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Combining experimental studies and computational modeling: the locus of semantic interference in the picture-word interference task

Bachelor thesis in Artificial Intelligence

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Abstract

In this project the discrepancy on the locus of the semantic interference effect in picture-word interference (PWI) is investigated with the combination of an experimental study and computational modeling. The experimental part consisted of a Psychological Refractory Paradigm experiment with a tone discrimination and a PWI task. It was investigated whether a short presentation duration of PWI stimuli forces participants into parallel processing of both tasks. If this is the case, it may explain the discrepancy among studies in the literature regarding the semantic interference effect in dual task studies. The second part consists of an investigation of how this line of experiments can be modeled using the existing ACT-R and RACE/A models in psycholinguistics.

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1. Introduction

The understanding of cognitive processes can be approached in two ways: experimentally and with computational models. Experimental research uses a bottom – up approach by observing the processes that are going on inside the brain. In experiments one of more variables are manipulated while measuring the effects of this manipulation on other variables. Experiments are used to predict effects and explain causal relations.

Computational modeling, or computationalism uses a top – down approach to cognition. Computationalism starts with identifying a cognitive task or problem. After that, a function that can perform the task or solve the problem is specified. Finally, the function is divided into components that can be implemented. The computational models that arise from this process can be used to simulate and predict results of experiments.

By combining both approaches to cognition the gap between biological descriptions of brain processes and computational descriptions of psychological processes can be narrowed down, this gap is also called the Leibniz Gap[1]. This combination can also be used to give insight into discrepancies between experimental studies in scientific literature.

In this project the combinational approach is used to investigate an issue from literature on which a lot of discrepancy is found. The issue that is investigated is the semantic interference effect in spoken word production. Based on a series of experiments by Piai et al.[2] an experiment was conducted to try to find consensus on when the semantic interference effect takes place in the process of spoken word production. The second part of the project consists of an analysis of two computational models. It was investigated how the ACT-R and RACE/A models can be adjusted to model the conducted experiment. In the future these adjustments could be implemented to simulate and predict the present and new experiments to provide new insights on the workings of spoken word production.

2. The present experimental study

Lexical selection is the process of finding the correct word in the mental lexicon to express a certain lexical concept[3]. This process can be studied with picture-word interference. The picture-word interference task is a task in which participants are presented with a stimulus consisting of a picture with a superimposed word. The superimposed word can either be semantically related or semantically unrelated to the object presented on the picture. Participants are instructed to name the picture object and to ignore the superimposed word.

The semantic interference effect is the effect that participants are slower in naming the picture objects when the superimposed word is semantically related to the picture object compared to when the superimposed word is unrelated to picture object.

There is an ongoing debate on the locus of the semantic interference effect in the process of word processing. Levelt et al.[3] have suggested a lexical selection hypothesis, which attributes the effect to the lexicalization stage of word processing based on experimental results.

To shed light on the debate around the locus of this effect, a dual-task procedure called Psychological Refractory Period (PRP) is used, in which participants perform a language task simultaneously with a tone distinguishing task. In the tone distinguishing task subjects have to identify tone stimuli as being either of low or high frequency by pressing a button. In several previous studies examining lexical processing in word production, the combination of the picture-word interference task and the tone distinguishing task is used. The stimulus onset asynchrony (SOA) is defined as the time between the onset of the first stimulus and the onset of the second stimulus in a task. In a Psychological Refractory Period paradigm study the effect of a factor which is manipulated in the second task (e.g., the semantic interference effect) can either be underadditive or additive with the effect of SOA. If the effect of a factor is underadditive it means that the effect of that factor decreases when the SOA between the two tasks is decreased. If the effect of a factor is additive, the effect of that factor is of equal magnitude at short (e.g., 0 ms) and long (e.g., 500 ms) SOAs.

According to some theories[2, 4], underadditivity implies that the effect of the manipulated factor occurs before a cognitive processing bottleneck during response selection[5]. When task 1 and task 2 in a PRP paradigm experiment co-occur in time and participants are instructed to execute task 1 first, task 1 accesses the central executive system first. This results in a delay of processes from task 2 that require the central executive system. Effects

of a factor that influence processing in task 2 before the need of the central executive system will be (partially) resolved during the delay. This (partial) resolution will cause a smaller effect of the factor when the tasks overlap in time more, thus when the SOA is smaller. In the same line of argumentation, additivity implies that the effect of the manipulated factor occurs after a cognitive processing bottleneck, see figure 1. If it can be determined whether the effect of a factor on a process is either additive or under additive with the SOA effect, conclusions can be drawn about when that process takes place (i.e., either before or after the response-selection bottleneck).

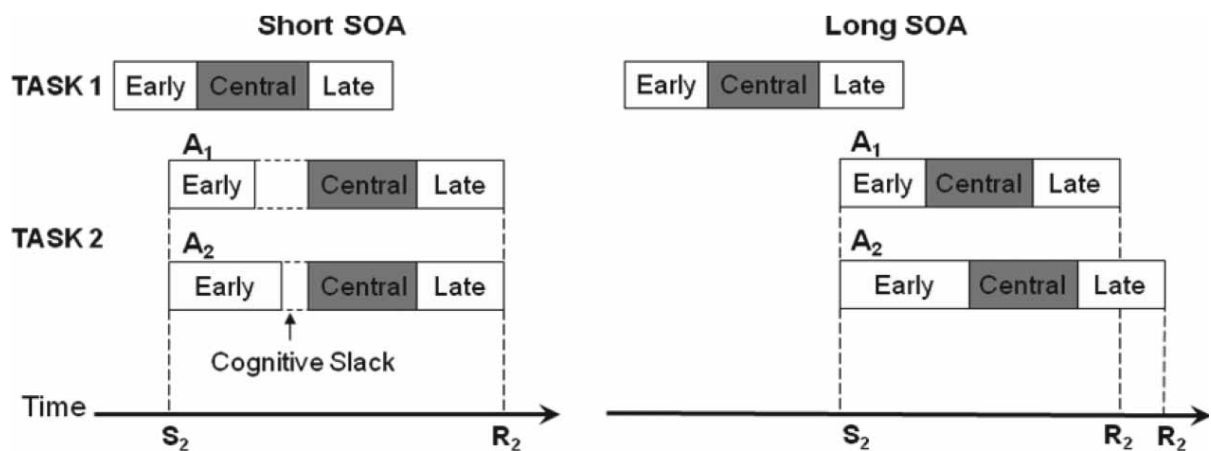


Figure 1: The cognitive processing bottleneck theory, adapted from [5].

Results from the study by Dell'Acqua et al.[4] suggest underadditive effects of SOA and type of stimulus (the semantic interference effect), which was interpreted by Dell'Acqua et al.[4] as evidence that the semantic interference effect emerges at a stage prior to response selection, during perceptual/conceptual encoding. However, results from Schnur et al.[6] suggest additive effects. In Piai et al.[2] the experiments from the different research groups were compared. Based on that comparison, six experiments were constructed to try to resolve the conflicting findings. These experiments take into account the variation in used tasks, SOA values, stimulus types etc. In the experiments additive effects of SOA and stimulus type were found. These results suggest that the locus of semantic interference takes place during or after the lexical response- selection stage.

For the understanding of the process of lexical selection it is important to determine whether the semantic interference effect takes place before the lexical selection stage, or during or after the lexical selection stage. In previous studies the picture- word stimulus presentation duration is not stated. To exclude that this factor influences the semantic interference effect and causes the discrepancies between previous studies a new experiment was conducted. In the present study the duration of the picture – word

stimulus presentation is manipulated. If the picture –word stimulus remains available after the tone presentation, participants can attend to the tone stimulus first before attending to the picture-word stimulus, while executing the tasks. Thus, they are not forced to execute both tasks in parallel. The research question of the experiment is thus whether the duration of stimulus presentation influences the semantic interference effect.

Manipulating the presentation duration of the picture-word stimulus can give an answer to the question why there are no consistent results in previous studies. In case of short presentation, participants may be forced into parallel processing of the picture – word stimulus and the tone stimulus, because the picture-word stimulus is only briefly available on the screen. If parallel processing takes place, it could explain why some experiments show underadditivity of stimulus type and stimulus onset asynchrony effects. In this case, the semantic inference could be resolved during the processing of the tone. In case of non – parallel processing of both tasks additivity would be found, because there is no concurrent task processing.

2.1 The experiment

The experiment resembles experiment 4 from Piai et al.[2], with the addition of the manipulation of the picture-word stimulus presentation duration.

The reading skills of the participants are measured in two additional tasks. This is done to control for the hypothesis that the size of the semantic interference effect is dependent on how fast participants are in reading the distractor words in a picture-word interference task. If the distractor words are read faster there will be less interference with the picture naming, as has been argued by Kleinman [7]. Furthermore, if participants spend less time reading the distractor word, they will be able to do a greater part of the tasks in parallel. This can result in a disappearance of the semantic interference effect at the 0-ms SOA.

2.1.1 Method

2.1.1.1 Participants

Thirty-five native Dutch speakers (10 male, mean age = 21.657, sd = 3.320) from the participants pool of the Radboud University Nijmegen participated in the experiment for course credit or monetary compensation. All participants reported normal hearing and no reading disorders. The data of 2 participants was discarded due to technical difficulties

during the experiment. Ten participants had too few observations left after discarding all trials with errors or technical failures. The resulting set of participants were twenty-three native Dutch speakers (7 male, mean age = 21.375, sd = 3.545).

2.1.1.2 Materials and design

The experimental session consisted of three parts: a PRP block with two tasks, followed by two reading tasks.

For the PRP part of the experiment thirty-two pictures from the gallery of the Max Planck institute for Psycholinguistics in Nijmegen were used. The pictures represented common objects belonging to eight different semantic categories, each category having four objects. In the semantically related condition each picture was paired with a semantically related distractor word, which was the name of one of the other pictures from the same category. In the unrelated condition each picture was paired with a semantically unrelated distractor word, which was the name of one of the objects from a different semantic category. All distractor words were part of the response set. The tones used in the first task of the PRP part were pure tones lasting 300 ms. The low tone had a frequency of 300 Hz and the high tone had a frequency of 800 Hz. SOAs of 0 ms and 1000 ms were used. Each picture – word stimulus occurred once with every SOA, with a total of 256 trials. Each participant had a unique list with randomized trials. Lists were randomized with Mix[8] with the same stimulus, SOA and tone not appearing on more than three trials after each other.

For the second part, the stimuli of the first reading task consisted of the distractor words from the first part of the experiment. Each participant had a unique list with randomized trails, in which every distractor word occurred twice. Lists were randomized with Mix[8]. For the third part of the experiment, the second reading task, the “Een-Minuut-Test”[9] was used.

2.1.1.3 Procedure and apparatus

The stimuli presentation and response recording of the first two parts of the experiment were controlled by Presentation Software (Neurobehavioral Systems, Albany, CA).

In the first part participants conducted a PRP task. For the 0 – ms SOA all trials began with simultaneous presentation of the picture – word stimulus and the tone. For the 1000 – ms SOA, the tone was presented immediately and after 1000 ms followed by the picture –

word stimulus. The picture – word stimulus remained on the screen for 250 ms, followed by a black screen for 2750 ms. The recording of the vocal responses started at the moment the picture-word stimulus was presented and lasted 3000 ms. The tones were presented to the participants by closed headphones and the vocal responses were measured with a voice key. Button presses were measured by a silent button box. Participants were instructed to rest their arms on the button box and to use their index fingers for pressing the buttons. The left button represented the low tones and the right button represented the high tones. This was indicated on the button box. Participants were instructed to name the picture and to ignore the distractor words. Also, they were instructed to first respond to the presented tone, then to the picture-word stimulus and that they should try to be as fast as possible and as accurate as possible in both tasks. Participants were acquainted with the pictures used in the experiment and their corresponding names using a booklet. The experiment started with two practice blocks for the first part of the experiment. The first practice block consisted of responding to the tone stimuli. The second practice block consisted of naming the pictures, with different material than used in the experimental block. For the other two experimental parts there were no practice blocks.

In the second part of the experiment only the distractor words were presented for a duration of 1000 ms, followed by a black screen for 500 ms. Participants were asked to read the distractor words out aloud. The registration of vocal responses started at the moment the distractor word was presented and lasted 1500 ms.

In the third part participants carried out the “Een-Minuut-Test”[9], or the one-minute-test. The participants were given a leaflet containing 116 Dutch words with increasing difficulty. Participants were instructed to read aloud as many words as possible correctly within the timespan of one minute. The timespan was measured by the use of a stopwatch. The number of correctly read words was notated as the one-minute-test score for that participant.

Between all parts of the session there was a brief pause. The total duration of one experimental session was approximately half an hour.

2.1.1.4 Analysis

For the analysis of the data from the PRP block, the same criteria were used as for the study by Piai et al.[2]. During the session influent or incorrect responses were coded as errors, while trials with voice-key errors were coded as such. After each session the coding of the vocal responses of the participants was added to the data on the computer. All trials in which a vocal response was given before the manual response were discarded. Also, all trials in which the vocal reaction time was shorter than 200 ms and the trials in which the manual reaction time was shorter than 100 ms were discarded.

By-participant (F1) repeated measures ANOVAs were calculated for both the manual and vocal reactions times (RTs) separately, with condition (related and unrelated) and SOA (0 and 1000 ms) as within-participant variables.

A by-item (F2) repeated measures ANOVA was calculated for the naming RTs with condition (related and unrelated) and SOA (0 and 1000 ms) as within-item variables. For every participant the average picture-naming time and the size of the semantic interference effect (SIE) were calculated for the SOA of 0 and 1000 ms. The size of the semantic interference effect was calculated by subtracting the average picture-naming time in the unrelated condition from the average picture-naming reading time in the related condition.

For the analysis of the data from the distractor reading task the average reading time for all words per participant was calculated. Pearson's product correlation was calculated between the SIE in the PRP task and the average reading time in the distractor reading task for both SOAs (0 and 1000 ms).

The data from the second reading task consists of a single measurement of the one-minute-test score. Pearson's product correlation was calculated between the SIE in the PRP task and the one-minute-test score for both SOAs (0 and 1000 ms). Pearson's product correlation was also calculated between the average reading time in the distractor reading task and the one-minute-test score, and between the average picture-naming time in the PRP task and the one-minute-test score for both SOAs (0 and 1000 ms).

2.1.1.5 Results

Figure 2 shows the vocal and manual response times for the PRP task as a function of SOA and condition.

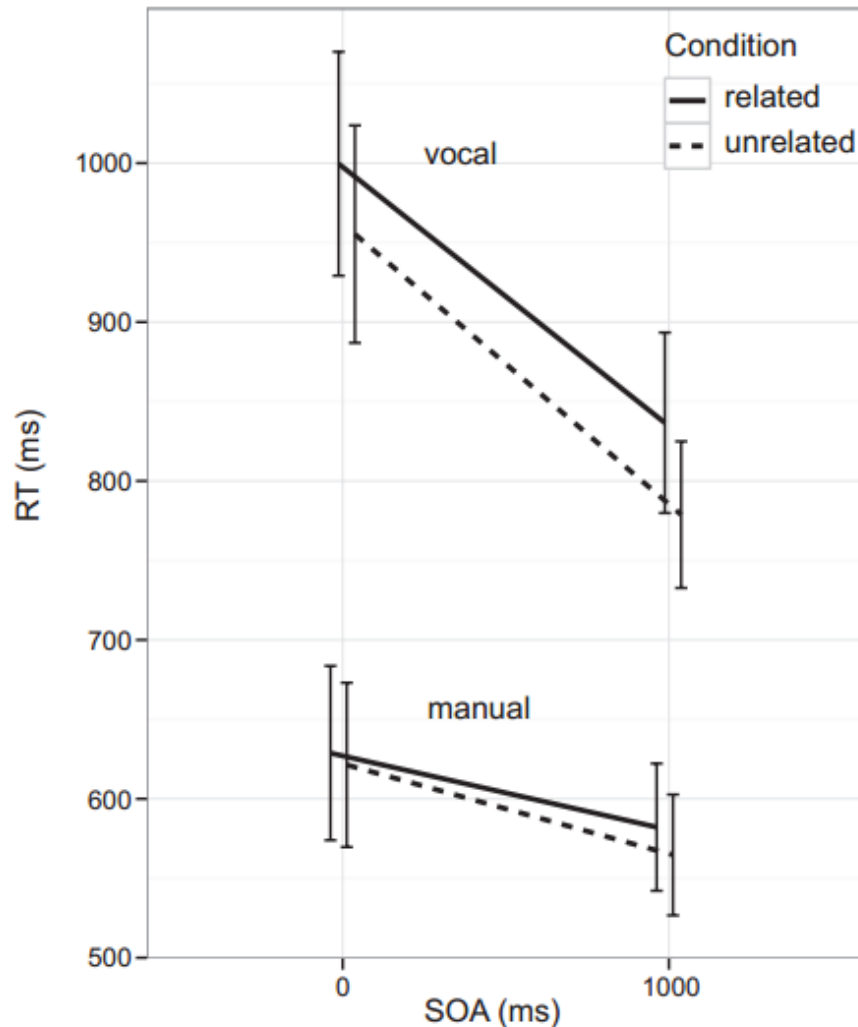


Figure 2: The vocal and manual response times for the PRP task, as a function of SOA and condition.

For the vocal response times in the PRP task, there was a significant main effect of SOA, $F(1,22) = 133.5$, $p < .001$, $F(1,31)=574$, $p < .001$, indicating that picture-naming responses were overall slower at the 0-ms than at the 1000-ms SOA, and a significant main effect of condition, indicating that picture-naming responses were overall slower for related than unrelated picture-word pairs, $F(1,22)=29.43$, $p < .001$, $F(1,31)=21.77$, $p < .001$. The interaction SOA x condition was not significant, $F(1,22) = 1.15$, $p = 0.295$, $F(1,31) = 1.752$,

$p = 0.195$. The lack of interaction indicates that the magnitude of the semantic interference effect was similar for both the 0 ms SOA and the 1000 ms SOA, thus the effects of condition were additive with SOA.

For the manual response times in the PRP task, there was a significant main effect of SOA, $F(1,22)=26.93$, $p < .001$, indicating that overall the response times for the 0 ms SOA are longer than for 1000 ms SOA and a significant main effect of condition, $F(1,22)=4.939$, $p = 0.0369$, indicating that overall the response times for the related condition are longer than for the unrelated condition. The interaction SOA x condition was not significant, $F(1,22) = 1.285$, $p = 0.269$. The lack of interaction indicates that the magnitude of the effect was similar for the 0 ms SOA and the 1000 ms, thus that for the manual responses the effects of condition were additive with SOA.

No significant correlations were observed between the SIE for the 0 ms SOA and the average reading time in the distractor reading task ($r = -0.15$, $t(21) = -0.7028$, $p = 0.4899$) and between the SIE for the 1000 ms SOA and the average reading time in the distractor reading task ($r = 0.14$, $t(21)=0.6593$, $p = 0.5168$).

No significant correlations were observed between the SIE for the 0 ms SOA in the PRP task and the one-minute-test score ($r = 0.25$, $t(21) = 1.2059$, $p=0.2413$) and between the SIE for the 1000 ms SOA in the PRP task and the one-minute-test score ($r = -0.04$, $t(21) = -0.1829$, $p = 0.8566$). Neither was there a significant correlation observed between the average reading time for the distractor reading task and the one-minute-test score ($r = -0.09$, $t(21) = -0.4371$, $p = 0.665$).

There was a correlation between the average picture-naming time in the PRP task for the 0 ms SOA and the average reading time in the distractor reading task ($r = 0.70$, $t(21) = 4.5318$, $p < 0.001$) and between the average picture-naming time in the PRP task for the 1000 ms SOA and the average reading time in the distractor reading task ($r = 0.66$, $t(21)=4.0534$, $p < 0.001$).

2.1.1.6 Discussion

The results show additive effects of condition and SOA for both vocal and manual responses in the experiment. These results are in line with the results from Piai et al.[2] and suggest that the semantic interference takes place in the lexical response- selection stage (or later, see Piai et al.[2] for discussion).

On the grounds that additive effects of condition and SOA are found, the results suggest that no parallel processing takes place. Hence, the hypothesis that a short stimulus presentation duration causes parallel processing of the tasks seems invalidated, because the semantic interference was not resolved during the processing of the tone stimulus.

The lack of correlation between the SIE for the 0 ms SOA in the PRP task and the average reading time in the distractor reading task, and the lack of correlation between the SIE for the 1000 ms SOA in the PRP task and the average reading time in the distractor reading task could indicate that the size of the semantic interference effect is not dependent of the reading skills of participants. This finding is in disagreement with the hypothesis of Kleinman[7].

The lack of correlation between the average reading times in distractor reading task and in the one-minute-test could indicate that the one-minute-test is a too broad measurement of reading skills for this experiment. Also, the correlation could be influenced by the fact that the one-minute-test uses different words than used in task 1 and task 2. It could be the case that not all participants were familiar with the words from the one-minute-test.

The correlation between the average naming times for both the 0 ms and 1000 ms SOA in the PRP task and the distractor reading task could indicate that the naming times are dependent of the participants' language skills.

3. Computational modeling of PRP experiments

With a computational model the earlier described experiment could be simulated to investigate whether the model replicates the experimental data. If the model shows the same behavior as is seen in the experiment, it can be excluded that PWI stimulus presentation duration causes the discrepancy between the studies. However, the current psycholinguistic models are not usable yet for simulating the conducted PRP experiment.

In this chapter two computational models are analyzed. In short the workings of these models are described, then it is investigated in how far it is possible to simulate the experiments with the models. Finally, it is specified what adjustments would be necessary to be able to correctly simulate the experiments.

3.1 The ACT-R theory

The Adaptive Character of Thought – Rational theory by Anderson[10, 11] is a theory of higher level cognition, based on a number of assumptions which will be explained below.

First, the model assumes a clear distinction between procedural and declarative memory. Procedural memory is the memory of how to perform certain types of actions and is mostly unconscious. Declarative memory consists of facts and knowledge that can be recalled consciously. A main difference between ACT-R and other cognitive theories is that in ACT-R knowledge does not leave the working memory of the system. Limitations on working memory are modeled by using a limited access to declarative memory, not by using a limited capacity of declarative memory. This means that all information is stored in declarative memory, but only most recent information is active. Older information can be activated if needed. Second, the model represents information in declarative memory by using chunks. Chunks have three important characteristics. Chunks can contain a maximum amount of three elements. Chunks can be organized hierarchically. For units larger than three elements, chunks need to be organized into sub chunks. Chunks can also have different roles, their organization can, for example, be semantic or propositional. The activation level of a chunk depends on a base –level activation, spreading activation from related chunks and a noise term. Third, procedural memory is built on production rules. Production rules consist of precondition – action pairs, when certain precondition is met, the corresponding action is executed. The preconditions and actions are described in terms of declarative memory chunks. Actions can create new declarative memory chunks.

In the ACT-R model, modules are used to handle the different cognitive components such as visual perception and motor execution, which can alter the knowledge available in declarative memory. When the model is executed, production rules are triggered sequentially depending on knowledge available in declarative memory. For each module only one production rule can be executed at a time, though multiple modules can execute actions in parallel. When a production rule requires the retrieval of a memory chunk, from all the chunks that fit the criteria the chunk with the highest activation level is selected.

3.1.1 Modeling the experiment with ACT-R

When one wants to model experiments like the PRP experiment described earlier a model is needed that functions in the same way as the experiments. However, ACT-R has a different working than the functioning of the experiments.

The main disadvantage of using ACT-R is that the theory does not take into account what happens when new information comes available during task execution. New information would only be considered after the current retrieval process is finished. Also, the theory does not elaborate on competition effects when more than one chunk matches the retrieval request. In conclusion, the architecture of this model is not optimal for modeling PRP experiments.

3.2 The RACE/A theory

The Retrieval by Accumulating Evidence in an Architecture theory by van Maanen et al. [12] is an extension of the ACT-R theory. The most important adjustment in RACE/A compared to ACT-R is the use of a dynamic retrieval process. In the RACE/A model changes in activation of declarative memory chunks are updated continuously. Thus, information that is presented during task preparation can still influence the execution. This change will be explained in more detail below.

The activation of a chunk in declarative memory is determined by base – level activation of that chunk (equal to the base – level activation in ACT-R) and the accumulated evidence for the chunk.

An accumulation process is used to determine which memory chunk should be retrieved when more than one chunk matches the retrieval request. The process continues until a

decision criterion is met by one of the chunks. That chunk is then retrieved from declarative memory.

The accumulation of a chunk starts at with the level of activation of that chunk at the moment of accumulation onset. This means that the starting point is influenced by base-level activation and prior retrievals. The accumulated evidence for the chunk is determined by a decay term, spreading activation from related chunks, external activation from stimuli and noise.

The RACE/A theory uses a relative decision criterion to determine whether enough evidence has been accumulated for one of the possible memory chunks. The retrieval time is set equal to the time needed by the chunk to pass the decision criterion. All possible chunks compete for retrieval with this mechanism. This results in slower retrieval times.

3.2.1 Modeling the experiment with RACE/A

With the RACE/A theory PRP paradigm experiments have been implemented successfully by van Maanen et al.[12]. For these experiments two models are used, one for each task in the PRP paradigm. The use of two different models for the tasks causes problems when one wants to investigate the influence of PWI stimulus presentation duration. In using two models the implicit assumption is made that the two tasks do not influence each other. However, parallel processing should be possible in order to answer the question whether short stimulus duration enforces parallel processing.

3.3 Suggested adjustments

The RACE/A extension overcomes the main disadvantage from ACT-R. Therefore, the simplest way to make simulating the described experiment possible is to adjust the RACE/A – model. RACE/A needs to be adapted to enable parallel processing. Below the two necessary adaptations are described on a computational level. These descriptions can be implemented in future work and then be used to further investigate PRP experiments.

First, the two process streams of the models should be integrated into one single model that contains both tasks. The production rules for the tone classification task and the picture naming task should be included in this new model together. In this way the possibility exists that short stimulus duration will enforce parallel processing of the tone distinguishing and the picture naming task.

Second, a priority function is needed. Since the two tasks are now integrated into one model, it is necessary to provide a means to give temporal priority to the tone classification task. The model needs to know that the tone classification task should be conducted before the naming task. The control state mechanism from the original model can perhaps be (partially) re-used for this purpose. This mechanism would only allow the retrieval of the response word after a tone task response is initiated.

3.3.1 Expected results

When these adjustments are implemented, the experiment can be simulated. The expectation is that the results will be in line with those of the experiment. If the PWI stimuli are presented briefly, additive effects of SOA and condition will most likely be found. This indicates that the short stimulus duration does not enforce parallel processing.

4. General discussion

With using the combination of a computational model and a theory-based experiment one can learn more about cognition. In the case of this project the discrepancy on the locus of the semantic interference effect was investigated. The semantic interference effect plays a central role in understanding spoken word production. Dell'acqua et al.[4] have found underadditive effects, suggesting a pre-lexical selection stage for the semantic interference effect, while Schnur et al.[6] en Piai et al.[2] have found additive effects, suggesting that the semantic interference effect takes place during or after the lexical response-selection stage.

In these experiments the PWI stimulus presentation duration was not stated. The present study aimed at investigating whether short PWI stimulus presentation duration forces participants into parallel processing of both tasks. Additionally, participants performed two reading skills tests to test the hypothesis by Kleinman[7] that the size of the semantic interference effect is dependent on reading skill. In the experiment additive effects of condition and SOA were found, suggesting that the semantic interference effect takes place during or after the lexical response-selection stage. Additionally, the additive effects suggest that short stimulus presentation does not enforce parallel processing. A lack of correlation between the size of the semantic interference effect and the reading skills of participants was found, contrary to the hypothesis of Kleinman[7].

Suggestions on how to implement the experiment with the RACE/A theory have been made. For future research these suggestions could be implemented and used to simulate the conducted and other experiments.

In conclusions, support has been found for the locus of the semantic interference effect during or after lexical response – selection stage. RACE/A needs a few adjustments to be able to model the PRP paradigm experiments as described. This implementation can have an important impact on the understanding of parallel cognitive processing.

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