The Role of Head Frequency in Position-Specific Letter Recall for Words and Non-Words.

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Abstract

The present study focused on the effect of high and low head frequency on letter recall (LR). Studies examining LR on the basis of the conceptual network model found an unexpected performance peak at the third letter position following an LR task. The current experiment examined the possibility of head frequency as an explanation of the unexpected finding. This experiment consisted of a Dutch LR task following a 2x2x5 design (N = 41) measuring response accuracy with two levels of word type: words and non-words, two levels of head frequency: high and low, and five different letter positions. Results supported the expected significant three-way interaction, but the finding of a u-shaped distribution did not support the hypothesised decay and reverberation effects for non-words. Additionally, we expected to find a performance peak at position three due to the centred warning signal, but no evidence was found to support this effect. Examining the graph we can deduce a significant effect of head frequency on the finding of the performance peak at position three in previous studies. Future research is needed to explore the effect of tail frequencies to explain the u-shaped distribution.

Keywords: Conceptual network model, head frequency, reverberation effect

The Role of Head Frequency in Position-specific Letter Recall for Words and Non-Words.

In daily interactions, it is easy to brush over the unique capabilities of our brain in word and letter processing. Any capable reader has the ability to recognise a word within a single glance as well as all of its individual constituting letters. It is clear that the path to word and letter recognition is ruled by subconscious processes. A well-known example is the word superiority effect: the phenomenon that we are more likely to recognise a letter within the context of a word than in a random sequence of letters (Cattell, 1886). A question that captivates cognitive psychologists (Grainger & Whitney, 2004) is what determines the limits of successful subconscious word and letter recognition?

In the current field of research on letter and word processing, there is an ongoing debate regarding the problem of the connection between the identity and position of a letter known as the binding problem. This problem causes much uncertainty about the process of word and letter recall. Many models were designed in order to explain the binding problem, each with its own advantages and weaknesses in the extent to which they can explain the problem. The current study aims to clear up uncertainty about word and letter recall based on letter position in sequences of letters forming either words or non-words. The study will build upon two previous studies focusing on the same phenomenon. Whittaker (2019), Mudogo (2019), Pink (2019), Buijsman (2019) and Schwartzkopf (2019) performed a general study to examine letter recall on specific positions and to study the effect that recognising a sequence of letters as a word has on letter recognition. In order to do this, participants were presented with a lexical decision task as well as a letter recall task. The study hypothesized that there would be a decrease in performance on the letter recall task from the first to the second to the last letter. This is because of the decay in the letter representations during serial binding. The decay of activity translates into a reduced strength of the temporary bond between letter identity and position, leading to a lower chance of correct letter recall for a given position. (de Vries, 2016) Additionally, the study hypothesized that there would be an increase for letter recall at the fifth position because of the reverberation effect. Lastly, the study tested the word superiority effect by hypothesizing that letter recall would be more accurate for words than for non-words.

The previous study (Whittaker (2019), Mudogo (2019), Pink (2019), Buijsman (2019) and Schwartzkopf (2019)) could not rely on traditional models of word recall because of their individual deficits for explaining the study's research question. A notable example is the Interactive Activation Model (IAM) by McClelland and Rumelhart (1981). This model assumes that perception is an interactive process with parallel processing through several levels. This model proved not be of any use for supporting the hypotheses of the previous study, because the model fails to explain the letter recall task. This is because the model requires position specific encoding where every letter position is absolute, which neglects the effect of the relative position of letters in a word. In response to the shortcomings of the IAM, Whitney (2001) proposed the Sequential Encoding Regulated by Inputs to Oscillations within Letter units (SERIOL) model based on ordered letter pairs. Similar to the IAM, the SERIOL assumes a structure with several levels, but in contrast it is based on sequential coding rather than parallel. The SERIOL assumes that letter units can take any position, depending on the time that the units are activated. The letter nodes are fired based on interactions between subthreshold oscillation. This results in a temporal firing pattern of the letter nodes. The SERIOL also assumes the existence of a bigram level, where nodes recognise ordered pairs of letters. This provides a problem for explaining the letter identification task used in the previous studies because the bigrams fail to use absolute letter positions and connect letter position and identity. Specifically, the SERIOL model does not suggest position-specific top-down activation from the word to its letter specifiers.

The IAM and SERIOL models both use a functional level of description to approach the binding problem. Functional models operate through assuming several components in a cognitive process and defining it in terms of their function (Dalenoort & de Vries, 1998). This provides a valid and parsimonious explanation but fails to go into detail about the causal processes behind the assumed components. In contrast to the functional approaches, the previous study therefore opted for a structural approach. This approach uses a counterstrategy, defining a process by its constituting parts at the micro level (Dalenoort & de Vries, 1998).

The specific structural model that was used in the previous studies is the conceptual network as developed by de Vries (2016). This structural model is based on the concept of self-organisation, implying that all functions in a system are the product of autonomous interaction between the elements of said system. Additionally, the binding problem plays a prominent role in the conceptual network, following from the argument that the representations of identity and location must hold separate locations on the spatial map or else an unrealistic amount of memory traces would be needed (superposition catastrophe). The concept of self-organisation described in de Vries (2016), follows the logic proposed by the Tanzi-Hebb learning rule. This rule states that if two neurons show simultaneous activity, the synaptic connection between them becomes more salient (Hebb, 1949; Tanzi, 1893). Hebb proposed that as a consequence of this rule, clusters of neurons exist called cell assemblies that have stronger connections with neurons inside the cell assembly than with other neurons outside of a cell assembly. A cell assembly also has a critical threshold implying that it is only activated when the threshold is reached. When the threshold is not reached, activation in the cell assembly will decay. When the threshold is reached, this will result in an outgoing excitation. As these cell-assemblies correspond to memory traces at the functional level, de Vries (2016) hypothesises that cell assemblies can be activated to put a memory trace in working memory. The activation of a cell assembly at a level below the critical threshold would correspond to a memory trace that is in a state of priming. Alternatively, activation above the critical thresholds would correspond to a memory trace that is in working memory.

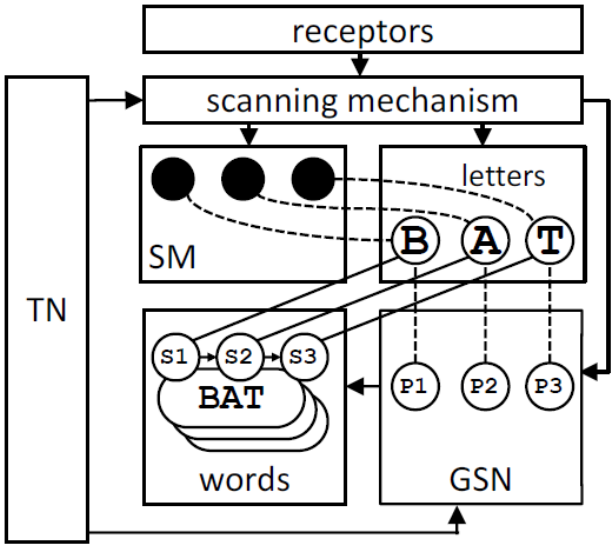

Figure 1 Schematic overview of the conceptual network for letter and word recognition. Arrows and solid lines indicate permanent connections between the different modules like: the spatial map (SM), global sequence network (GSN) and the task network (TN). Dashed lines indicate temporary connections.

For the processing of each letter of a word, two excitation patterns exist: one for letter identity and one for letter location. Would the processing of all letters take place in parallel, there would be heavy interference of spike frequencies. To avoid this interference, letter processing takes place in a serial manner regulated by a *scanning mechanism*. The scanning mechanism transforms external input to excitation pairs and releases the excitation pairs one after the other into the GSN. The subsequent excitation pairs are subject to decay increasing with each letter position. The previous studies expected this decay effect to be present in the letter recall assignment, causing a decrease in letter recall accuracy with each consecutive letter position. With the binding of each letter, two fans of excitation loops excite the letter position corresponding to the correct memory trace of a letter in each local sequence network. Word nodes with corresponding letter and identity, experience a cumulative increase in activation. This triggers top-down activation for veridical words. The quick succession from one position node to the next ceases at the activation of the final position node. The excitation will reverberate between the *memory trace* for the last letter and the last position node in the global sequence network. This effect, referred to as the *reverberation effect*, causes the final position node to have increased strength. The previous studies also hypothesized to see this effect in their letter recall task. The decay effect combined with the reverberation effect shaped the expected hook-shape over the five positions for the mean accuracy graph for non-words. Alternatively, for words, the activation of the final position node will trigger an increase in activation, pushing the word node over the critical threshold. The activation above the threshold will trigger top-down activation for words, helping to recognize a sequence of letters as a word. This top-activation is not present for non-words, which is why the previous studies expected the average accuracy in letter recall to be higher for words than for non-words.

While the other two hypotheses were supported by the outcome of the previous study of 2019, there was an unexpected finding for the decay effect for non-words in two of the five studies (Whittaker, 2019; Buijsman, 2019). Specifically, a performance peak in mean letter recall accuracy was observed at position three for non-words. The corresponding results can be observed in Figure 2. A possible explanation was offered by Whittaker (2019), who mentioned in his discussion that there might be a confounding factor in perceptual salience where the centre of the letter sequence might have been the area of fixation. By focusing on the centre of the letter sequence, the attention of the participant might be fixated on the third letter position, causing an improvement in recall. This possible explanation could be disregarded by looking at the findings of the group of experiments performed by Freericks (2018), Seibel (2018), Donelan (2018) and Bhouri (2018). In this study, a similar experimental method was used on German words. However, the focus of the studies is on the effect of shifts in attention on word and letter processing. The studies use two attention conditions: The use of distributed or centred warning signals (Seibel, 2018; Donelan, 2018) and the presence of flankers (Freericks, 2018; Bhouri, 2018). By manipulating the warning signal shown before the presentation of the letter sequence, this study examined the effect of attention on letter recall on different letter positions. The study hypothesized that the attention conditions would decrease performance for some letter positions on the letter recall task for non-words. However, this hypothesis could not be supported by the outcome of any of the experiments for words and nonwords of the German language.

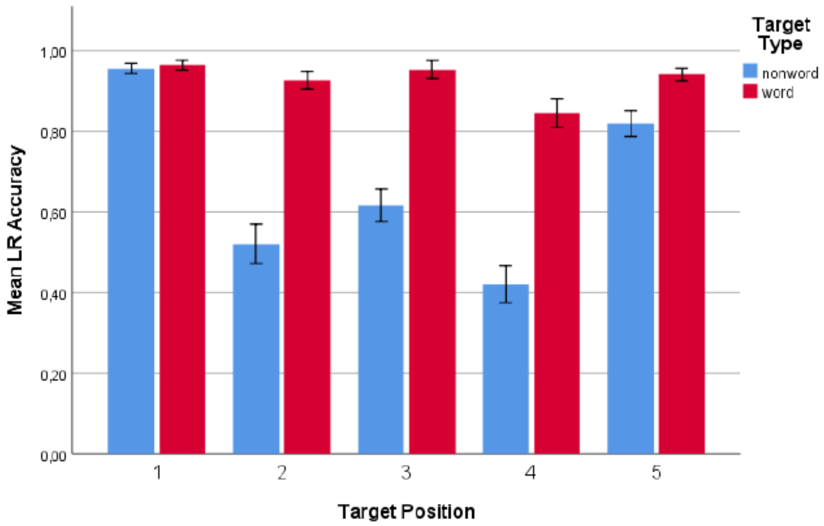

Figure 2 Mean letter recall accuracy against target position for words and non-words. Results from Whittaker (2019).

The present experiment will focus on another possible explanation for the performance peak found in Whittaker (2019) and Buijsman (2019). When looking at the lists of words utilized in the four studies, it could be concluded that the Dutch non-words used for the experiments of Whittaker and Buijsman had particularly frequent combinations of letters in the first three letter positions (high head frequency) compared to the English and German non-words in the experiments of Mudogo (2019), Pink (2019) and Schwartzkopf (2019), where no performance peak was found for the third letter position. The central experiment of this thesis is part of a study made up of six separate experiments examining this hypothesized effect. In the other experiments, the effect of shifting attention is tested with distributed and centred warning signals in a different language than in the study by Seibel (2018) and Donelan (2018). In one condition, low head frequency is kept constant (Zomerman, in preparation), while in another condition high head frequency is kept constant (Hennink, in preparation). Additionally, all three conditions are also studied with English words (Gontijo-Santos Lima, in preparation; Bosutar, in preparation; Seppälä, in preparation).

The central experiment of this thesis focuses on the effect of high and low head frequency on letter recall in Dutch words and non-words. Based on the conceptual network (de Vries, 2016), we expected to see a decay and reverberation effect for the non-words resulting in a hook-shaped distribution of mean letter recall accuracy. Additionally, we hypothesized that the accuracy in letter recall will decay less steeply across positions for high head frequency non-words relative to low head frequency non-words. We expected to see this effect because the frequent letter combinations in the first three positions of non-words with a high head frequency are expected to result in an increase of top-down activation. Lastly, because the effect of attention shifts on letter processing was only tested on German words in previous experiments (Freericks, 2018; Seibel, 2018; Donelan, 2018; Bhouri, 2018), we could still expect to see a performance peak at letter position three for low-frequency non-words. Adapting the original explanation by Whittaker (2019), the centred warning signal might cause a fixation on the third letter position of the letter sequence causing a peak in letter recall accuracy. We did not expect to see a performance peak for words nor for high-frequency non-words, due to the top-down activation of the conceptual network. For words we did not expect to see any significant increase or decrease in letter recall for any of the letter positions, due to the top down activation processes of word recognition.

Method

Design

The experiment consisted of a letter recall (LR) assignment in a 2x2x5 design. One independent variable (IV) is head frequency with the two levels: low head frequency and high head frequency. Another IV is word type with the two levels: word and non-word. Lastly, the IV letter position has five levels, one for each letter position. The dependent variable (DV) in the experiment is the mean accuracy in letter recall expressed as the total ratio of correct answers. During the letter recall assignment, participants were asked to recall a letter from a specific position in a sequence of letters. The accuracy with which the participant recalls the specific letter is the DV of interest.

Participants

The participant sample consisted of three separate sample groups. The first sample consisted of first-year students following a bachelor in Psychology at the University of Groningen. This subsample consisted of N=25 participants, 32 percent male and 68 percent female with a mean age of 19 ranging between 17 and 25 years of age. These participants were sampled through the research participant pool of the department of psychology, and received study credits for completing the experiment. The second subsample consisted of N=11 prolific participants sampled from the paid participant pool of the University of Groningen. This sample was 36 percent female and 64 percent male and had an average age of 25 ranging between 18 and 34 years of age. The prolific subsample received a monetary reward of £2,- for their participation. The last subsample consisted of N=5 voluntary participants sampled through the personal connections of the researcher. This sample consisted of 2 male and 3 female participants with an average age of 18 ranging between 18 and 20 years of age. This sample did not receive any reward for participation. The complete sample consisted of N= 41 participants. All participants indicated to have Dutch as their native language.

Stimuli

The words used in the experiment were taken from the CELEX centre for Lexical Information (Webcelex, 2001) and were also used for the previous studies with Dutch words: Whittaker (2019) and Buijsman (2019). The words were selected in pairs with one critical letter difference to make sure that the participants would not benefit from the *word substitution effect* (Reicher, 1969). This effect entails a participant correctly recalling the critical letter because it is the most suitable option. Using a pair of words with two possible critical letter options, eliminates this effect. Non-words were constructed manually by creating an anagram of each word with the critical letter staying the same. Using the same letters for the non-word as for the word ensured that the general frequencies of the letters would be similar. Similar to words, non-words were also created in pairs where the critical letter was the sole difference. The words and non-words in the experiment were separated into high head frequency and low head frequency conditions determined by the frequency of letter combinations in the first three letter positions. For high head frequency, the non-words had letter combinations that also formed the beginnings of words. For low head frequency, the non-words had beginnings with highly infrequent letter combinations. Words were also separated into conditions with low head frequency (first three letter sequence occurs relatively little in the set of words with a frequency >7 million), and high head frequency (first three letter sequence occurs relatively often in the set of words). For each letter position, four compatible sets of six non-words, and four compatible sets of six words were created.

Within these sets, the distribution of frequency was similar. To randomize over participants, one of the sets was randomly selected for use as targets in the trials for each participant.

Procedure

This experiment was approved by the Ethics Committee of the Faculty of Behavioural and Social Sciences of the University of Groningen. The experiment took place in OSWeb, an online environment for experiments created in OpenSesame (Mathôt and Theeuwes, 2012). The experiment was run in the participants own setting and thus could not benefit from controlled research lab conditions. To diminish environmental effects, the experiment duration was kept rather short with a total duration of maximum 20 minutes. Preceding the experiment, participants were presented with a survey in the Qualtrics environment (Qualtrics 2021). In the survey: the study was introduced, informed consent was obtained and sample descriptives (age, sex, nationality, first language) were collected for each participant. The experiment consisted of an LR assignment with 2 blocks of practice containing 10 trials each and 4 blocks of the experiment containing 30 trials each. Each trial was a presentation of four consecutive screens. First, a blank screen was presented lasting 1000 ms. Next, a preparation screen was presented with a centred warning signal (500 ms) followed by the target presentation surrounded by flanking hedges (50 ms) and lastly a masking screen was shown (see Table 1).

The centred warning signal consisted of two vertical lines above and below the area where the third letter position in the sequence of letters would appear in the target presentation. The space between the two lines focused the attention of the participant on the third letter position, which is the middle of the letter sequence. The target presentation contained a letter sequence of 5 letters with a flanking hedge on each end (e.g. #LOPEN#). The hedges were placed on each end of the letter sequence to control for a possible confounding factor. This factor is a significant difference in difficulty identifying letters with or without a letter adjacent to it. The masking screen consisted of @ symbols surrounded by flanking hedges and was placed to counteract possible benefits that a participant might receive from the afterimage. In the masking screen, a number was placed to indicate the letter that the participant was asked to recall. For the letter recall task, participants were instructed that the flanking hedges were not to be counted as positions (see Appendix).

The task for the participant was to recall the letter at the indicated position and to submit the letter by typing it in the box provided on the masking screen and pressing the enter key. During the practice trials, the participant was given direct feedback by the masking screen switching to green in case of a correct answer or red in case of an incorrect answer. In the experiment phase, feedback was also given in the form of a feedback screen showing the percentage of correct answers after each block of trials. During this inter-block feedback, the participant was instructed to take a short break if needed. All symbols were presented in the Courier New font at the size 11, because it presents the letters with equal size and spacing. This ensures that the preparation signal is correctly lined up at the centre of the target letter sequence. Following the experiment, the student and volunteers subsamples received a debriefing consisting of graphs depicting the individual's results and supporting text.

Table 1

Trial Sequence

<table>
<tr><th></th><th>Screen</th><th>Presentation</th></tr>
<tr><td>Blank screen</td><td>1000 ms</td><td></td></tr>
<tr><td>Prep. Signal</td><td>500 ms</td><td>|
|</td></tr>
<tr><td>Target</td><td>50 ms</td><td>#LOPEN#</td></tr>
<tr><td>Mask</td><td>Until key
response</td><td>#@@@@@#
5
□</td></tr>
</table>

Results

For statistical analysis, an alpha level of 0.05 was applied. The statistical analyses were performed using IBM SPSS version 25.0 and JASP 0.11.1. Prior to analysis, the data was aggregated and restructured in SPSS using the method described in Lacroix and Giguère (2006). A selection of cases (N= 5) was filtered out prior to performing the analysis. This included one outlier case with a mean accuracy score lower than 10 percent. This outlier case likely did not understand the assignment or experienced technical difficulties during the experiment. Additionally, four cases were filtered out for participants of which double data was collected. By a technical error, these participants were forced to quit the experiment with data collection finished but no credits granted. These participants subsequently repeated the study, but were assigned another experiment design. For these cases, the data of the experiment that was done secondly was not used in the analysis to avoid possible confounds. The study design described in the method section allowed for the assumption of independence of observations. The final sample size for the analysis consisted of N = 41.

Notably, according to Mauchly's test of sphericity, the assumption of sphericity was not violated for any of the factors in the analysis (Position ($X^2 = 14.788$, $p = 0.097$); Wordtype * Position ($X^2 = 9.685$, $p = 0.377$); Frequency * Position ($X^2 = 4.069$, $p = 0.907$); Wordtype * Frequency * Position ($X^2 = 15.555$, $p = 0.077$)). Additionally, the Q-Q plot shows an approximately normal distribution for the DV, meeting the assumption of normality.

The three independent variables: word type, head frequency and letter position were analysed by performing a Repeated Measures (RM) ANOVA on the restructured data. The results of this analysis showed that the expected three-way interaction between the independent variables is significant ($F = 30.933, p = < 0.001$). The other F-ratios resulting from this analysis can be seen in Table 2. The three way interaction becomes clear when looking at the graphs displayed in Figure 3. As further explained by the data presented below, the graphs show that the significant two-way interaction between head frequency and letter position varies across the two levels of the third variable word type.

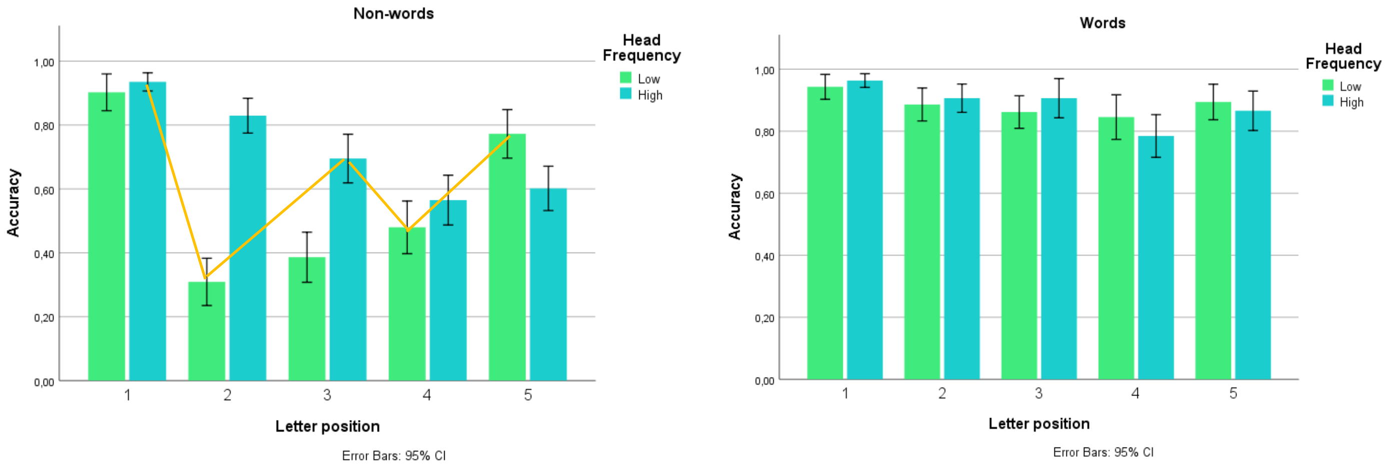

Figure 3 Mean accuracy in performance per letter position for low and high frequency heads in non-words and words. The green bars represent low head frequency letter combinations, the blue bars represent high head frequency letter combinations. Error bars show the 95%

confidence interval. The yellow line shows the pattern that could have been found if the experiment would have been performed without controlling for high and low head frequencies.

In order to further analyse the hypothesised effect of head frequency on performance for the specific letter positions, a post hoc analysis was done using Bonferroni adjusted alpha levels. The graph for non-words shows a large difference in the patterns for low head frequency and high head frequency non-words. The graph for low head frequency non-words shows a very different result to the predicted outcome. As expected there are significant differences between the first and second position and between the fourth and fifth position both with $p < 0.001$. However, the differences between positions for the second, third and fourth position are not significant with $p > 0.288$. The pattern therefore shows a significant negative incline followed by a statistically flat line $M(pos1) = 0.902$, $CI[0.830, 0.975]$; $M(pos2) = 0.309$, $CI[0.236, 0.382]$; $M(pos3) = 0.386$, $CI[0.314, 0.459]$; $M(pos4) = 0.480$, $CI[0.407, 0.552]$). Subsequently, there is a significant positive incline to the final position ($M(pos5) = 0.772$, $CI[0.700, 0.845]$). Following these results, the observed pattern for the low frequency non-words can be described as a U-shaped pattern. The high head frequency non-words graph follows the expected pattern of decay with a significant difference between each subsequent letter pair from position 1 to position 4 with all differences having $p < 0.02$. These subsequent positions show a steady decline in average performance ($M(pos1) = 0.935$, $CI[0.872, 0.998]$; $M(pos2) = 0.829$, $CI[0.767, 0.892]$; $M(pos3) = 0.695$, $CI[0.633, 0.758]$; $M(pos4) = 0.565$, $CI[0.502, 0.628]$). Only the expected positive incline from the fourth position to the final position ($M(pos5) = 0.602$, $CI[0.539, 0.664]$) is not significant with $p = 1.000$. These results indicate that the graph for high head frequency non-words does not follow the expected hook-shaped pattern completely. The distribution is missing the expected positive incline from the fourth to the fifth letter position caused by the reverberation effect.

As can be observed in the graph for low frequency non-words in figure 3, no significant performance peak was found for the third letter position. However, considering that the previous studies (Whittaker, 2019; Buijsman, 2019) did not control for head frequency, the yellow line indicates the pattern that could have been observed would low and high head frequencies have been combined in the present experiment. In these alternative results, a performance peak would possibly have been observed, which supports the overarching hypothesis that head frequency has a significant effect on recall of letters in non-words.

The results for the words follow close to the expected straight lined pattern, as we would not expect to see any significant differences between letter positions due to the top-down activation associated with word recognition (de Vries, 2016). For high head frequency words, the difference between the third and fourth subsequent letter positions diverts from this pattern with a $p = 0.009$. The other differences are all not significant with $p > 0.081$. This creates a straight line pattern of mean accuracy scores from position 1 to position 3($M(pos1) = 0.963, CI[0.909, 1.018]$; $M(pos2) = 0.907, CI[0.852, 0.961]; M(pos3) = 0.907, CI[0.852, 0{,}961]$). Followed by a slight negative incline between position 3 and 4 ($M(pos4) = 0.785, CI[0.730, 0.839]$) and finally a straight line between position 4 and 5 ($M(pos5) = 0.866, CI[0.812, 0.920]$). For low head frequency words there are no significant differences between any of the subsequent letter positions with $p > 0.249$ for all positions. The pattern shows the expected straight line: $M(pos1) = 0.943, CI[0.888, 0.998]$; $M(pos2) = 0.831, CI[0.831, 0.941]$; $M(pos3) = 0.862, CI[0.807, 0.917]$); $M(pos4) = 0.846, CI[0.791, 0.900]; M(pos5) = 0.894, CI[0.839, 0.949]$.

Table 2

F ratios as the outcome of the RM ANOVA.

	F	df	p
Wordtype	261.635	1	< 0.001
Frequency	76.645	1	< 0.001
Position	48.112	4	< 0.001
Wordtype * Frequency	72.969	1	< 0.001
Wordtype * Position	30.678	4	< 0.001
Frequency * Position	43.928	4	< 0.001
Wordtype * Frequency * Position	30.933	4	< 0.001

Discussion

In the current experiment we examined the role of high and low head frequency in letter recall as a follow up on previous studies focusing on explaining word and letter recall in terms of the conceptual network (de Vries, 2016). In the previous studies of 2019 by Whittaker and Buijsman, a surprising peak in performance on letter position three for the non-words was found that could not be explained by the conceptual network. The hypothesis whether this performance peak was influenced by attention was examined in previous studies in 2018 by Seibel and Donelan. Evidence was found that attention did not have an effect on letter recall performance for German words. In the current study, we followed up on the two sets of previous studies by examining the role of high and low head frequency on letter recall performance. This specific experiment design used a selection of Dutch words and a centred warning signal.

Based on the conceptual network (de Vries, 2016), we hypothesised to see a decay in performance from position 1 to 4 followed by a growth in performance caused by the reverberation effect on position 5 for non-words with both high and low frequency heads. The graph for high head frequency non-words showed a decay effect as expected, however the reverberation effect was not significant. The graph for low head frequency non-words did not show the predicted decay effect following a U-shaped pattern instead of the expected hook-shaped pattern. Also, we expected to find a peak in letter recall performance for the third letter position for non-words due to use of the centred warning signal. Evidently, no peak at the third position was found that can be attributed to the use of the centred warning signal. Additional comparisons of the centred and distributed warning signals for this study were not part of the research design of the main experiment of this thesis, conclusions about these comparisons can be found in Zomerman (in preparation) and Hennink (in preparation). Additionally, we hypothesized that the hook shape would generally be higher for high head frequency non-words than for low head frequency non-words, because according to the conceptual network model there would be less top-down activation for non-words with a low head frequency than for non-words with a high head frequency. Visual inspection of the non-word graph does show a considerable high-frequency superiority. However, a statistical analysis of mean difference between high head frequency and low head frequency non-words goes beyond the scope of this thesis . This finding is not consistent with the results of previous studies. In both of the previous sets of studies significant hook shapes were found for non-words in similar experiment designs (Whittaker, Buijsman, Mudogo, Pink and Schwartzkopf, 2019; Freericks, Seibel, Donelan, Bhouri, 2018). The effect of head frequency on word and letter recognition was not tested before, so more data on this effect can be gathered from the other experiments of the present study.

Following the findings of the two previous studies, we expected to see a performance peak at position three for non-words (Whittaker, Buijsman, 2019). No direct evidence was found for a performance peak at position three for non-words due to the effect of frequency heads, as a significant difference could not be observed in the mean differences between the critical first three positions. However, would the significant difference between head frequencies have been disregarded, a performance peak would likely have been found for position three. So, looking at the yellow line in figure 3: if an experiment was done with high head frequency non-words in position 1; low head frequency non-words in position 2; high head frequency non-words in position 3; low head frequency non-words in position 4 and high head frequency non-words in position 5, a performance peak would have been found signified by the w-shaped pattern. This finding would support the overarching hypothesis that head frequency has an effect on word and letter recall. Following this evidence, in the case of Buijsman (2019) and Whittaker (2019), there might have been an abundance of words with a high head frequency in the set of words used for the experiment, causing the observed peak in performance for the third letter position.

The graph for words largely followed the expected pattern for both high and low head frequency, namely no significant differences between performance on subsequent letter positions. However, a surprising significant difference was found between the third and fourth position for words with a high head frequency. In this difference, performance was significantly worse for letter recall on the fourth position than on the third position.

Overall, the results of the experiment do not support the effects that we expected to find looking at the results of previous studies and the conceptual network model (de Vries, 2016). One of the most surprising findings was the u-shaped graph for low head frequency non-words. This finding could be evidence against the decay hypothesis from de Vries (2016), implying that this hypothesis is ineffective for explaining patterns in word and letter recognition for low head frequency non-words. An alternative hypothesis could be that in focusing on creating non-words with a low head frequency, perhaps incidentally non-words were created with a higher tail frequency. During the creation of non-words as anagrams of words, the focus would be on creating a low head frequency with unusual letter combinations. The remaining letters would then be added randomly, possibly creating letter combinations that are quite frequent. An example of this from the database of non-words used for the experiment is the low head frequency non-word BNNEE from the Dutch word BENEN. The last three letter positions in this letter combination form the Dutch veridical word NEE which might lead to a burst in top-down activation for the last three letter positions. This tail frequency effect might also explain the missing reverberation effect or last letter superiority for high head frequency non-words. The hypothesised high tail frequency might cause the last letter positions in non-word sequences to be processed as words with a spike in top-down activation. This would result in the final letters being processed without significant differences in letter recall between the letter positions, thereby inhibiting last letter superiority. This hypothesised tail frequency effect for non-words would need to be followed up in future studies, both in its applications for the decay effect in low head frequency non-words and for the reverberation effect in high head frequency non-words.

An additional contradicting finding was the significantly lower performance in letter recognition for letters at position 4 in words. In previous studies (Dhonelan, 2018; Bhouri, 2018), the fourth position was also identified as the significantly lowest scoring letter position for words. Interpreting from the conceptual network model (de Vries, 2016), the low accuracy score could imply that top-down activation for this position is significantly less than for the other positions. Perhaps due to its late activation in the serial binding order. However, not enough evidence was found to report on the consistency nor the cause of this effect, so this should be subject to future studies.

The other experiment designs in the present study show results that both agree and disagree with the results of this experiment. Notably, the results for the identical experiment design but with English words (Gontijo-Santos Lima, in preparation) produced very similar results. For example, the English version of this experiment also produced a significant three-way interaction with an almost identical U-shaped graph for low frequency non-words. In contrast, no significant mean difference was found for this English experiment for any of the positions in the pairwise comparisons for words. Additionally, the expected reverberation effect on position 5 for high frequency non-words was found to be significant, resulting in the expected hook shape. Lastly, in the analysis by Gontijo-Santos Lima, sphericity was violated for several of the ANOVA tests, therefore Greenhouse-Geiser corrections were applied. The other two experiments with Dutch words found very contrasting results. The experiment using only low head frequency letter combinations to study the effect of centred and distributed warning signals, did not find a significant three-way interaction. This indicates that warning signal does not have a significant effect on word and letter recognition (Zomerman, in preparation). Inconsistent findings included a U-shaped graph for centred words and a U-shaped graph for both centred and distributed non-words. Similarly, the experiment using only high head frequency letter combinations did not find a significant three way interaction (Hennink, in preparation). Surprisingly, a significant main effect was found for position, wordtype and preparation signal. Similar to this experiment, no evidence was found supporting last letter superiority for non-words nor for a performance peak at position three. Also, a significant decrease in accuracy was found at the fourth letter position for words identical to the findings of the central experiment of this thesis.

The English experiment using only low head frequency letter combinations again did not find a significant three way interaction (Seppälä, in preparation). Similar to Zomerman (in preparation), a U-shaped pattern was found for non-words instead of the expected hook shape and similar to Hennink (in preparation), no evidence was found for a performance peak at letter position three. Lastly, the English experiment using only high head frequency letter combinations did not find a significant three way interaction, securing the hypothesis that the use of centred or distributed preparation signals does not have a significant effect on word and letter recognition (Bosutar, in preparation). In this experiment a significant hook shape was found for non-words consistent with Gontijo-Santos Lima (in preparation). Also a significant performance peak was found at position three for non-words. This performance peak was of equal height for the distributed and centred preparation signals.

The present study has several limitations. Firstly, the sampling for the experiments was done in a decentralised manner with two or three separate sampling groups depending on the experiment design. Consequently, the sample is largely a convenience sample, which has major drawbacks for the external validity of the study. Also, the use of a voluntary sample collected through the personal connections of the researchers might have affected the homogeneity of the sample between experiments of the study. Additionally, there were some technical issues during the assessment of the experiments causing some experiments to crash which may have caused confusion and affected the internal validity of the study. Also, there were some participants that indicated to not have perceived the target screen in some or any of the trials. This might be due to the fact that some of these participants were external volunteers and may thus not be accustomed to the manner of experimentation used in common psychological experiments. Alternatively, the missing target screen might also be the result of technical error. However, not enough cases were reported in order to make a concluding statement about this.

The aim of the present study was to increase understanding about the process of word and letter recall as described by the conceptual network model (de Vries, 2016). More precisely, this study served as a follow up on inconsistent findings in previous studies examining the effect of warning signals and the decay hypothesis. Despite its limitations, the study provides a valuable support of the conceptual network model (de Vries, 2016), by clarifying the significant role of head frequency on letter recall. Future research in this area could further investigate the role of tail frequencies in letter recall for low head frequency non-words and the absence of last letter superiority for Dutch high head frequency non-words.

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Appendix

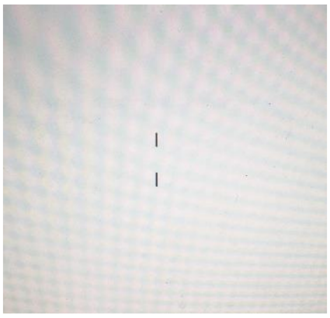
Instructies, passend bij experiment D1D

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.

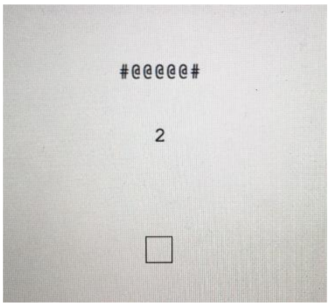
Het experiment ziet er als volgt uit:

1. Als eerste zullen er twee lijnen te zien zijn, aan de boven- en onderkant van het scherm. Deze lijnen zijn bedoeld om je aandacht naar het midden van het scherm te brengen, omdat dit is waar de middelste letter van het (niet) woord te zien zal zijn (positie 3). De manier waarop de letters te zien zijn kun je hieronder zien in figuur 1. Zoals je kan zien, zullen eerst deze twee verticale lijnen te zien zijn. Daarna is het (niet)woord kort te zien, waarna deze vervangen wordt door #@@@@@# tekens.

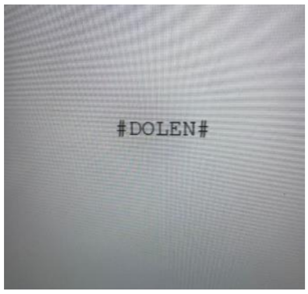
Figuur 1:



Figuur 2:



Figuur 3:



2. Nadat de letterreeks is gepresenteerd, zal een getal onder de symbolen verschijnen, zoals te zien is in figuur 3. 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 met de linker pijltjestoets 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 herhaald.

5. Voordat de daadwerkelijke data collectie 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. Vervolgens zul je 4 blokken van 30 letterreeksen krijgen, wat het echte experiment is. Bij deze blokken zul je niet onmiddellijk feedback krijgen, maar krijg je het percentage goede antwoorden te zien aan het einde van het blok. Je mag kleine pauzes nemen tussen de blokken als dat nodig is.

Veel succes!