

# **The Role of Working Memory Capacity and Age on the Generation of Predictive Inferences**

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## **Abstract**

Predictive inferences are the readers' anticipation of a likely consequence of the events described in a text. They aid the creation of a mental representation during reading, facilitate the processing of upcoming information in a text and are dependent of several factors. The current study assessed the contribution of working memory capacity and age on the generation of predictive inferences in two experiments. The first experiment, in which children aged 9 to 12 participated, assessed the generation of predictive inferences using a behavioral task. The results show that for the children's experiment, age was not a significant contributor to the generation of predictive inferences nor to working memory capacity. However, working memory capacity was found to be positively significantly associated with the generation of predictive inferences. This result indicates that higher working memory capacity coincides with better predictive inference generation in children. The second experiment, in which adults aged 19-30 participated, assessed the generation of predictive inferences using an eye tracking methodology. Here difference in gaze durations at target words in predictable and less predictable conditions were recorded. In the second experiment no significant relationships were found between any of the variables, suggesting that neither age nor working memory capacity contribute significantly to the ability to generate predictive inferences.

## Introduction

Reading is a complex cognitive process in which symbols, letters and words are decoded. The purpose of reading is to obtain a meaningful representation from these symbols, letters and words. The basic components for successful reading include phonological awareness, decoding, fluency, and vocabulary knowledge, which are collectively called basic reading skills (National Reading Panel, 2000). However, higher-order reading skills are also essential to successful reading (NRP, 2000; Oakhill, Cain, & Bryant, 2003; Paris & Paris, 2003; Snow, 2002; van den Broek, 2005; Kendeou, et al., 2006). These high-order skills include summarization, integration, and comprehension. Reading comprehension entails understanding the meaning of a text as a whole, in other words it is more than the sum of the meaning of each word or sentence mentioned in the text (Rapp, van den Broek, McMaster, Kendeou, & Espin, 2007). Findings from cognitive research propose that the construction of a coherent representation of text in memory is central to successful comprehension (Rapp et al., 2007). This coherent representation is a meaningful network of connections between actions and events described in a text and the reader's background knowledge. This coherent representation, in turn, is established through the generation of inferences. Inferences fill in details that are not explicitly mentioned in the text by using background knowledge and context information. There are two types of inferences, namely bridging and elaborative inferences (Singer, 1994). Bridging inferences serve to create links between sentences and texts, in other words they summarize and integrate the explicit content in a text (Singer, 1994). Elaborative inferences, on the other hand, serve to fill in missing details that were not explicitly mentioned in the text. Predictive inferences are one type of elaborative inferences and are the focus of the current study. They are predictions based on the information mentioned in the text of what is likely to occur next or to be the outcome/consequence (McKoon & Ratcliff, 1986). The generation of predictive inferences is dependent on text

properties, but also on properties of the individual reader (Sweet & Snow, 2003). A reader property that is of influence on the generation of predictive inferences is working memory capacity (WMCapacity; Linderholm, 2002). Working memory is a cognitive resource, with limited capacity, that is used to store and manipulate incoming information whilst integrating it with activated background knowledge and context information (Baddeley, 1986). Another reader property that plays a significant role in the generation of predictive inferences is age (Casteel & Simpson, 1991). The aim of the current study is to explore the contribution of WMCapacity and age on the generation of predictive inferences. In the following paragraphs, the skills that are necessary for efficient reading and reading comprehension are briefly discussed. Next, previous research on the role of predictive inference generation in reading comprehension is reviewed and the influence of WMCapacity and age on the generation of predictive inferences is discussed. To conclude, the research questions for the current study along with the hypotheses are presented.

### **Reading Comprehension and Predictive Inferences**

Reading comprehension is the process of deriving meaning from a text. This is a constructive process resulting in a coherent and integrated mental representation of the statements and actions described in a text. This representation is referred to as a mental model (Johnson-Laird, 1983) or a situation model (Kintsch, 1998). In order to construct this coherent mental representation readers must engage in a number of processes, from deriving meaning, to identifying the key characters to making inferences (Oakhill & Cain, 2006). Inferences are especially important for reading comprehension, because they aid in the construction of the situation model while also facilitating the processing of upcoming information and encouraging active engagement with the text (Allbritton, 2004; Fincher-Kiefer, 1993;

Linderholm, 2002). As mentioned previously, two main groups of inferences can be distinguished, namely bridging and elaborative inferences (Singer, 1994). Predictive inferences, also known as forward inferences, are one type of elaborative inference. They are predictions or anticipations of what is likely to occur next or to be the outcome based on the information mentioned in the text (McKoon & Ratcliff, 1986). An example of such an inference is the following;

‘Steven had been married for years, and his resentment had been building up. One day, no longer able to control his anger, he threw a delicate porcelain vase against the wall’ (Klin, Murray, Levine, & Guzmán, 1999).

In this example, the breaking of the delicate porcelain vase is a highly probable consequence of the vase being thrown. In order to generate predictive inferences readers must activate background knowledge and context information, thus going beyond what is explicitly mentioned in the text. Inferences also require the reader to keep track of objects, people, places, actions and events described in a text expanding over several sentences (Greasser et al., 2003). The generation of these predictive inferences are effortful yet they also ease the processing of future text events when the anticipated event or (re)action is confirmed (Linderholm, 2002). The current study will focus on the contribution WMCapacity and age on the generation of predictive inferences. Previous literature with regards to the relationship between age, WMCapacity and the generation of predictive inferences is discussed in the next section of this dissertation.

### **Working Memory Capacity, Age, and Predictive Inferences**

Children have been found to generate inferences from an early age, four years old, however they do not generate as many as older children and adults do (Casteel & Simpson, 1991;

Casteel, 1993). Studies have found that as children grow the inferences become more numerous, more complex, and more accurate (Kendeou et al., 2008). Currie and Cain (2015) assessed the relationship between working memory and inference generation in children aged five through ten years old. Children listened to short narratives and answered questions to assess local and global coherence inferences after each one. Local coherence inferences are used to integrate explicitly made propositions within a text, while global coherence inferences are aimed at inferring goals and motivations for a particular action or establishing the overall theme of a text. Global coherence inferences rely on the ability to connect ideas that are not explicitly stated in a text (Currie & Cain, 2015). The results confirmed developmental improvements on both types of inference and WMCapacity was also found to be positively correlated with inference generation.

Linderholm (2002) examined the relationship between WMCapacity and predictive inferences in undergraduate students and found that readers with high WMCapacity consistently made predictive inferences when texts were highly predictable. Low WMCapacity readers however, showed no evidence of making predictive inferences, even when there was a high degree of causal sufficiency. One particular theory, the Verbal Efficiency Theory (VET; Perfetti, 1985; Perfetti & Hart, 2001), posits an explanation as to why low WMCapacity readers fail to make predictive inferences. This theory proposes that low WMCapacity readers might need to invest a lot of cognitive capacity in basic reading skills and therefore not have sufficient spare cognitive capacity to invest in higher order processes, such as inference generation. As readers get older and more experienced however, these basic processes become automatic allowing more resources to be invested in high order processes.

Calvo (2001) also examined the relationship between WMCapacity and predictive inferences in undergraduate students. Eye fixations during reading were monitored while

participants read context sentences predicting likely events or non-predicting control sentences. These sentences were followed by continuation sentences in which a target word represented an event to be inferred (inferential word) or an unlikely event (non-predictable word). Gaze durations were recorded during this task. Gaze duration is the amount of time a person fixates on a certain word or word cluster before moving to the next word or word cluster (Calvo, 2001). Results showed that high WMCapacity was related to shorter gaze durations across sentence regions. Calvo (2001) also found that high WMCapacity readers compared to low WMCapacity readers, drew inferences earlier and more efficiently. These results indicate that the time course of predictive inferences is inversely related to WMCapacity; meaning that the more WMCapacity a reader has available, the less time they require to generate and process inferences. Estvez & Calvo (2000) propose that this effect is due to the fact that inferences are time-consuming elaborations that place a high demand on the limited capacity of working memory. The findings mentioned above suggest that age positively influences the generation of inferences, however WMCapacity has also been found to increase with age (van den Broek, 1997). One could then infer that the observed improvement in the generation of inferences as we age can be attributed to greater WMCapacity. In this study, the aim is to better understand the contribution of age and WMCapacity to the generation of predictive inferences.

### **Research Questions and Hypotheses**

The focus of the current study lies on describing the contribution of WMCapacity and age on readers' ability to generate predictive inferences. This will be done in two experiments, an experiment with children aged 9 to 12 (Experiment 1) and an experiment in which adults aged 19 to 30 participated (Experiment 2). The research question that this study sought to answer is whether age functions as a mediator between the ability to generate predictive inferences and WMCapacity. However, before mediation can be established, significant



relationships need to be established between the variables separately. That leads to the formulation of the following research questions, a) Is age a significant predictor for WMCapacity?; b) Is age a significant predictor for the ability to generate predictive inferences?; c) Is WMCapacity a significant predictor for the generation of predictive inferences? Below the hypotheses for each research question is presented. The hypotheses presented below apply for both the children as the adult experiment.

The first relationship to be established is the relationship between age and WMCapacity. The expectation is that age functions as a significant predictor for WMCapacity. The second aim is to establish a significant relationship between age and the ability to generate predictive inferences. The hypothesis with regards to this relationship is that age is a predictor for the ability to generate predictive inferences. The third aim is to establish a relationship between WMCapacity and the ability to make predictive inferences. Here it is hypothesized that WMCapacity predicts the ability to generate predictive inferences. Once a significant relationship has been established between these variables, in each experiment, the final analysis can be conducted. This final analysis is to examine whether the effects of age on the generation of predictive inferences is mediated by WMCapacity

## **Experiment 1**

Experiment 1 was part of a larger scale research conducted by the Child and Educational Studies department at Leiden University. To be concise only the measures and tests that are relevant for the current research study will be described.

## Method

### Participants

A total of 48 children, 22 boys(45.83%) and 26 girls(54.16%), participated in the current experiment. Written parental agreement was obtained for all children's participation. The children originated from three different Dutch elementary schools and their ages ranged between 9-12, with an average age of 10.33 years (SD = .476). All participants had a normal development.

### Measures

*Predictive Inferences Task.* The Predictive Inferences Task is based on stimuli from Van Berkum, Brown, Zwitserlood, Kooijman, and Hagoort (2005) and has been adapted to be conducted collectively in the classroom, and age appropriate. All items were pre-tested in a pilot study with adult participants in order to determine the predictability of the target words. In the predictive inference task, the participant is asked to read two-sentence long stories where a target word is missing towards the end. The participant's task is to write down the first word that comes to mind after reading the short story. Thereafter, participants are asked to rate how difficult it was to come up with a word on a scale from one to seven. The participants have twenty minutes to complete this task. The task includes 25 short stories, and the target word is highly predictable as it is initiated by a full sentence offering enough context.

*“Tonight Dennis plans to ask his girlfriends’ hand in marriage in a traditional manner. He therefore has a diamond ring in his pocket”.*

How difficult did you find this task?

1 -2 -3 -4 -5 -6 -7

In the example above 'ring' is the predictable target word. A participant's score on this task is the sum of all semantically correct responses for the predictable condition. For example, if 'ring' was the correct word in the example above, 'engagement ring' also counted as a correct response.

*Sentence Span Measure (SSM).* To assess WM Capacity the sentence span measure was used. In this task, the researcher reads aloud sets of unrelated sentences to the participants and asks them to recall the final word of each sentence after each set. Participants were then first asked to answer a question about the content of one of the sentences. Thereafter, the participant was asked to report the words that they were able to remember. The following is an example of a practice set:

1. The baby's toy fell under the bed. .... bed
2. They walked towards the back of the yard. .... yard

Question:

What fell under the bed? the baby's toy

Now repeat the words, please

The task starts with two sentences and for each new level a sentence was added, so as the experiment progressed the difficulty increased. Each level contained two sets and there were a total of four levels with a maximum of six sentences. Participants were given an instruction at the beginning of the task and were also given three practice trials to ensure that they understood the task. When these were successfully completed the instructor proceeded to the actual task. The instructor went through the levels and discontinued the task when the participant had one or more incorrect answers on each set within a level. A participant's total

score on this task equaled the sum of correctly recalled words, only including sets in which the answer to the question was correct.

## **Procedure**

All tasks were conducted in the children's school environment. The sentence span measure was administered individually and the Predictive Inference Task was administered collectively in the classroom. All tasks were preceded by instruction and practice trials to ensure that participants understood the task.

## **Data Analysis**

Our aim for the current study is to understand the relationship between WM Capacity, age, and the generation of predictive inferences. To better understand this relationship a mediation analysis was chosen. A mediation analysis is applied when there is mention of a third variable that is presumed to influence the dependent variable through the independent variable. A variable must meet the following conditions in order for it to function as a mediator (Baron & Kenny, 1986): (a) variations in levels of the independent variable must significantly account for variations in the dependent variable; (b) variations in levels of the independent variable must significantly account for variations in the presumed mediator variable; (c) variations in the mediator must significantly account for variations in the dependent variable; (d) variations in the mediator must significantly account for variations in the dependent variable, while controlling for the independent variable. These four requirements will be analyzed by means of three regression analyses. The first is a single linear regression to see if age significantly predicts the generation of inferences. The second is another single linear

regression to see if WMCapacity significantly predicts the generation of predictive inferences. The third step is to conduct another simple linear regression to determine if age significantly predicts WMCapacity.

If the conditions in the first three analyses are met, then the final analysis can be conducted. This final analysis is a multiple linear regression to see if WMCapacity significantly predicts the generation of predictive inferences, while controlling for age.

## Results

Prior to the analyses a sample inspection was performed. Outliers and cases with missing data were excluded from the analyses. Means and standard deviations for the sentence span measure and the predictive inference task are presented in Table 1 below.

Table 1. *Means and standard deviations for the sentence span measure and the predictive inference task.*

	M	SD
Sentence Span Measure	3.98	2.43
Predictive Inference Task	8.25	3.756

The first analysis explored the relationship between WMCapacity and age by means of a single linear regression. The regression model was not significant,  $F(1,44) = .46, p > .05$ , suggesting that in this sample age is not a good predictor for WMCapacity.

Another single linear regression analysis was conducted to analyze the relationship between age and the generation of inferences. This relationship was also found not to be

significant,  $F(1,44) = .24, p > .05$ , indicating that age is not a good predictor for the generation of predictive inferences.

Lastly a single linear regression was conducted to analyze the relationship between WMCapacity and the generation of predictive inferences. The relationship between WMCapacity and the generation of predictive inferences was found to be significant,  $F(1,47) = 8.78, p < .05$ . This finding suggests that WMCapacity is a good predictor for the generation of predictive inferences. Higher scores on the SSM were significantly associated with higher scores on the Cloze task. The results described above however do not meet all the criteria necessary for a mediation analysis and are therefore insufficient to proceed with a multiple regression.

### **Intermediate Discussion**

In this section, the relevant results in relation to the research questions and hypotheses for the first experiment are summed up. The goal of experiment 1 was to explore the relationship between age, WMCapacity and the generation of predictive inferences in children. With regards to the first research question exploring the contribution of age to the generation of predictive inferences, the hypothesis was that age is significantly associated with WMCapacity. However, contrary to results from previous studies, age was not associated with WMCapacity, implying that WMCapacity does not significantly differ with age. It is important to note however that in the current experiment working memory capacity was based only on the trials in which the answer to the question was correct. Trials in which the answer to the question was incorrect were excluded from further analysis. The analysis of one and not the other could have influenced the results found. In the final discussion I will elaborate further on the possible consequences of this measurement choice.

Second, it was hypothesized that age would be significantly associated to the ability to generate predictive inferences. However in the current sample age was not found to be associated with the ability to generate predictive inferences. This finding is not in line with findings from previous studies. Previous studies have found that increases in age coincides with better and faster predictive inference generation, due to increased prior knowledge, more efficient use of strategies for establishing relations and attentional capacities (Omanson, Warren & Trabasso, 1978; van den Broek, 1997). In the current experiment, however, no significant contribution was observed, suggesting that age does not significantly contribute to the generation of predictive inferences.

Third, it is hypothesized that WMCapacity would have a significant effect on the generation of predictive inferences. The results with regards to this hypothesis indicate that in the children's experiment WMCapacity was significantly associated with the generation of predictive inferences. This result is in line with the results found in previous studies. In the final discussion of this dissertation I will elaborate further on these results and their implications.

## **Experiment 2**

Experiment two was also part of a larger study, in this case an intervention study. The purpose of this study was to examine whether working memory could be improved through training and whether this had any influence on the generation of predictive inferences. To be concise only the measures and tests that are relevant for the current research study will be described.

## **Method**

### **Participants**

A total of 42 native Dutch speakers, all students at Leiden University, 30 (78.94 %) women and 8 (21.05 %) men participated in the study. Five participants were bi-lingual and none of the participants had any language impairments. Their age ranged between the ages of 19 to 30, with the average age being 21.92 years ( $SD=2.715$ ). All participants attended Leiden University and received either money or course credit as a compensation for their participation in the experiment. Prior to participation in the experiment all participants read and signed an informed consent.

### **Measures**

**Working Memory Capacity.** To assess WMCapacity the sentence span measure was administered. The task and procedure for the SSM was the same as described in Experiment 1.

**Inference Generation.** In this task participants were asked to read a total of 80 short stories. The stories had been validated previously in a pilot study and were the same as the stories the children (Experiment 1) had received. There were two conditions, highly predictable items and less predictable items. For each item the first sentence was a normal sentence providing background information, followed by a sentence with a target word. The target word could be either highly predictable considering the preceding information or it was less likely, nonetheless possible for the situation. The following is an example of a highly predictable item:



*“Tonight Dennis plans to ask his girlfriends’ hand in marriage in a traditional manner. He therefore has a diamond ring in his pocket”.*

The conforming target word in this case is the word ‘ring’. In this short story, it is highly predictable that Dennis will have a ring in his pocket. The reader can predict this by activating background knowledge from known situations. A story in which the target word is less predictable is the following:

*“Tonight Dennis plans to ask his girlfriends’ hand in marriage in a traditional manner. He therefore has a diamond necklace in his pocket”.*

The less predictable target word in this case is the word ‘necklace’. In this short story it is less predictable that Dennis, who wants to propose in a traditional manner, will do so by means of a necklace. The stories were presented on a computer screen and after reading the sentences participants received a question regarding the sentences they had just read. The question served to make sure participants were paying attention. Each answer option pertained to a number on the keyboard. During this task participants gaze duration at both the predictable and non-predictable target words were recorded.

## **Procedure**

Participants were greeted by the experimenter and were provided with an informed consent form. Next the experimenter proceeded to note the demographics about the participant, such as gender, date of birth, study track, native language etc. Once this was completed, the experimenter proceeded to the testing. There was no particular order to the presentation of the tasks and all tasks were preceded by instruction and practice trials. During the inference generation task eye-tracking methodologies, specifically Eyelink 1000, was used to record the gaze duration at the target words in both conditions.

## Data Analysis

The regression analysis was the same as described in Experiment 1.

## Results

Prior to the analyses a sample inspection was performed. Outliers and cases with missing data were removed previous to conducting the analyses. The means and standard deviations (SD) for the difference in gaze durations between the two conditions and the sentence span task are presented in table 2 below.

Table 2. Means and standard deviations for gaze duration (m.s.) and sentence span measure

	M	SD
Sentence Span	7.85	4.54
Inference Score	43,09	109,17

A single linear regression was conducted to examine the relationship between age and WMCapacity. The regression equation found was not significant,  $F(1,38) = .038, p >.05$ .

To examine the relationship between age and the generation of predictive inferences a regression was performed. Predictive inferences were assessed by recording the gaze durations at target words during the predictive inference task. A participant's score on the predictive inference task was the average of their gaze duration at the less-predictable target words minus their average gaze duration at the predictable target words. This regression, was not significant,  $F(1,42) = 1.01, p >.05$ .

Lastly, a single linear regression was conducted to see if WMCapacity

predicted the generation of predictive inferences. The results found were not significant,  $F(1,38) = .001, p > .05$ . The results found do not meet the criteria necessary for a mediation analysis and are therefore insufficient to proceed with a multiple regression.

### **Intermediate Discussion**

The goal of experiment 2 was to explore the relationship between age, WMCapacity and the generation of predictive inferences in adults. In this section, the results for this experiment are summed up.

With regards to our first research question exploring the relationship between age and the generation of predictive inferences, it was hypothesized that age would be positively associated with WMCapacity. However, contrary to results from previous studies, age was not found to be associated with WMCapacity. This implies that differences in age do not account for significant differences in WMCapacity.

Secondly, it was also hypothesized that age would be a good predictor for the generation of predictive inferences. Contrary to results from previous studies age was not associated with the generation of predictive inferences, implying that age does not affect the generation of predictive inferences.

Third, it was hypothesized that WMCapacity would be positively associated with the generation of predictive inferences. However in the current experiment WMCapacity was not found to be associated with the generation of predictive inferences. Contrary to expectation no significant relationship was observed between WMCapacity and the generation of predictive inferences, implying that differences in WMCapacity do not account for significant

differences in the generation of predictive inferences. In the following paragraph I will elaborate further on these results and their implications.

## **General Discussion**

In this section the relevant results in relation to our research questions, hypotheses and their implications are summed up. In the present study, the contribution of age and WMCapacity on the generation of predictive inferences was examined by comparing the results from two experiments.

The contribution of age to WMCapacity was assessed in both samples. Contrary to expectation, no significant relationship was found between age and WMCapacity in either one of the experiments. Working memory capacity was assessed through the Sentence Span Measure and was based only on the trials in which the answer to the question was correct. Trials in which the answer to the question was incorrect were excluded from further analysis. The Sentence Span Measure has two aspects; the first aspect requires the participant to recollect the last word of the sentence. The second aspect, however, requires the participant to understand and conceptualize what is being said. It could be that low and high working memory participants or participants of different ages perform differently on the different aspects of the measure. A comparison between the trials in which the answer to the final question was incorrect and the trials in which the answer was incorrect might reveal valuable information with regards to these different demands and how participants cope with these demands.

The second analysis assessed the contribution of age on the generation of predictive inferences. Contrary to findings from previous studies, no significant relationship was found

between age and the generation of predictive inferences, implying that age and the generation of predictive inferences are not associated.

The last analysis assessed the contribution of WMCapacity to the generation of predictive inferences. In line with the hypothesis and findings from previous studies it was found that children with higher WMCapacity performed significantly better on the predictive inference task. Children with a higher WMCapacity were thus found to be better at generating predictive inferences. In the adult experiment, however, no significant contribution was observed. An explanation for the presence of a significant relationship between WMCapacity and the generation of predictive inferences in the children's sample and not in the adult sample is that in developmental populations there is a larger spread of ability compared to adult populations. Participants from experiment 1 were children from three different elementary schools. Participants in the adult experiment, however, were all university students, which may have led to a fairly homogenous sample. This, in turn, could have possibly lead to less variance in the sample while also affecting the extent to which the findings can be generalized beyond the cases studied.

Another explanation for the discrepancy could be due to the fact that adults have been found to set more conservative speed/accuracy response criteria than children (McKoon & Ratcliff, 2013). This means that adults are usually more concerned in avoiding errors even if doing so slows performance. In the adult experiment gaze duration was used as a measure for the generation of predictive inferences. Gaze duration is a time based measurement. Adults might be inclined, even when they have made predictive inferences, to take their time and gaze longer, thus making the effects unnoticeable. Gaze duration is also an early or initial processing measure. Elaborative inferences, and thus also predictive inferences, have however been found to occur with some delay (Calvo et al., 1999). Calvo (2001) suggests that, even though the process possibly begins as soon as the reader fixates on the target word,

it is not completed until after the eyes have left the word. Other studies have found that the effects of predictive inference generation carried over into the post-target region or word. Late processing measures such as regression-path reading time, the probability of regressions to preceding regions and re-reading time of target regions/words may therefore be better suitable measures for assessing the generation of predictive inferences.

Unfortunately these results imply that in the current experiments age does not function as a mediator between WMCapacity and the generation of predictive inferences, seeing that age is not associated with either factors in either sample. However the factors described above might have influenced the results found and should be taken into consideration for future research.

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