The Role of Warning Signals for English Words and Nonwords

Aniela-Georgeana Bosutar

S3635732

Department of Psychology, University of Groningen

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Group: 38

Supervisor: prof. dr. P. H. DeVries

Second evaluator: prof. dr. A.C. Mülberger Rogele

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In collaboration with: Gerbrich Beintema, Caroline Gontijo-Santos Lima, Julia Hennink, Aarni Seppälä and Timo Zomerman .

Abstract

This paper aims to explain previous studies' findings investigating letter recognition accuracies for words and non-words based on the conceptual network of De Vries (2016). Past studies, predicted a hook-shaped pattern of letter recall accuracies in non-words, however, an unexpected peek at the third letter occurred. Another set of studies attempted to explain the peak by utilizing warning signals. The researchers hypothesized that a centered warning signal was expected to produce a peak in letter recall accuracy for nonwords, however, the results were not significant for German words and non-words. To explain the results of past studies, the current paper will account for head frequency, a variable that was not accounted for in past research. The current study will control for the head frequency of non-words, using only high head frequency English non-words. It is hypothesized that if participants will be presented with exclusively high-frequency nonwords, the results of this study will be similar to those of previous studies which used German words and nonwords, meaning that the distribution of accuracies will be hook-shaped. Moreover, the participants will be presented with centered and distributed warning signals, however, no effect of warning signals over letter recall accuracy is expected since only high-frequency nonwords will be used. To test for these hypotheses, an online letter recognition task following a 2x2x5 design was conducted (N= 45). The results of this study found support for the expected hook shape pattern.

Keywords: letter recognition, conceptual network, warning signals, head frequency

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The Role of Warning Signals in English Words and Nonwords

Reading is an essential part of a person`s life no matter the age or social background. People receive and transfer information through reading based on print media like newspapers, books, magazines, or the internet. Since this ability is so crucial for our consumption of information, many researchers have tried to explain the processes that are involved in reading. This bachelor thesis is a follow-up study that aims to explain the unexpected results found in the previous bachelor thesis. When summarizing the findings of these previous theses we will refer to them as Study 1 (Buijsman, 2019; Pink, 2019; Mudogo, 2019; Schwarzkopf, 2019; Whittaker, 2019) and Study 2 (Bhouri, 2018; Donelan, 2018; Fredricks, 2018; Seibel, 2018)

Study 1 aimed to explain letter recall accuracy in Dutch words and non-words using a conceptual network (De Vries, 2016). Based on this model, the researchers expected a gradient decrease from position one to position four followed by an increase in position five. However, an unexpected performance peak at position three was found. To explain this result Study 2 was conducted which tested for the possible role of attention in causing this result by utilizing warning signals. The researchers expected that a centered warning signal would explain this peak found in position three, however, no significant effect of warning signals was found for German words, thus no explanation for this peak was found.

As explained in these studies, many of the existing models for word processing are not able to explain the results of this task. Models that cannot explain these results are models that are based on position-specific slot encodings such as the interactive activation model (IAM) developed by McClelland and Rumelhart, (1981) and the dual-route cascaded model (Coltheart et al, 2001). Additionally, the SERIOL model developed by Grainger and Whitney (2004) will be explained. This model is based on context encoding.

The Interactive activation model (IAM) makes three assumptions: a) perceptual processing takes place within a system in which there are several levels of processing. For example, for visual word processing, there is a visual feature level, a letter level, and a word level, as well as a higher level of processing that provides top-down input to the word level, b) visual perception involves parallel processing at all levels, meaning that processing at letter levels occurs simultaneously with processing at the word level and the feature level; c) perception is an interactive process (McClelland & Rumelhart, 1981).

Another model, similar to the IAM is the Dual Route Cascaded model. Its theory suggests that three cognitive routes are involved in reading aloud: the lexical-semantic route, the lexical non-semantic route, and the GPC route. (Coltheart et al, 2001). Like the IAM, the dual-route model proposes interactive connections between lexical and sublexical structures, thereby explaining the word superiority effect. (Grainger & Ziegler, 2001). Moreover, both models use position-specific slot encoding. (Grainger & Whitney, 2004). Position-specific slot encoding assumes separate slots of specific letter codes, one slot for each letter position. For example, the word cat would be coded by activating three-letter codes C1, A2, and T3 while the word act would be coded as A1, C2, and T3. Using these models, we cannot explain the results found in past studies because these models cannot explain how people are able to understand a word that has a lexical error or a word written as a jumbled word, in our case, a non-word. Moreover, since these models are based on position-specific slot encoding, the models do not allow for easy identification of a letter at a given position within a word.

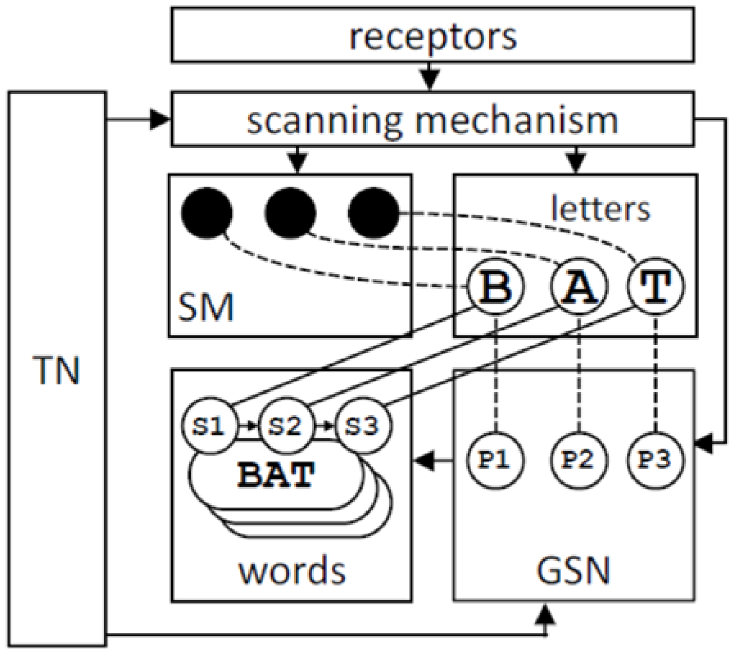
In response to the shortcoming of the IAM and the Dual-Route Cascaded model, Whitney (2001) proposed an encoding based on ordered letter pairs abbreviated the SERIOL model. According to this open-bigram approach to letter position coding, the perception of printed words is relatively insensitive to letter transpositions because enough correct relative-position information is present in transposed stimuli. (Grainger & Whitney, 2004). Moreover, these groups of letters do not contain precise information about letter position, or about which letter is next to which. Using an example provided by Whitney (2001), the first letter node to fire for the word CART would be C, then A, then R, and finally T. At the bigram level, the sequence of bigrams to become active would be CA, AR, RT, CR, AT, and CT.

It is important to note, one shortcoming of the SERIOL model is its use of bigrams to indicate letter position. Despite bigrams being more efficient than the letter-position units in slot-based coding, they are still not an efficient way of coding letter position, leading to many binding errors (von der Malsburg, 1999), such as identifying the phoneme CR in the word CART. Furthermore, the use of bigrams complicates the ability to report a letter at a specific position within a word. Since bigrams do not offer all letter positions for a specific word but combine letter identity and letter position. This is similar to the identity-position processing units in the IAM.

The limitations of these models lead the researchers of previous studies to base their experiments on the conceptual network of De Vries (2016). This model is based on principles of neural connectivity and self-organization. Its basic assumption is the Tanzi-Hebb rule (Hebb, 1949; Tanzi, 1893): Connected neurons that repeatedly fire concurrently will increase their connectivity over time. This is commonly summarized as “Neurons that fire together, wire together”, and is considered the central neural mechanism underlying learning phenomena. This group of connected neurons is called a cell assembly and it has temporary and permanent connections with each other. Based on these temporary connections we can explain the letter position identity dilemma. These connections enable us to prime one concept with another through binding rather than through many pairs of letter and position nodes, as described in old models. The conceptual network is built on the mechanism of serial binding. This is a process by which the memory trace of a letter becomes temporarily connected to the memory trace of its location and position. Based on temporary binding, this model can explain how letters can be identified at a given position within a word. In contrast, old models require permanent memory traces for each combination of letter nodes and bigram nodes which is not very plausible.

Figure 1.

The conceptual network



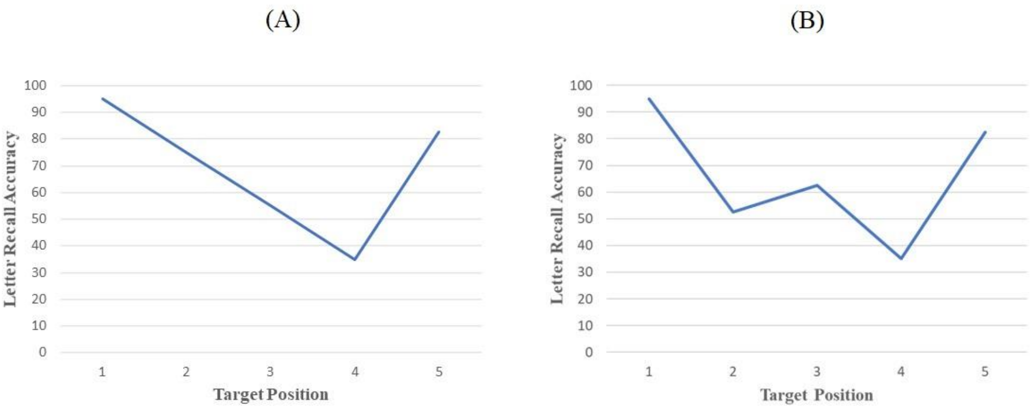
Note. Figure 1 is a schematic representation of the conceptual network for letter- and word recognition. The rectangles indicate modules for the input (receptors, scanning mechanism), a spatial map (SM), subnetworks for letters and words, a global sequence network (GSN), and a task network (TN). The arrows and solid lines indicate the activation of one module by another utilizing permanent connections, a dashed line represents a temporary connection (binding). 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 above figure represents how a word is recognized based on the conceptual network of De Vries (2016). The figure's dashed lines between the SM, letters and GSN squares represent serial binding connections between these subnetworks. According to the model, they occur in a series, and therefore the first connection will be the strongest followed by the second connection, and so on, until the last letter is activated above the critical threshold where the recognition increases. It is important to note that this process happens in rapid succession from one position node to the next which ceases at the activation of the final node. This is called the reverberation effect which causes the final position node to have increased strength.

Based on the conceptual network (De Vries, 2016), the experimenters of Study 1 hypothesized that based on top-down activation words will have better performance on a letter recognition task when asked about a specific letter compared to non-words. Furthermore, the experimenters of Study 1 hypothesized that letter recall accuracy will decrease from position one to four in nonwords. The letter at the fifth position will be recalled more accurately than the letter at the fourth position in non-words. The results indicate that a higher letter recall accuracy for letters in words compared to nonwords has been identified, reflecting the word superiority effect. However, letter recall accuracy for nonwords did not decrease systematically from position one to position four followed by an increase in letter recall accuracy at position five, instead, there was an increase in letter recall accuracy at position three.

Figure 2.

The graph represents expected hook (a) and unexpected peak found in Study 1 (b)



Study 2 aims to explain these results by using warning signals which are meant to change the attention of the participant. The warning signals were two vertical lines (centered warning signals) meant to attract attention in the middle of the screen or dots (distributed warning signals) which are meant to distribute the participant`s attention across all letter positions. The researchers wished to investigate if these different cues and their spatial differences affect the attention of the participants. The results of Study 2 indicate that participants correctly recalled the letters of words with no effect of warning signals on letter recall accuracy. Furthermore, the analysis showed a steeper decline for the second, third and fourth letters in non-words followed by an increase in letter recall accuracy for the last letter, resulting in a graph with a hook shape pattern. This means that no effect of warning signals on German nonwords was found.

After a visual inspection of the Dutch non-words used in Study 1, a possible hypothesis explaining the peak at position three concerns the frequency of the first three beginning letters of a non-word. It is possible that the non-words used for position three had a high frequency, whereas other positions used low-frequency nonwords. If the frequency of the first three beginning letters was high, letter recall would have been easier based on top-down activation

The experiment of this thesis aims to explain the unexpected results found in Study 1 by controlling for head frequency and warning signals. Since Study 2 was restricted to only German words and was presented to native German speakers it is possible that centered warning signals do play a role in English words and nonwords presented to participants who are non-native English speakers. However, no effect of centered warning signals is expected because this study uses only high-frequency non-words, meaning that the top-down excitation will be so strong it will obscure the effect of the fixation point, this activates the central location of the spatial map leading to a positive effect in the third letter. Moreover, it was expected that there will be a lower decrease in performance over positions for words than for non-words, due to the assumed position-specific top-down activation. Furthermore, it is hypothesized that if participants will be presented with exclusively high-frequency nonwords, the results of this study will be similar to those of Study 2, meaning that the distribution of letter recall accuracy of centered warning signals in nonwords will be hook-shaped. Additionally, the words letter recall accuracy distribution is expected to follow a straight-line pattern, as we would not expect to see any significant differences between letter recall accuracies due to the top-down activation associated with word recognition (de Vries, 2016)

It is important to note that, this experiment is part of a study made up of six separate experiments aiming to explain the unexpected result found in Study 1. A similar experiment to the one presented in this paper is conducted by Hennik (in preparation) except it makes use of Dutch words and nonwords which are presented to Dutch participants. Furthermore, in other experiments, the participants are presented with exclusively low-frequency English nonwords (Seppälä, in preparation) or Dutch nonwords (Zomerman, in preparation). Additionally, in other experiments, the effect of head frequency is tested for, where participants are presented with low and high-frequency English words and nonwords (Gontijo-Santos Lima, in preparation) or low and high-frequency Dutch words and nonwords (Beintema, in preparation) and solely centered warning signals.

Method

Participants

This study has been approved by the Ethics Committee of the Faculty of Behavioural and Social Sciences from the University of Groningen.In this study, 45 participants were recruited via volunteer sampling as well as a participant pool. The participant pool consists of first-year students of the Department of Behavioral and Social Sciences from the University of Groningen. It is important to note that, two participants were removed from the sample due to double participation, meaning that this study had 43 eligible participants. Eight participants were recruited using the participation pool and 35 participants were recruited via volunteering. The participants recruited via the participation pool were first-year students of the Department of Behavioral and Social Sciences from the University of Groningen, who were required to participate as volunteers in experiments to receive course credits. Of these participants, 30 were females and 13 were males. The average age of the participants was 23.75 years old with a standard deviation of 6.1. Furthermore, all participants were proficient in English, either natively (eight participants) or as a second language (35 participants). It is important to mention that because this study tested for letter recall accuracy, students who suffer from dyslexia and students who are visually impaired were advised to not participate in this study.

Design:

This study measured letter recall accuracy using a 2x2x5 design. This study has three independent variables. The first independent variable is word type with two levels, where the participants were either presented with English words or nonwords. The second independent variable is target position, which represents the position of the letter the participants are asked to recall. The target position has five levels. Since five letter words were used, these positions range between one to five. For example, target position one is the first letter position of a word. The third independent variable is the warning signal presented to the participants, with two levels: distributed or centered. Finally, the dependent variable is the accuracy of letter recall in the letter recognition task. This dependent variable, for the trial, consists of two levels; correct or incorrect and for the experimental blocks it represents the proportion of letter recall accuracy for each participant.

Stimuli:

For this experiment, 28 pairs of words were selected for each target position. The words were selected in pairs so that they would only differ in one letter, this is called the target letter, and is the letter we are testing for. The pairs were selected specifically to avoid the word substitution effect, preventing distortion of results on the dependent variable. This way, it was ensured that the right target letter was not chosen out of memory, for words but truly chosen based on its true constituting presented letters (Reicher, 1969). This approach was used in Study 1 and Study 2 and it is based on the experiment done by Reicher (1969). For example, if we are testing for the first letter position, the pair “badly” and “madly” was selected so that the target letter could not be estimated by processing the surrounding letters. Nonwords were constructed by mixing the letters within the words, and were constructed in accordance with the following rules: each non-word had to contain the same letters as the corresponding word, the target letter has the same position in both the word and non-word, the non-word should have at least one impossible letter combination. Moreover, the nonwords were constructed twice for each pair of words. For this experiment, it was important to construct high-frequency nonwords however low-frequency non-words were also used in the trial block.

For the other experiments in the group study, when constructing a low-frequency nonword, the first three letters do not form the beginning of a common word, that is a set of words with a word frequency of less than seven per a million words. Moreover, when constructing a high-frequency nonword, the three beginning letters will form the beginning of a relatively common word that will occur relatively often in a set of words, each having a frequency of at least seven times per million words. The information regarding word frequencies was retrieved from CELEX, Centre for Lexical Information. (2001).

Procedure

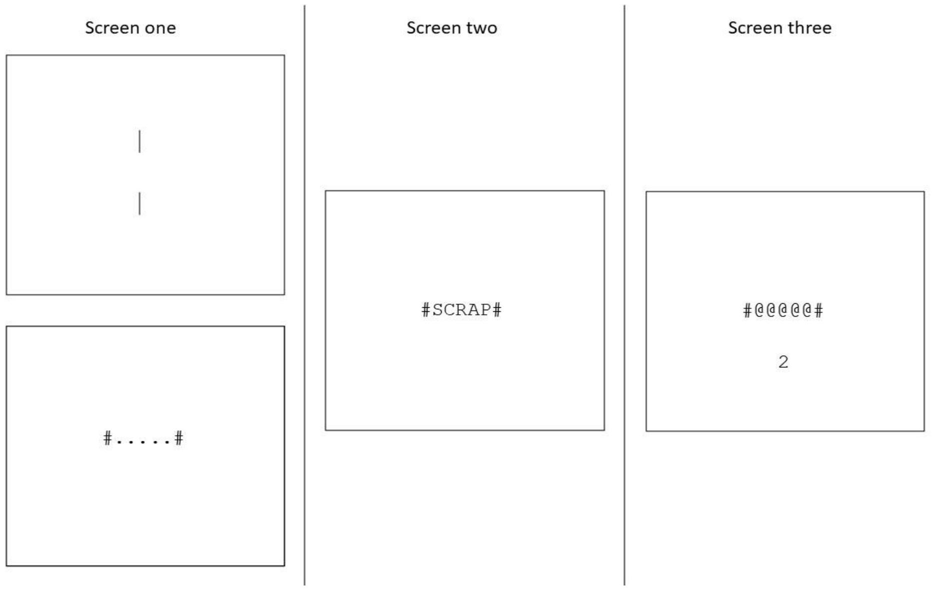
The experiment was conducted online, meaning that the participants were allowed to use a laptop or desktop to complete the experiment. Furthermore, the stimuli were presented in capital letters in Font Courier New to ensure that each letter will occupy the same size. First, the participants were directed to a Qualtrics (Qualtrics, Provo, UT) webpage to read and sign the informed consent and receive instructions on how to participate in the experiment. The information form will be found in Appendix A. Once the participants signed the informed consent and read carefully the instructions, an example trial was presented. If the participants responded correctly, they will be redirected to a separate webpage, OSWeb created by means of Mathot, Schreij and Theeuwes (2011) to participate in the experiment. However, if the participants did not respond correctly to the example trial, they were instructed to read the instructions once more and try again.

Once the experiment started, the participants were presented with two practice blocks with ten trials each. After each block was completed, the participants received a letter recall accuracy score. The warning signals alternated between each block. When participants are presented with centered warning signals, they are advised to focus their attention on the middle of the screen, which would be the third letter of a presented word or non-word. The participants were instructed to distribute their attention equally across all letter positions for distributed warning signals. After the practice block was completed, the participants started the experiment which consisted of four experimental blocks. Each block consisted of 30 trials, meaning that the experiment consisted of 120 trials total.

Every experimental trial started with a blank screen for 1000 milliseconds. Afterward, either a distributed or centralized warning signal was presented for 500 milliseconds. The participants should have fixed their attention according to the presented warning signal in this period. Then, a word or non-word between a ‘#’ symbol to both sides appeared for 50 milliseconds, for example, #SCRAP#. These adjacent ‘#’-symbols ensure the first and last letter will have a neighboring symbol, decreasing the salience of the beginning and end letter. Immediately after the word was presented, the masking of letters would appear (#@@@@@#). This was done to prevent the possibility the participants were creating an afterimage of the presented word. Lastly, after the masking of letters was presented, the participant would be instructed to name a letter position. Figure 3 illustrated how participants viewed the study. After the experiment was completed, the participants were debriefed. The debriefing can be found in Appendix B.

Figure 3.

The figure represents the structure of the experimental trial



Note. Screen one has two figures because it represents the warning signal presented to the participants during an experimental block. Screen one remains consistent throughout the experimental block and it only changes once the experimental block has ended.

Analysis

The results of this study were aggregated and restructured in SPSS (IBM Corp., Armonk, N.Y., USA) and the restructured data will be analyzed in JASP (version 0.12, JASP team, 2020) by conduction of repeated measures within-subject ANOVA analysis.

Results

This study aimed to show the effects of letter recall accuracy based on positions of English words and high-frequency non-words alongside centered and distributed warning signals. To test the hypotheses of this study, the raw data was restructured and aggregated in SPSS. Afterward a three-way RM ANOVA was conducted followed by four one-way RM ANOVAs. The conditions for the four one-way RM ANOVAs are as follows; centered words, centered nonwords, distributed nonwords, and distributed nonwords. This was done to examine the differences in letter recall accuracy across the five positions.

The data was tested on the assumptions of normality and sphericity. The assumption of normality was violated, as revealed by visual inspection. While there were no outliers, the distribution of conditions with higher mean accuracy values experienced a ceiling effect, resulting in a left skew. Furthermore, based on analysis, the Shapiro-Wilk test indicated a violation of the normality assumption that showed a significant deviation from normality for all means. However, normality was considered robust due to the large sample size ($n = 43$) (Agresti, 2018). In contrast, Mauchly's test indicated that the assumption of sphericity has not been violated. The following information concerns Mauchly's test results: position $\chi2(9) =$

12.40, p = .19; warning signal*position $\chi2(9)$ =15.88, p= .07; position*word type $\chi2(9)$ =8.63, p= .47 and warning signal*position*word type $\chi2(9)$ =11.61 p= .23.

Of most importance, the three-way interaction between warning signals, position, and word type was not found significant (*F* (4,168) =. 78, *p* =. 53, η^2>. 00) This is due to the warning signals which had no main effect, meaning that each interaction with this variable will yield insignificant results.

Furthermore, the three-way RM ANOVA analysis showed significant results for two main effects, position and word type whereas no significance for warning signals. Moreover, the two-way interaction between position and word type was found significant, whereas the interaction between warning signals and position as well as the interaction between warning signal and word type was not significant. Based on the hypothesis of this study, the significant interaction between position and word type was expected due to the assumed position-specific top-down activation. Furthermore, the non-significant interaction between warning signal and position was expected, as well as the non-significant interaction between warning signals and word type because of the aforementioned top-down activation.

Table 1

Within Subject Effects

	df	*F*	*p*	η^2
Warning Signal	1, 42	1.50	. 22	.00
Position	4, 168	48.97	< .001	.18
Word Type	1, 42	124.52	< .001	.1

Warning Signal* Position	4, 168	.86	.48	>.00
Warning Signal* Word Type	1, 42	2.19	.15	>.00
Position* Word Type	4, 168	19.77	< .001	.05
Warning Signal* Position* Word Type	4, 168	.78	.53	>.00

To understand why the expected three-way interaction is absent; four one-way ANOVAs need to be examined.

Table 2

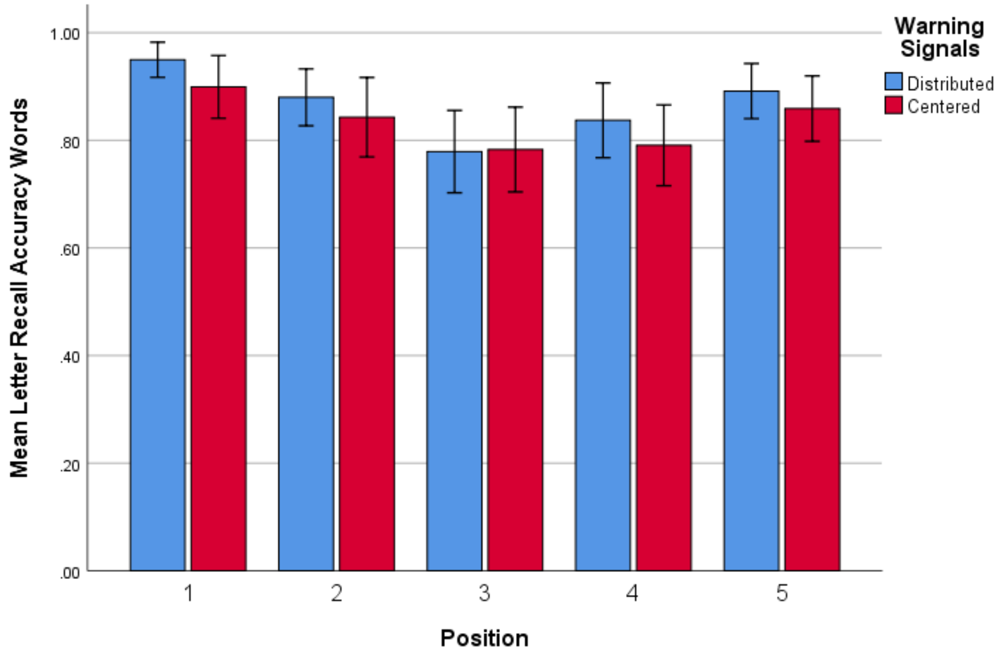
F Table for the Four One Way ANOVAs

	df	*F*	*p*	η^2
Distributed NonWords	4, 168	34.60	< .001	0.45
Distributed Words	4, 168	7.742	< .001	0.15
Centered NonWords	4, 168	20.30	< .001	0.32
Centered Words	4, 168	20.30	<.0.01	0.32

When analyzing pairwise comparisons of the one-way RM ANOVA analyses, the differences over distributed and centered warning signals were not significant for words except for distributed warning signals on words from positions two to three. As can be visualized in the below graph.

Figure 4.

Mean Letter Recall Accuracy for Words with Distributed and Centred Warning Signals



Although visually there seems to be a slight U-shaped drop between positions one and five, these drops were not significant enough to disprove our initial hypothesis that the overall letter recall accuracy for both word conditions would remain relatively stable and follow the expected straight-line patter due to the top-down activation associated with word recognition (de Vries, 2016)

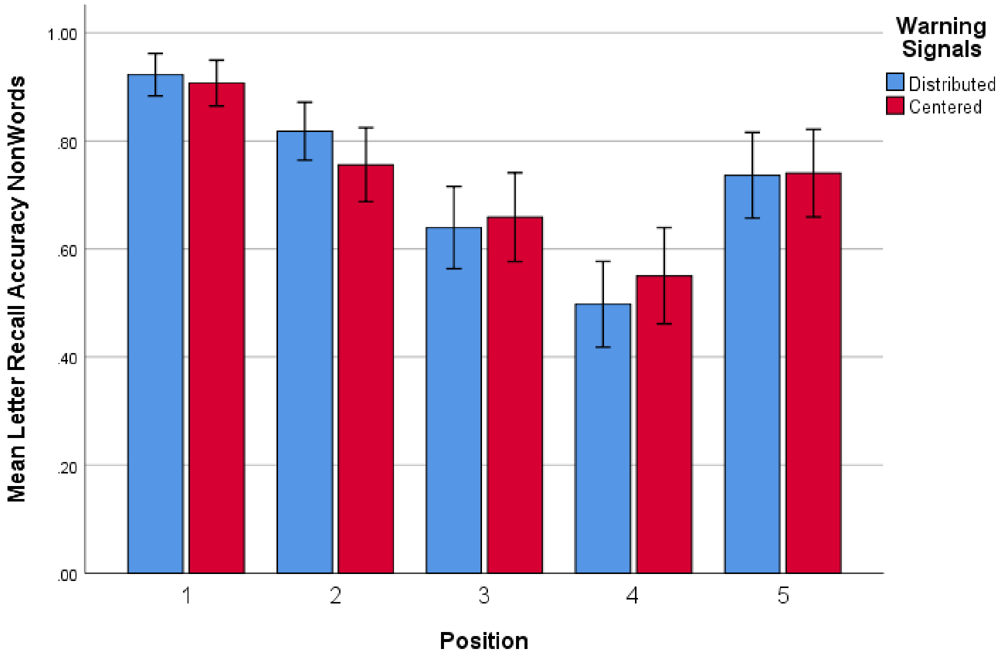
In relation to the effect of centered warning signals on words, pairwise comparisons with Bonferroni corrections show no significantt decrease in letter recall accuracy from position one ($\bar{x}$ =.89, CI= (. 84 -. 95)), to position two ($\bar{x}$ =.84, CI= (.76 -. 91)) to position three ($\bar{x}$ = .78, CI= (. 70 -. 86)) to position four ($\bar{x}$ = .79, CI= (.71 -. 86) and to position five ($\bar{x}$ =.85, CI= (. 79 -. 92)). All with $p > .50$.

In regards to the effect of distributed warning signals on words, pairwise comparison with Bonferroni correction show no significant difference in letter recall accuracy from position one ($\bar{x}$ =.95, CI= (. 91 - .98)) to position two ($\bar{x}$ =.88, CI= (. 82 -. 93), and form position four ($\bar{x}$ =.83, CI= (.76 -. 90)) to position five ($\bar{x}$ =.89, CI= (.84 -. 94)). All with $p > .30$. However, there is a significant decrease in letter recall accuracy from position two ($\bar{x}$ =.88, CI= (. 82 -. 93) to position three ($\bar{x}$ = .77, CI= (. 70 - 90)), with a p(pos2pos3) =.02.

Regarding nonwords, when analyzing pairwise comparisons of the one-way RM ANOVA analyses, the differences between distributed and centered warning signals are mostly significant for all positions. Except for centered warning signals from position two to position three, and from position three to position four. As well as distributed warning signals from position one to position two. This can be visualized in the graph below which follows the expected hook-shaped pattern.

Figure 5.

Mean Letter Recall Accuracy for Non-words with Centred and Distributed Warning Signals



When investigating pairwise comparison with Bonferroni correction, there is a significant difference in letter recall accuracy for the effect of centered warning signals on non-words. There is a significant decrease from position one (x̄ =.90, CI= (. 86 -. 94)), to position two (x̄ =.75, CI= (.68 -. 82)) and from position four (x̄ = .55, CI= (.46 -. 64)) followed by an increase for position 5 (x̄ =.74, CI= (. 65 -. 82)). All with $p < .003$. However, position two (x=.75, CI= (.68 -. 82)) to position three (x̄ = .65, CI= (. 57 -. 74)) to position four (x̄ = .55, CI= (.46 -. 64) showed no significance, $p > .10$

Moreover, when investigating pairwise comparison with Bonferoni correction on the effect distributed warning signals have on non-words, there is a significant decrease from position two (x̄ =.75, CI= (.68 -. 82)) to position three (x̄ =. 65, CI= (. 57 -. 74)), followed by a slight increase from position four (x̄ = .55, CI= (.46 -. 64)) to position five (x̄ =.74, CI= (. 65 -. 82)). All with $p < .004$. However, there is no significant decrease from position one (x̄ =.92, CI= (. 88 - .96)) to position two (x̄ =.81, CI= (. 76 -. 87)) p= .08.

Discussion

This study hypothesized that: 1. Since this study uses only high-frequency non-words, the effect of the fixation point required by centered warning signals will be obscured by the top-down excitation. Moreover, if the participants will be presented with exclusively high-frequency non-words, the distribution of letter recall accuracies over positions will be hook-shaped. 2. A smaller decrease in performance over positions for words than for non-words is expected based on the aforementioned top-down activation

The first hypothesis was confirmed, letter recall accuracy was not significant for the third position of nonwords with centered warning signals. Meaning that the top-down excitation was so strong it compensated for the fixation point. The high-frequency letters activated the central location of the spatial map regardless of the fixation point. Moreover, as it can be observed in Figure 4, the distribution of accuracies for non-words is hook-shaped. This is possible due to the letter decay effect, which is caused by a top-down process in the scanning mechanism (De Vries, 2016).

Furthermore, the second hypothesis was confirmed as well. This can be seen in Figure 4 compared to Figure 5. As it can be observed in Figure 4, the bar graph shows a higher letter recall accuracy for words, with a letter recall accuracy mean ranging from .95 to .77. Furthermore, as it can be observed in Figure 5, the bar graph shows a lower letter recall accuracy for non-words, regardless of their warning signals, with means ranging from .90 to .49. Additionally, this hypothesis has also been supported in Study 1 and Study 2. This finding can be supported by the word superiority effect, stating that people have better recognition for letters presented within words compared to letters presented within non-words strings (Cattell, 1886). However, there is a significant drop in letter recall accuracy for distributed words from position two (x=88, CI=(. 82 -. 93) to position three (x= 77, CI= (. 70 - 90)), with a p(pos2pos3) =.02. An explanation for this result could be that the presented words may not be well known. The words were randomly assigned to the warning signals, and it is possible that some words occurred more in the distributed warning signal condition than the centered warning signal condition.

Other Experimental Findings

Since this study is part of a group project, other researchers conducted similar experiments. In other experiments, the independent variables have been controlled for at different levels as well as the language in which the words or non-words have been presented.

Hennink, (in preparation), conducted a similar study to the study presented in this paper but for Dutch words and nonwords with distributed and centered warning signals. In this study, also no three-way interaction between position, word type, and warning signals has been found. Furthermore, partial support was found for the hook shape pattern found in the distribution for accuracies for nonwords. 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 letter 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. (Hennik, in preparation). Furthermore, an interesting finding is that for words there has been a significant decrease in letter recall accuracy in the fourth letter position which has been present in Study 1 as well. In Study 1, the researchers asked the participants to rate if the presented word was veridical or not. This was done to check the differences between position accuracies in words. The researchers found a significant decrease in letter recall accuracy between veridical words and non-veridical words. Based on the significant drop in letter recall accuracy found in the paper from Hennink, (in preparation), it is possible that fewer known Dutch words were used.

On a different note, Gontijo (in preparation) researched whether low and high-frequency non-words with only centered warning signals would have an effect on letter recall accuracy for English words while Beintema (in preparation) researched the same effect on Dutch words and nonwords. For these studies, the main interaction between head frequency, letter position, and word type have been significant (Beintema, in preparation; Gontijo, in preparation). Moreover, for both studies, a hook shape distribution has been presented for high-frequency non-words but an inverse hook shape for low-frequency non-words.

A different type of experiment included low-frequency head frequencies with centered and distributed warning signals for English (Seppälä, in preparation) and Dutch words and non-words (Zommerman, in preparation). In these studies, a non-significant three-way interaction effect between warning signals, position, and word type has been found. This is due to the preparation signal, which had no main effect, meaning that each interaction that had warning signals was not significant (Seppälä in preparation).

These different experimental designs seem to line up with the hypotheses and findings of the present study. Based on the findings of all experiments, it is clear that words have a higher letter recall accuracy compared to nonwords. Moreover, based on the findings of Beintema (preparation) and Gontijo (in preparation), it is possible that the peak at position three found in Study 1 happened because the head frequency was not controlled for. It is possible that Study 1 may have had the second and fourth letter low frequency, while the third letter may have been high frequency, creating the peak at the third position (Gontijo, in preparation).

Limitations and Future Directions

When considering the following results, it is important to take into consideration the following limitations. Firstly, the experiment was done online based on the inability to welcome participants into the laboratory due to the implications the CoronaVirus pandemic has had on education. Since the participants had the freedom to participate in the experiment at home, we cannot be sure that they fully understood the instructions since they could not ask questions about the experiment during the experiment. Moreover, since the experiment was done at home, we cannot guarantee that the participants have done their best or had no distractions during the experimental blocks. In the future, the experiments should be done in a laboratory where the environment is controlled for distractions and participants can interact with the researcher if they have questions

Secondly, participants for whom English is not their first language were used in this experiment. Since the participants of this study are bilingual, it is possible that some non-words were similar to words in their language. After investigating the high-frequency non-words used in this study 14 strings of letters, deemed as non-words, were actual words in other languages. Such as German (strom, falke), Norwegian (loven, brede), Italian (mensa), French (virer), Romanian and Spanish (carne), and even English (fates). Future research should be done by administering a lexical decision task, where participants would be asked if the presented word or nonword, was a veridical word.

Thirdly, head-frequencies even though they are high for English words, could have not been easily recognized by participants who are not very accustomed to English. Furthermore, this could also be a possible explanation why the present study did not have an absence in letter recall accuracy increase at the fifth position for high-frequency English nonwords, as seen in the experiment done by Hennink, (in preparation). A potential hypothesis could be that for non-native speakers, high-frequency English nonwords are not so strongly associated as would high-frequency nonwords for their native language, leading the participants to produce less error in the letter recognition task. In the future, it would be advisable to do a similar study that would include only participants for whom English is their first language.

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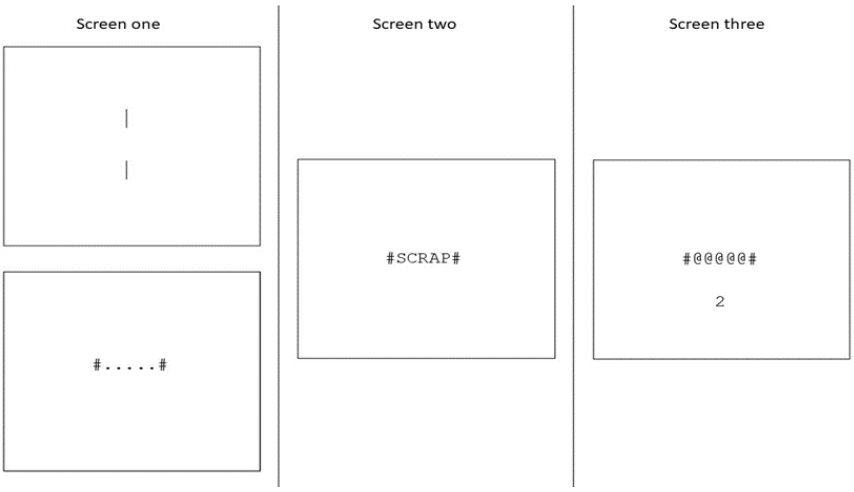
Appendix A: Instructions

Today, you will complete a short task in which you will be briefly presented with English words or nonwords (i.e., a string of letters ordered randomly), after which you will be asked to recall a letter at a specific position within such a (non)word. The experiment will be carried out as follows:

1. This experiment uses two types of warning signals, which will appear first on the screen before a word or a nonword. The two warning signals can be two vertical lines (figure 1) or five dots (figure 2). If two vertical lines appear, please bring your attention to the center of the screen. Furthermore, if you are presented with five dots, please divide your attention equally across all five positions. These warning signals will alternate between blocks. The way the letters will be shown can be seen below in figure 3, the space where the (non)word will appear will be shown to you between the ## signs. Then, the (non)word appears briefly, after which it is replaced by the #@@@@@# signs.



2. After the (non)word has been shown, a number will appear below these symbols, as can be seen in the fourth image. This number represents the letter position you are

asked to reproduce. Please note that the # signs do NOT count as a position. For example, if the word #SCRAP# [PdV1] appears, followed by number 2, you are asked to recall the second letter of the word, i.e. C.

3. In the square provided at the bottom of the screen, please type which letter you think belonged to that position. If you made a mistake and wrote the wrong letter, simply correct your answer by deleting it using the left arrow key, and replacing it with your desired response.
4. To submit your answer, please press the “enter” button on your computer. The system will automatically take you to the next trial to repeat this process.
5. Before the actual data collection begins, you will be presented with two practice blocks consisting of 10 trials each. This will help you get acquainted with the task, and these practice blocks will give you immediate feedback by glowing green if you answer correctly, or red if incorrect. Subsequently, you will be presented with 4 blocks of 30 trials for the actual experiment. These blocks will not give you immediate feedback, but the accuracy of correct scores at the end of the block. You may take small breaks in between blocks if necessary.

Good luck!

Appendix B: Debriefing

Thank you for your participation. This experiment was conducted to dissect how humans process words. Based on a model of information processing, it was predicted that letter-recall accuracy would drop for each consecutive position with exception of the fifth for nonwords (see graph 1). For words, on the other hand, it was predicted that letter-recall accuracy would be high across all five positions (see graph 2). The dots in the graph represent your scores. We tested the effect of the frequency of the three-letter combination at the start of a nonword in the English language (i.e., the 'head-frequency'). Next to words, you were presented with exclusively low-frequency nonwords, for which we expect the accuracies to be distributed as described above (hook-shape). Moreover, it was tested whether the participant's attention might influence accuracy at specific positions by utilizing a centralized (i.e., the vertical lines) and a distributed (i.e., the five dots) warning signal, represented by black and red bars respectively in the graphs. For the distributed warning signal, no effect on accuracy is expected. For the centralized warning signal, however, a performance peak at position 3 is hypothesized for nonwords. It is predicted that the effect of the centralized warning signal will be stronger for word nonwords with a low frequency than nonwords with a high frequency.