their relative positions.

In previous studies, done as bachelor thesis research by our predecessors, research was done concerning letter recall based on letter positions. These studies were aimed at examining letter recall dependent on the position of the letter in words and non-word letter sequences, and whether the participants recognizing a word as such was impacting the letter recall. This was done by means of a letter recall task where participants had to give the correct letter for a certain position of a word or non-word that was showed for a short amount of time, and a lexical decision task where the participants had to decide whether they perceived the word or non-words as such (Whittaker, 2019). They used the idea of the word-superiority effect and the research that has gone into that to make a basis for the current study. The word-superiority effect is being described as the more rapidly and more accurately identification of a letter in the context of a word than in the context of a non-word (Lukatela et al., 1981). A non-word is a scrambled collection of letters (Krueger, 1992). In further research, letter recognition has been examined by means of priming, which has led to several models that take letter position into account when elaborating on word recognition. The way in which the combination between letter position and word recognition is made, has several explanations, and can be viewed as one instance of the binding problem. The binding problem either refers to the scientific challenge of identifying mechanisms that may achieve binding or to the difficulty that mind, and brain may have with binding in certain situations (Burwick, 2014).

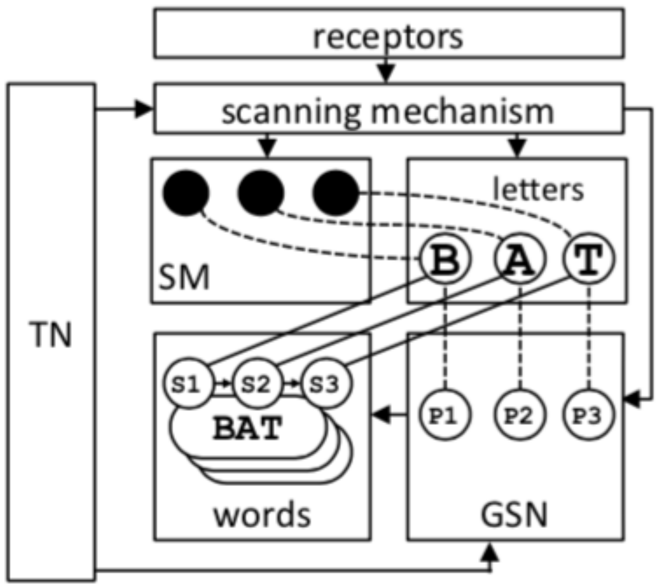
When trying to explain the role of letter position in terms of letter recognition, the researchers of the previous study tried doing this based on the Interactive-Activation Model (McClelland & Rumelhart, 1981). The model suggests that when a sequence of letters is presented, a process of activating detectors specific for letters and words begins. These activations grow stronger when they encounter more exposure, and they begin to activate detectors for words that are consistent with the letters. The active word detectors then produce feedback, which reinforces the activation of the detectors for the letters in the word. This results in a better recognition of letters in words, because they receive more activation than representations of either single letter or letters in an unrelated context (McClelland and Rumelhart, 1981). This fits to the hypothesis of the previous study that letter recall accuracy will be higher in words than in non-words. Unfortunately, the model failed in trying to explain the role of letter position when discussing letter recognition. The model uses conjunctive coding, which means that in word recognition, representations are used that put letter identity and position together. Letter strings are processed in parallel by a set of length-dependent, position-specific letter detectors (e.g. a different unit for the T as a first letter of a four letter words and a different unit for the T as a first letter of a five letter word). This led to an incredible number of representations encoded, which could lead to combinational explosion, (i.e., when all these letter representations are connected to tens of thousands of different location and position representations) (Grainger, 2008). Therefore, the Interactive-Activation Model does not provide a good explanation for the binding problem.

The researchers of the previous study evaluated a different model too. This model, the SERIOL model (sequential encoding regulated by inputs to oscillations within letter units), was proposed by Whitney (2001). The model suggests that serial processing is involved, and that letter position is encoded by a temporal firing pattern across letter units. This provides a solution to the position specific letter detectors in the IAM, but it still does not propose the existence of a position-specific top-down activation from the word to its letter nodes (Pink, 2019), something that would be necessary to explain why letters in words are more easily recognized than letters in non-words.

When addressing the binding problem, it is necessary to distinguish whether a model of word recognition is described at a functional level or a structural level. A model that is described at a functional level is an information-processing model, which lacks the mechanisms necessary for explanation on the biological level. Models that are described at a structural level do provide mechanisms that refer to this level (de Vries, 2016). The conceptual network is such a structural model. This model is based on the work of Dalenoort and de Vries (2004). The basic assumption of this model is the Tanzi-Hebb rule (Hebb, 1949; Tanzi, 1893). It says that when connected neurons fire simultaneously, it will increase their connectivity over time. This creates cell assemblies: clusters of neurons that are more strongly connected with each other than with surrounding neurons (Whittaker, 2019). These cell assemblies are important, as they represent the identity of a concept, which is independent of its position and location. Necessary for these cell assemblies are the critical thresholds. The activation of a cell-assembly at a level below the critical threshold corresponds to a memory trace that is in a state of priming. Alternatively, a cell-assembly with an activation level above the critical threshold, corresponds to a memory trace that is in working memory (de Vries, 2016).

Figure 1

The Conceptual Network



Schematic representation of the conceptual network. Adapted from de Vries, P. H. (2016). Neural binding in letter- and word-recognition. In K. E. Twomey, A. Smith, G. Westermann, & Padraic Monaghan (Eds.), *Progress in neural processing. Neurocomputational Models of Cognitive Development and Processing* (pp. 17–33). World Scientific Publishing.

The conceptual network uses four categories of nodes: letter identity, word identity, location, and position, as can be seen in Figure 1. The spatial map (SM) holds information about the location. The global sequence network (GSN) represents positions within a sequence, corresponding one-to one to a position. Letter identity is similarly represented by cell assemblies, and the same goes for words. To enable word recognition, a local sequence network (LSN) is introduced. Each word has its own LSN with its own position nodes, which are permanently connected to the corresponding letter identities of the respective word (Whittaker, 2019).

The model assumes serial binding, rather than parallel binding. In Figure 1, the dashed lines represent this serial binding, i.e., temporary connections between letter identity and letter position. This is necessary to avoid the combinational explosion, that was seen in the Interactive-Activation Model. Because the binding occurs in a serial manner, the activation of letter nodes decays, creating the so-called letter decay effect, meaning that the first connection will be the strongest, with a slight decrease in strength for each consecutive position, with an exception for the last position, where a slight increase takes place. This increase happens because of a reverberation that takes place, the excitation reverberates between the memory trace for the last letter and the last position node, increasing the strength of the last connection (de Vries, 2016). The strength of the letter decay effect is proportional to the levels of activation of these memory traces at the moment of their binding. This effect creates a "hook-shape". This is expected to only be found in non-words. For words there is an equally strong connection for each position. This happens because when a word is presented, the successive activation of the position nodes leads to word node activation. A top-down activation from word to letter level becomes active. Therefore, all temporarily connections between a position node and the letter node become equally strong. Accordingly, performance will be equally strong for all consecutive letters. When the last position is reached, the corresponding word node will receive increased activation. The moment at which this activation reaches the critical threshold would correspond to the subjective experience of recognizing that word at a single glance (Whittaker, 2019).

As mentioned before, the previous studies tried to explain the role of letter position in terms of letter recall by using the conceptual network. Their hypothesis was that binding was necessary for letter recognition and therefore that non-words would have the highest accuracy at position one, with a decrease in accuracy for position two, three and four and then a slight increase in accuracy in position five, causing the "hook-shape" to arise. They also expected that the overall performance of letter accuracy was higher for words than for non-words, as these letter combinations have a stronger connection, since they receive more excitations and therefore have a lower activation threshold. The previous studies examined this by means of the n-th letter task. This is a task where a participant gets to see a word or non-word for a short amount of time, and then must recall the letter that was shown in a specific position.

In one set of these previous studies (Whittaker, 2019; Mudogo, 2019; Pink, 2019; Buijsman, 2019; Schwartzkopf; 2019), the hypotheses were examined by administering a n-th letter task combined with a lexical decision task. It was theorized that, veridically perceiving a word would allow for more position-specific top-down activation to its letters, aiding reportability of a letter given its position (Pink, 2019). Again, it was expected that letter recognition accuracy would decrease with each letter position, except for the last position, for non-words. The first hypothesis, namely that letters in veridically perceived words were recognized better, was supported. This effect was not found in non-words (Mudogo, 2019). The second hypothesis, namely that recall performance will decrease from position 1 to position 4 in non-words, was not supported, there was a peak in performance for the third position for non-words (Whittaker, 2019). Interestingly, this peak was only found in Dutch non-words.

In a second set of studies (Freericks, 2018; Seibel, 2018; Donelan, 2018; Bhouri, 2018), the hypotheses were examined by administering a n-th letter task with different types of preparation signals. These preparation signals were expected to pre-activate areas on the spatial map, a module of the conceptual network, as can be seen in Figure 1. This pre-activation was assumed to facilitate binding in the model, leading to a higher recognition proportion in the n-th letter task (Seibel, 2018). The study made use of different types of preparation signals, either a distributed one, where the participants had to focus equally on all the possible positions, or a centered one, where the participants had to focus on the third position. It was hypothesized that the centered preparation signal would yield higher mean accuracies of letters in the center of the words (Donelan, 2018). The study also used flankers; hashtags presented on each side of the word. It was hypothesized that their presence leads to a decreased performance in the n-th letter task (Freericks, 2018). So, they expected that the presence of the centered warning signal would explain the peak found in the first set of studies, but they found no significant effect of the warning signal for German words. Thus, after this study, no explanation for the peak in the third position has been found.

In the current research, we will elaborate further on the peak that was seen in the previous studies. This will be done by partially replicating the previous study that was done with German words, but instead with Dutch words in the current experiment. So, a n-th letter task will be administered, where a distinction will be made between words and non-words, and the centered and distributed warning signals will be used. Hereby, there will be made a difference between a non-word and a word. But, in the present study, a new variable will be introduced to see whether this can explain the peak in position three. The variable introduced is head frequency, which means that the first three letter of a non-word will either be of a combination that is common (high head frequency) or that is uncommon (low head frequency). Each of the six experiments in this study will each focus on different combinations of beforementioned variables, resulting in three different designs with each design being administered in both English and in Dutch. This experiment will focus on only Dutch high-frequency non-words and words, with using both the centered and distributed warning signal. In this design, the centered warning signal is not expected to have an influence because of the influence of the high-head frequency, whereas in the ‘sister experiment’ with low-head frequency the centered warning signal is expected to have an influence. Following out of this design, the hypotheses for the present study are: 1a. For non-words, there will not be a peak in performance in position 3 for both centered and distributed warning signals; 1b. There will be a hook-shape in the distribution for both the centered and distributed warning signal; 2. For words, each position will have a similar performance for both the distributed and the centered warning signal; 3. The overall performance will be better for words than for non-words.

Method

Participants

For the study, 41 participants were recruited out of different sources. The participants (7 male and 34 female) were either first year psychology students at the University of Groningen (17), volunteers (16), or people recruited through Prolific (8), with a mean age of 30.83 and a standard deviation of 16.32. They are native Dutch speakers, and they volunteered for the study. The students received study credits for their participation and the participants from Prolific received a payment of £2, -. People with dyslexia were excluded from the research. The Ethical Commission of the Faculty of Behavioral and Social Sciences at the University of Groningen approved this study.

Design

This study used a letter recall task in a 2 x 2 x 5 design, with an independent variable of word type with two levels (word or non-word), an independent variable of warning signal type (centered or distributed) and an independent variable of letter position (1 … 5). The dependent variable was the response accuracy, numerically expressed as a proportion of percentages, in the letter recall task.

Stimuli

The Dutch words used in this experiment were selected out of the CELEX Centre for Lexical Information (2001) and were the same as in the previous studies done by our predecessors. The words were selected in pairs, and each pair contained the same letter in the same order, except for the target letter (e.g., BAARD and WAARD: a Dutch word pair where the participants had to report the first letter). The target letter is the letter that remained the same in both words of the pair. This was done to avoid that participants reported the letter, simply based on the surrounding letters. For instance, when you show the word QUIZ to participants, and ask them to report the second letter, they could report the letter U without seeing it (Reicher, 1969). This because in Western languages, the first letter Q is always followed by the letter U (Pink, 2019). With the letters of the two words, a non-word was created. This was done by keeping the target letter at the same position and mixing the other letters around. This was done to make sure the frequency of the letter combinations was the same for words and for non-words (Reicher, 1969). The non-words that were created, either had high frequency begin letters, or low frequency begin letters. This means that the first three letters of the non-words, were either common letter combinations, or either uncommon letter combinations (e.g., BAA for high frequency and BDR for low frequency). The low and high frequency words were chosen out of a pool with words that have a word frequency that is larger than seven per million.

Procedure

Since the experiment was done online, the participants used their own computers and logged into the environment where the experiment took place. The study information, consent form, and instructions were shown in Qualtrics (Qualtrics, Provo, UT). The instrumentation used for the training and the experiment was OpenSesame (Mathôt, et al., 2012). The participants received an information sheet (appendix A) and were asked to fill in a consent sheet before the experiment started. The experiment consisted of two practice blocks, each with 10 trials, and four regular blocks, each consisting out of 30 trials. Each trial had different screens, each consisting out of different tasks. Initially the screen would be blank for 1000 ms, followed by a warning signal that was either two hashtags with five dots in-between them or two vertical lines above each other with a white space in between them, that were visible for 500 ms. This was done so that the participant would have an indication of where the word or non-word would appear. When the participants were shown the first warning signal, so the one with the hashtags, the instruction was to divide their attention equally over the five dots. When the warning signal with the two vertical lines was shown, the participants were instructed to focus their attention on the space between the two lines. Next, the stimulus was presented for 50 ms, at the same place as where the warning signal was; between hashtags at the place of the five dots or between the vertical lines with the third letter between the two lines. The hashtags were added so that all letters would be surrounded by another character, ensuring that the surrounding whitespace at the left and right of a word or non-word would not have any influence on the outcome of the experiment. Finally, a mask ("#@@@@@#") replaced the stimulus and below the mask a number was presented to indicate which position the participant had to recall. When counting the letters, the hashtags should not be included in the counting, so the counting begins at the first letter and stops after the fifth letter. After the participant had entered the letter they perceived at that position, the next trial became visible. A visual representation of the experiment is shown in Table 1.

Table 1

Visualization of the Experiment

<table>
<tr><th>Screen</th><th>Visualization</th><th>Duration (ms)</th></tr>
<tr><td>Blank</td><td></td><td>1000</td></tr>
<tr><td>Warning Sig.</td><td>#.....# or |
|</td><td>500</td></tr>
<tr><td>Target</td><td>#BAARD#</td><td>50</td></tr>
<tr><td>Mask</td><td>#@@@@@#
2</td><td>Until response</td></tr>
</table>

The experiment started with two practice blocks each consisting out of 10 trials. In these trial blocks, the participants received feedback about their performance, so if the letter was filled in correctly, the mask turned green and if the letter was filled in incorrectly, the mask turned red. This was followed by four trials, with each 30 trials. Two of these four trials used centralized warning signals, and the other two used the distributed warning signal. Per participant, one set was randomly selected for each of the twenty conditions. It was randomized between participants whether they start with a centered or a distributed warning signal. For each of the ten non-word conditions, namely five letter positions with either a high or a low frequency, four compatible sets of six non-words were constructed. This was done so that each participant would get compatible words with compatible frequencies in it. Also, for each of the ten word-conditions, namely five letter positions with either a high or a low frequency, four compatible sets of six non-words were constructed. This was done for the same reason as for the non-words. In this experiment, only high frequency words and non-words were used, with either a centered or distributed warning signal, resulting in twenty different conditions, in which each participant had to do six different tasks. Once the experiment was done, the participants received a debriefing (Appendix B).

Due to the online administration of the experiment, the duration was limited. The total duration was around 20 minutes.

Analysis

To analyze the data, we use a repeated measures ANOVA with measures within subjects because with this analysis we can compare the results of the participants on the different conditions. Aggregation and restructuring were done in SPSS (Version 28). The analysis was done in JASP (Version 0.16).

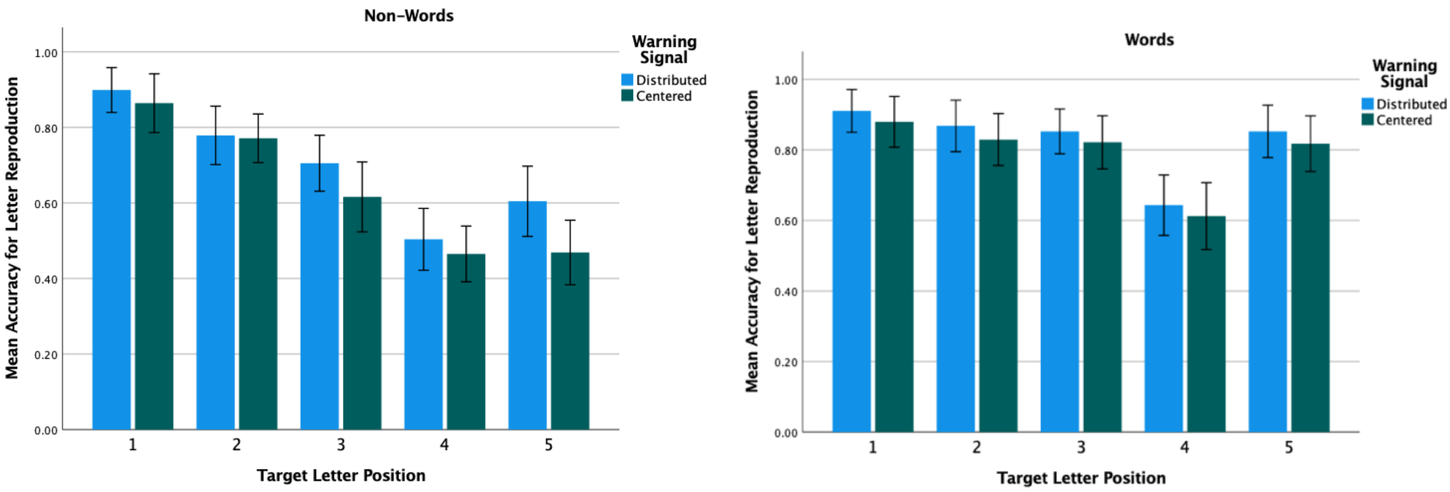
Results

All the analyses were done by means of a repeated measures ANOVA. Three separate analyses were conducted, each to support the three hypotheses that were examined in this study. Based on these analyses, all the hypotheses will be tested to see whether support can be found for the notion that warning signal influences letter recognition for high head-frequency words. The corresponding assumptions for the repeated measures are checked. An examination of a Q-Q plot showed that the assumption of normality was not violated. By means of Mauchly's test of sphericity, the assumptions of sphericity were violated for the main effect of position ($\chi^2(9) = 43.07$, $p < .001$) and for the interaction effect between position and word type ($\chi^2(9) = 18.20$, $p < .033$). This indicates that the variances of the differences between all combinations of related groups (levels) are not equal. This was corrected by using the Greenhouse-Geisser correction. The last assumption, independent observations, was not violated, since the methodology of this study was designed to make sure the observations were independent of each other. For instance, each participant received a different set of 20 words and 20 non-words, and the words or non-words in the sets were randomized for each participant.

The initial analyses showed that the three-way interaction between warning signal, position and word type is not significant ($F(4) = .88$, $p = .48$, ${\eta_p}^2 = .02$), as was expected. For the non-words, a hook shape was expected, for both the distributed and the centered warning signal, with a sequential decrease in accuracy for positions one to four followed by a small increase for the last position. If the three-way interaction would be significant, a peak in performance for the third position would have occurred, as was seen in the previous studies. The hook-shape can be seen in Figure 2. For words, it was expected that there would not be a difference in performance for each of the consecutive positions, as both warning signals should not make a difference over positions. This effect can be seen in Figure 2.

Figure 2

Mean Accuracy for Target Letter Position Reproduction for High-Frequency Words and Non-Words



As seen in Figure 2, for non-words a hook-shape is seen in the graph, for both the distributed and centered warning signal, as was hypothesized. There is a decrease for each consecutive position, and an increase for the last position. But when you take a closer look, not all these differences between consecutive positions are significant. For the distributed warning signal, the decrease between Position 3 (*M* = .62, *95% CI* [.62; .77]) and Position 4 (*M* = .49, *95% CI* [.41; .58]) is significant ($p < .001$). All the other consecutive differences are not significant ($p > .08$). Even though the decrease between position 1 and 2 is not significant, the decrease between position 1 (*M* = .90*, 95% CI* [.84; .96]) and 3 is significant ($p < .001$). For the centered warning signal, the decrease between position 2 (*M* = .76, *95% CI* [.69; .83]) and position 3 (*M* = .60, *95% CI* [.51; .69]) is significant ($p = .004$). All the other consecutive differences are not significant ($p > .055$). Similarly, to distributed non-words, the decrease between position 1 (*M* = .86, *95% CI* [.78; .94]) and position 3 is significant ($p < .006$).

For the words, no significant decrease or increase between the consecutive positions was hypothesized. As seen in figure 2, only partial support for this hypothesis was found. For position 4, there is a sudden decrease in performance. For the distributed warning signal, this decrease was between position 3 (*M* = .85, *95% CI* [.79; .92]) and position 4 (*M* = .63, *95% CI* [.55; .72]). For the centered warning signal, this decrease was also between position 3 (*M* = .81, *95% CI* [.73; .89]) and position 4 (*M* = .61, *95% CI* [.51; .71]). Both these decreases were significant ($p < .001$).

For the final hypothesis, that performance on words would be higher than on non-words, support was found. The main effect for Word Type is significant, meaning that Word Type has a significant influence on performance. When you look at Figure 2 you can see that the graph displaying the words, has an overall higher performance than the graph displaying the non-words.

Table 2

F-ratios including statistics

Cases	Sum of Squares	df	Mean Square	F	p	η^2_p
Warning Signal	0.43	1	0.43	8.98	0.005	0.18
Position	10.72	4	2.68	64.18	<.001	0.62
Word Type	4.17	1	4.17	142.73	<.001	0.78
Warning Signal * Position	0.11	4	0.03	1.05	0.382	0.03
Warning Signal * Word Type	0.03	1	0.03	0.934	0.340	0.02
Position * Word Type	1.92	4	0.48	19.065	<.001	0.32
Warning Signal * Position * WordType	0.09	4	0.02	0.88	0.480	0.02

In Table 2, there is an overview of all the main- and interaction effects. The main effect for warning signal was significant ($F(1) = 8.98$, $p = .005$, ${\eta_p}^2 = .18$). The main effect for position was also significant ($F(4) = 64.18$, $p < .001$, ${\eta_p}^2 = .62$). The final main effect, for word type, was significant as well ($F(1) = 142.73$, $p < .001$, ${\eta_p}^2 = .78$). It was not expected that the main effect for warning signal would be significant, but the analysis showed that for both non-words and words, the performance on the distributed warning signal was better than for the centered warning signal for each position. An overview of this effect can be seen in Table 3a and 3b. Since this effect was not hypothesized, it will be further elaborated on in the discussion.

Table 3a

Main Effect Warning Signal for Non-Words

Condition	Mean	95% Confidence Interval for Mean: Lower Bound	95% Confidence Interval for Mean: Upper Bound
Distributed, position, 1	.90	.84	.96
Centered position, 1	.86	.78	.94
Distributed position, 2	.77	.69	.85
Centered position, 2	.76	.69	.83
Distributed position, 3	.69	.62	.77
Centered position, 3	.60	.51	.69
Distributed position, 4	.49	.41	.58
Centered position, 4	.46	.36	.54
Distributed, position 5	.59	.49	.69

Centered, position 5	.47	.38	.56

Table 3b

Main Effect Warning Signal for Words

Condition	Mean	95% Confidence Interval for Mean; Lower Bound	95% Confidence Interval for Mean; Upper Bound
Distributed, position 1	.91	.84	.97
Centered, position 1	.87	.79	.95
Distributed, position 2	.87	.79	.94
Centered, position 2	.83	.75	.91
Distributed, position 3	.85	.79	.92
Centered, position 3	.81	.73	.89
Distributed, position 4	.63	.55	.72
Centered, position 4	.61	.51	.71
Distributed, position 5	.85	.77	.92
Centered, position 5	.81	.73	.89

Discussion

When looking at the network model and the findings of the previous studies, we expected that there would not be a peak in performance for position three in non-words, because of the influence of head-frequency. We also expected to find a hook shape in the distribution for non-words, which was consistent with the decay theory in relation to binding, described with regards to the conceptual network (de Vries, 2016). Further, we expected that for words, there would be an equal performance on each position, for both the distributed and the centered warning signal. Finally, we expected that the overall performance on words would be higher than on non-words.

For the first hypothesis, namely that a peak in performance for the third position for non-words was expected, support was found. In the previous studies, there was a peak in performance for the third position for non-words. In those studies, it was hypothesized that the peak occurred because of the perceptual salience (Whittaker, 2019). When presented with a centered warning signal, the focus of the participant lies at the third position, making it easier to recall that specific letter. This experiment controlled for that phenomenon, by using only high frequency begin letter words and non-words. As proposed, no peak in performance was found in this study, since the frequency of the three begin letters had a bigger influence of the letter recall accuracy than the warning signal. For the second hypothesis, that there would be a hook-shape seen in the distribution of the non-words, partial support was found as well. This was consistent with de Vries (2016). When taking a closer look at the hook-shape, most of the differences between the sequential letters are not significant, with the increase in letter recall accuracy for the fifth position as the most prominently absent. A possible explanation for this could be that the use of high frequency non-words would make the participants focus more on the first three letters of the non-word. It could be possible that these three letters activated a word node, and this word node would activate the corresponding letter nodes for the fourth and fifth position. This would make the participant type in the wrong letter, namely the letter that corresponds with the activated word node and not the letter that was seen. Future research should be done to further examine this phenomenon. This could be done by administering a lexical decision task with high frequency words and non-words, so a distinction could be made between whether the participants correctly viewed the non-words as non-words and words as words. For the third hypothesis, that for words there would be an equal performance for each position for both the distributed and the centered warning signal, no support was found. For both the distributed and the centered warning signal, a decrease in performance in the fourth position can be found. This dip was significant in both the centered and distributed words. A similar finding was found in previous studies (Whittaker, 2019). The dip in position four was then explained by the notion that people did not perceive the word to be a word. So, when they recognized the word as a non-word, their performance went down, because for non-words the performance is the worst for letter at the fourth position. This can be interesting to examine in future research, to see if the dip in the fourth position is caused by the inaccurate recognizing of words, for instance by adding a lexical decision task to the experiment. For the final hypothesis, namely that words would have an overall higher performance than non-words, support was found. The data showed that words did have a significant higher performance than non-words. This can be explained in terms of the conceptual model. Words are more frequently seen, and by top-down activation, it is easier to identify the individual letters, because they are more often activated. The memory traces connected to these individual letters become more activated and will be quicker to reach the critical threshold.

In the same line as this experiment, five different studies were conducted. There were three different designs, which each two experiments, one in Dutch and one in English. In the first set of designs, both the distributed and the centered warning signals were used, and high frequency non-words and words. For the Dutch design, which is the experiment described in this paper, the results were already discussed. For the English design (Bosutar, 2022), the results were the same as for the Dutch design. For the second set of experiments, only the centered warning signal was used, and both low and high frequency words and non-words were used (Beintema, 2022; Gontijo-Santos Lima, 2021). It was hypothesized that there would be a hook shaped distribution for both low-frequency and high-frequency non-words, but instead an inverse hook shape was found for the low-frequency non-words, with only the decrease between position 1 and position 2, and the increase between position 4 and position 5 was significant. They also hypothesized that there would be a less steep decay for high frequency non-words than for low frequency non-words, but since an inverse hook shape was found for the low frequency non-words, no comparison could be made. The last hypothesis was that there would be a performance peak for the third letter of the non-words, this effect was found when connecting the low frequencies of position 2 and position 4 to the high frequency letter in position 3. All the above was found in both the Dutch and the English design. For the last set of experiments, both distributed and centered warning signal was used, but only low frequency words and non-words (Zomerman, 2022; Seppälä, 2021). The first hypothesis was that words should have a higher overall performance compared to non-words. This was confirmed. It was also hypothesized that there would be a hook shaped distribution for the low frequency non-words, this was not found, the results show a more U shape like pattern. The last hypothesis was that there would be a peak in performance for the third position of the centered non-words condition. This was not confirmed. The above was found for both the Dutch and the English design.

A remarkable finding is that the main effect for Warning Signal is significant. The performance on the distributed warning signal was better than on the centered warning signal, as can be seen in Table 3a and Table 3b. Since, in this experiment, only high-frequency non-words and words were used, you would expect that the main effect for Warning Signal is not significant, since the effect of the high-frequency begin letters is strong enough, so that Warning Signal does not make an extra contribution to the effect. This finding was not part of the hypothesis, so it can be interesting to further study this in future research.

Unfortunately, because of the online administration of the experiment, this study comes with some limitations. For instance, it cannot be certain whether the participants had any technical issues during the administration. Also, there is no way of knowing whether the participants were distracted during the administration, causing them to fail in reporting the correct letter. This can result in less reliable data. So, for future research, it is preferable to administer the experiment in person, instead of online.

For future research, it can be helpful to distinguish native speakers and non-native speakers when administrating the experiment. In the current research, both native and non-native speakers were used, but it can make a difference when separating them. It seems likely that for the native speakers, it is easier to accurately report the asked letter, but for non-native speakers, this can be more challenging. It is possible that for non-native speakers, the neural pathways of the letters and words are less frequently activated, causing them to fail more often in reporting the correct letters.

In conclusion, high frequency begin letters can explain why a peak in position three was found in previous studies. As expected, high-head frequency is a more important factor for explaining the peak in performance at position three for non-words than warning signal. This shows that the conceptual network is a good addition to the cognitive theories, providing an explanation for the binding problem. But still, there needs to be done some more research to, for instance, explain the dip in the fourth position in words that was found. The current study has shown that the binding processes depend on serial processes, just as proposed by the conceptual network.

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Appendix A

Vandaag zal je een kort experiment uitvoeren waarin je kort Nederlandse woorden en niet-woorden - een reeks van random geordende letters - te zien gaat krijgen, waarna je gevraagd wordt om te benoemen welke letter er te zien was op een specifieke positie in een (niet)woord.

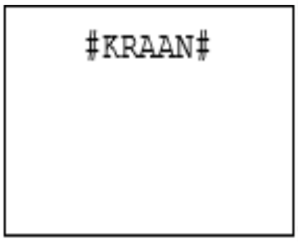
Het experiment ziet er als volgt uit:

1. Dit experiment maakt gebruik van twee soorten waarschuwingssignalen, die op het scherm te zien zijn voordat je het woord of niet-woord te zien krijgt. Deze waarschuwingssignalen kunnen bestaan uit ofwel twee verticale lijnen (figuur 1) ofwel uit vijf puntjes (figuur 2). Wanneer de twee verticale lijnen te zien zijn, breng dan je aandacht naar het midden van het scherm, tussen de twee verticale lijnen. Wanneer de vijf puntjes zichtbaar zijn, verdeel dan je aandacht over deze vijf puntjes. Deze waarschuwingssignalen zullen zich afwisselen per blok. De manier waarop de letters te zien zijn kun je hieronder zien in figuur 3. Zoals je kan zien, zal eerst de ruimte waar de letterreeks te zien zal zijn, zichtbaar zijn tussen de ## tekens. Daarna is de letterserie kort te zien, waarna deze bedekt wordt door #@@@@@# tekens.

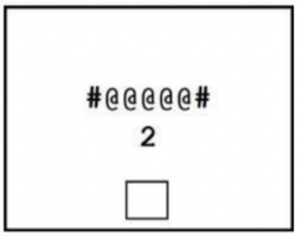
Figuur 1:

Figuur 2:

Figuur 3:



Figuur 4:



2. Nadat de letterreeks is gepresenteerd, zal een getal onder de symbolen verschijnen, zoals zichtbaar is in figuur 4. Dit getal representeert de letterpositie die je moet benoemen. Hou er hierbij rekening mee dat de # symbolen NIET meetellen als een

positie. Bijvoorbeeld, als het woord #DOLEN# te zien is, gevolgd door het getal 2, moet je de tweede letter van het woord benoemen, in dit geval O.

3. In het hokje onder het woord, kun je de te benoemen letter typen. Wanneer je een fout hebt gemaakt, kun je het antwoord corrigeren door de foute letter te verwijderen en de juiste letter te typen.
4. Om het antwoord door te geven, druk je op de “enter” knop op je toetsenbord. Het systeem stuurt je automatisch naar de volgende letterserie, waar dit proces zich herhaalt.
5. Voordat de daadwerkelijke datacollectie begint, zul je twee oefenblokken krijgen, die elk uit 10 letterreeksen bestaat. Dit helpt je om te wennen aan de taak, en je zult directe feedback krijgen door groen te kleuren bij een correct antwoord, of rood te kleuren bij een incorrect antwoord. Bij een van deze oefenblokken krijg je de eerder beschreven lijntjes te zien, bij het andere oefenblok zul je deze niet te zien krijgen. Vervolgens zul je 4 blokken van 30 letterreeksen krijgen, wat het echte experiment is. Bij deze blokken zul geen onmiddellijke feedback krijgen, maar zul je aan het einde van het blok het percentage goede antwoorden te zien krijgen. Je mag kleine pauzes nemen tussen de blokken als dat nodig is.

Veel succes!

Appendix B

Bedankt voor uw deelname. Dit experiment is uitgevoerd om te bestuderen hoe mensen woorden verwerken. De verwachting, gebaseerd op een model voor informatieverwerking, was dat de nauwkeurigheid in letter-herinnering zou dalen voor iedere opeenvolgende positie met uitzondering van de vijfde positie voor non-woorden (zie grafiek 1). Voor woorden, daarentegen, werd er verwacht dat er een hoge nauwkeurigheid in letter-herinnering zou zijn voor alle vijf posities (zie grafiek 2). De stippen in de grafiek vertegenwoordigen jouw eigen scores. We hebben het effect van de frequentie van de drie-lettercombinatie getest aan het begin van een non-woord in de Nederlandse taal (d.w.z., de 'kop-frequentie'). Om dit te testen ben je enkel gepresenteerd met non-woorden met een lage kop-frequentie. Voor deze non-woorden verwachten we dat de nauwkeurigheid in letter-herinnering een 'haak-vorm' aanneemt (zoals hierboven beschreven). Daarnaast is er getest of de aandacht van de deelnemer een effect heeft op letter-herinnering door gebruik te maken van een verspreid (de vijf stippen) en een gecentraliseerd (de verticale lijnen) waarschuwingssignaal - respectievelijk aangeven door rode staven en zwarte staven in de grafiek. Voor het verspreide waarschuwingssignaal wordt er geen effect op letter-herinnering verwacht. Voor het gecentraliseerde waarschuwingssignaal wordt, daarentegen, een prestatie piek op de derde letterpositie verwacht. De hypothese is dat het effect van het gecentraliseerde waarschuwingssignaal groter is voor non-woorden met een lage kop-frequentie dan voor non-woorden met een hoge kop-frequentie.