Disruption of reading comprehension by irrelevant speech: The role of updating in working memory

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ABSTRACT

This investigation examined the relationship between updating in working memory and the effect of irrelevant speech on reading comprehension. In updating tasks, participants can make two types of errors labelled delayed intrusions and immediate intrusions. Delayed intrusions measures people's ability to suppress active information in working memory, while immediate intrusions measure people's ability to inhibit information from becoming too active. In our study, a negative relationship between reading comprehension and delayed intrusions was found, and reading comprehension was disrupted by irrelevant speech. This disruption was larger for participants with poor updating ability, specifically for those who made a lot of immediate intrusion errors. The results suggest that people with poor updating ability are not only less able to comprehend what they read, but also more susceptible to the disruptive effects from background speech while reading.

Keywords: irrelevant speech, reading comprehension, updating, working memory

INTRODUCTION

A few investigations have proven reading comprehension to be disrupted by irrelevant speech (Martin et al. 1988; Oswald et al. 2000). For example, Oswald et al. (2000) had participants read prose in silence, and with a meaningful and a meaningless task-irrelevant background speech. Performance was most hampered by meaningful irrelevant speech. The authors concluded that the presence of meaning in the irrelevant sound increases disruption on tasks that call upon semantic processes. However, what semantic processes that are related to the effect of irrelevant speech on reading comprehension remained undetermined. One such semantic process is people's ability to select relevant information for further processing. This type of process is performed by the executive function labelled *updating* (e.g., Miyake et al. 2000). The purpose of the present study was to investigate the relationship between updating and the effect of irrelevant speech on reading comprehension.

There is a well-known relationship between reading comprehension and working memory performance (see Daneman & Merikle 1996, for a review), especially that between reading comprehension and updating (Carretti et al. 2005; De Beni et al. 1998; Palladino et al. 2001). Palladino et al. (2001) developed an updating task which emphasizes language processes. This task is labelled the *Word updating task*. In this task, sequences of words are presented to the participants. The participant's task is to recall the three words that correspond to the three smallest objects. Hence, the participants have to update the contents of working memory when the objects held in memory are larger than an upcoming object. Palladino et al. found performance on the Word updating task to be related to reading comprehension performance. The participants can make two types of errors when performing tasks such as Word updating. First, they can make delayed intrusions. Delayed intrusions are made when participants recall items from the sequence that once were appropriate for recall, but should have been replaced as more appropriate items were presented later in the sequence. Second, they can make immediate intrusions. An immediate intrusion error is made when participants recall an item that should never have been considered appropriate for recall because more appropriate items were presented before it in the sequence. The significance of holding these two types of errors separate is that delayed intrusions measures the ability to suppress information in working memory that is no longer relevant, while immediate intrusions measures the ability to inhibit irrelevant information from gaining access to working memory. Several investigations have found that poor comprehenders make more delayed intrusion errors than do good comprehenders (e.g., Carretti et al. 2005; Palladino et al. 2001). It seems as if poor comprehenders have difficulty with suppressing information held in working memory that no longer is relevant. This inability is held by many to be a mediating factor, responsible for the relationship between performance on updating and reading comprehension (Carretti et al. 2005; Chiappe et al. 2000; Gernsbacher 1993).

Several investigations have found that people with good working memory capacity are less impaired by noise than those with poor working memory capacity (e.g., Beaman 2004; Elliott et al. 2006; Kjellberg et al. 2008). This finding suggests that the effect of irrelevant speech on reading comprehension is smaller for those with good updating ability. One possible reason for this is that people with good updating ability are able to inhibit information from gaining access to working memory. In this context, immediate intrusion errors are of special interest. As immediate intrusions are related to people’s ability to inhibit irrelevant information from entering working memory, the tendency to make immediate intrusions could be related to the tendency to become distracted by irrelevant speech while reading. This suggestion is in line with the finding that people with poor working memory capacity (as measured with operational span) are more likely to report hearing their own name spoken in a task-irrelevant speech (Conway et al. 2001), which indicates that people with poor working memory capacity have problems with inhibiting irrelevant sounds from entering working memory. The present investigation administered an updating task and a reading comprehension task and asked participants to perform these tasks with and without an irrelevant background speech in order to determine the relationship between updating and the effect of irrelevant speech on reading comprehension.

METHOD

A total of 40 people (25 women) with a mean age of 23.70 (SD = 4.39) years participated in the experiment in exchange for a cinema ticket. All reported having normal or corrected-to-normal vision, normal hearing ability and normal reading skills. The irrelevant speech was recorded in an anechoic room. The speech consisted of a story about a fictive culture, read by a male actor. The recording was downloaded into a computer and divided into 14 parts. Silent pauses between words and sentences were removed with computer software in order to maintain a constant flow of words. This manipulation did not reduce intelligibility. The sound was played back through headphones at approximately 70-75 dBA. A within-subject design was used. The participants were seated alone in a silent room in front of a computer. They were asked to wear the headphones throughout the experiment, even if no sound was played. Afterwards, they were asked if they had complied with this requirement and everyone acknowledged that they had. They were also instructed to ignore any sound they would hear in the headphones. The participants performed the tasks in two phases. First, they began with performing one updating task in silence and another with irrelevant background speech; and second, they performed one reading comprehension task in silence and another with irrelevant background speech. The order of the background conditions and the tasks was counterbalanced within the phases.

Two number updating tasks were constructed (Carretti et al. 2007). Each task consisted of 14 unique lists. Each list consisted of 10 two-digit numbers. The lists were presented in the centre of the computer screen with a 72 point font-size. Each list was preceded by the symbol ## which indicated to the participants where the numbers would be presented. Thereafter, the ten numbers in the list were presented sequentially. The numbers were displayed for 2 seconds and the inter stimulus interval was 1 second. The numbers in each list varied pseudo randomly between 15 and 99. The arithmetic distance between the lowest and the highest number within each list varied between 30 and 36. The difference between two arithmetic adjacent numbers within the list varied between 2 and 6. These restrictions were made because the arithmetic distance between within-list numbers has been found to affect performance (Carretti et al. 2007). The numbers to be recalled occurred only once within each task. Of the 14 lists, half required 5 updates and half required 2 updates. The order of the lists within each test was the same for each participant and pseudo random. That is, the same list type was never presented more than twice in a row. The participants began with reading an instruction for the task. They were told that they should recall the three smallest numbers in the list in their order of presentation. They were instructed to guess if they had forgotten a number and make sure to place the numbers they remembered on the correct serial position. They were also given an example of a list and shown the correct recall for that list. The participants began with performing 2 practice trials, one of each list type, and then proceeded throughout the remaining 12 lists. A recall box appeared on the screen two seconds after the final number had been presented in each list. The participants typed their answer in the box and pressed a button allowing for the next list to be presented. When the updating task was performed in the irrelevant speech condition, the irrelevant speech began playing one second before the symbol ## was presented and stopped one second before the recall box appeared on the screen. Each list was accompanied with one of the 14 parts of irrelevant speech. Each part was only played once within the test and the parts were presented in the same random order for each participant. The updating task was scored according to the following criteria. A correct answer was made when one of the three smallest list numbers was recalled in the correct serial position. A delayed intrusion was made when the participants recalled a number that once was appropriate for recall, but should have been replaced by a lower number presented later in the list. An immediate intrusion was made when the participants recalled a number that should have been immediately discarded because more appropriate numbers preceded it. An order error was made when the correct number was recalled, but at wrong serial position. Innovations were made when participants typed a number that had not been presented in the list.

The two reading comprehension tasks were constructed in a similar manner. Each task consisted of 20 short texts. The texts were presented sequentially on the computer screen. Each text was accompanied with a question and four alternative answers (out of which only one was correct). The participants were given 90 seconds to answer each question respectively. In the first 5 of the texts, the question was written below the text and in order to answer the question, the participants had to draw conclusions from the meaning of the text and select one of the four alternative answers. In the remaining 15 texts, a word was missing in the text. The participant's task was to select one of four words that should be placed at the position of the missing word in order to make the text coherent. Each of the four alternatives would make the phrase grammatically correct, but only one of them was accurate given the meaning of the text. Before the participants begun the task, they were shown two text examples with questions and alternative answers. The participants gave an answer by a button click on the computer keyboard. When an answer was given or if the participants failed to give an answer within the time limit, the next text was presented. The computer calculated the number of correct answers and the time taken to complete each question. When the test was performed with irrelevant speech, the 14 parts of the speech were played sequentially in the same random order for each participant throughout the test.

RESULTS

The updating task was scored in terms of correct answers, delayed intrusions, immediate intrusions, order errors, and innovations. These results are summarized in Tables 1 and 2. A 2 (list type: lists with 5 vs. 2 updates) × 2 (background conditions: irrelevant speech vs. silence) × 2 (condition order: irrelevant speech first vs. silence first) analysis of variance revealed that the participants made less correct answers with lists that demanded 5 updates in comparison with lists that demanded 2 updates, $F(1, 39) = 70.89$, $MSE = 5.82$, $p < .000001$, $\eta^2 = .65$. This finding is consistent with previous research (Carretti et al. 2007). Further, irrelevant speech reduced the overall number of correct answers, $F(1, 39) = 10.52$, $MSE = 5.82$, $p < .01$, $\eta^2 = .22$. However, no interaction between list type and background conditions was noted, $F < 1$. There was no main effect of condition order, $F < 1$, but condition order interacted with background conditions, $F(1, 39) = 10.52$, $MSE = 5.82$, $p < .01$, $\eta^2 = .22$. Follow-up analysis of this interaction revealed that participants who first did the updating task in silence and then with irrelevant speech had a close to equal performance with a mean score of 20.95 (SD = 5.06) in silence and 20.95 (SD = 7.54) with irrelevant speech. The participants who first did the updating task with irrelevant speech and later in silence, on the other hand, had a mean score of 16.95 (SD = 4.82) with irrelevant speech and 21.90 (SD = 5.91) in silence, $t(19) = 4.93$, $p < .0001$. Compared on the updating task made first on a between-participants basis, the difference between those who made the updating task in silence and those who had background speech was significant, $t(38) = 2.56$, $p < .05$. The analysis of variance revealed no interaction between all three variables.

Table 1: Total score on the updating task performed in silence and with irrelevant speech

	Silence M (SD)	Irrelevant speech M (SD)	*F*	η^2
Total number of correct answers	21.43 (5.45)	18.95 (6.56)	8.46**	.18
Lists with two updates	12.40 (3.84)	11.00 (3.37)	5.44*	.12
Lists with five updates	9.03 (2.42)	7.95 (3.79)	5.59*	.13

* $p < .05$, ** $p < .01$

Table 2: Errors on the updating task performed in silence and with irrelevant speech

	Silence M (SD)	Irrelevant Speech M (SD)	*F*	η^2
Total number of errors	14.55 (5.42)	17.10 (6.59)	6.28*	.42
Delayed intrusions	2.40 (1.82)	2.63 (2.29)	< 1	.01
Immediate intrusions	1.40 (1.57)	1.28 (1.19)	< 1	< .01
Order errors	3.95 (3.53)	4.03 (3.07)	< 1	< .01
Innovations	6.80 (2.70)	9.18 (4.41)	14.77*	.28

* $p < .01$

A 2 (background conditions: irrelevant speech vs. silence) × 2 (condition order: irrelevant speech first vs. silence first) on type of error (delayed intrusions, immediate intrusions, order errors, and innovations) multivariate analysis of variance was performed in order to outline the effect of irrelevant speech on different types of errors in the updating task. The analysis revealed a main effect of background conditions, $F(4, 35) = 6.28$, Wilks' lambda = .58, $p < .001$, $\eta^2 = .42$. There was no main effect of condition order, $F(4, 35) = 1.26$, Wilks' lambda = .87, $p = .30$, $\eta^2 = .13$, but a marginally significant interaction between background conditions and condition order, F(4, 35) = 2.49, Wilks' lambda = .78, $p = .06$, $\eta^2 = .22$. As can be seen in Table 2, irrelevant speech increased the number of innovations, $F(1, 19) = 14.77$, $MSE = 7.64$, $p < .001$, $\eta^2 = .28$. However, no difference between the background conditions was noted on the other type of errors, all $F < 1$, and no significant difference was found between the two condition orders on any type of error. An interaction between background conditions and condition order was noted on innovations, $F(1, 38) = 4.26$, $MSE = 7.64$, $p < .05$, $\eta^2 = .10$, but not on the other type of errors. This interaction indicates that the difference between the background conditions was larger when the participants performed the first updating task with background speech and the second in silence.

The mean score on reading comprehension was 11.55 (SD = 2.24) in silence and 10.58 (2.93) with speech. Time taken was 14.22 minutes (SD = 3.00) in silence and 14.41 (SD = 2.56) in speech. A 2(background conditions: irrelevant speech vs. silence) × 2 (condition order: irrelevant speech first vs. silence first) multivariate analysis of variance on reading comprehension score and the time taken to complete the test revealed a main effect of background conditions, $F(2, 37) = 3.38$, Wilks' lambda = .85, $p < .05$, $\eta^2 = .15$, but no main effect of condition order, $F(2, 37) = 1.17$, Wilks' lambda = .94, $p = .30$, $\eta^2 = .06$, and no interaction between background conditions and condition order, $F(2, 37) = 1.98$, Wilks' lambda = .90, $p = .15$, $\eta^2 = .09$. The univariate tests revealed that irrelevant speech disrupted reading comprehension, $F(1, 38) = 6.34$, $MSE = 2.99$, $p < .05$, $\eta^2 = .14$, but it did not affect the time taken to complete the task, $F < 1$. There was neither a main effect of condition order on reading comprehension score, $F < 1$, nor on time taken to complete the test, $F(1, 38) = 2.33$, $MSE = 10.68$, $p = .14$, $\eta^2 = .06$, and there was no interaction between the variables on reading comprehension score, $F(1, 38) = 1.84$, $MSE = 2.99$, $p = .18$, $\eta^2 = .05$, nor on time take to complete the task, $F(1, 38) = 2.49$, $MSE = 1.96$, $p = .12$, $\eta^2 = .06$. Hence, irrelevant speech was found to disrupt reading comprehension performance. This result did neither depend on the time take to complete the task nor on the presentation order of conditions.

In order to investigate the relationship between updating and the effect of irrelevant speech on reading comprehension, residual analyses were calculated rather than analyses of simple difference scores following the statistical advice in Cronbach and Furby (1970) and Zumbo (1999). However, consistent results were found with analyses based on difference scores. In order to test if the effect from irrelevant speech on reading comprehension is larger for participants with poor updating ability, a hierarchical regression analysis was calculated. Reading comprehension with irrelevant speech was selected as dependent variable, reading comprehension in silence and condition order were selected as independent variables in the first step, and correct answers on updating in silence and with background speech was selected as independent variables in the second step. Both models were significant, $R = .59$, $F(2, 37) = 9.65$, $MSE = 5.93$, $p < .001$, and, $R = .67$, $F(4, 35) = 6.97$, $MSE = 5.31$, $p < .001$, respectively. Reading comprehension in silence, $\beta = .53$, $t(39) = 3.74$, $p < .001$ (in the second step), and updating in silence, $\beta = .36$, $t(39) = 2.08$, $p < .05$, added significantly to the prediction while condition order, $\beta = .08$, $t(39) = 0.56$, $p = .58$, and updating with background speech, $\beta = -.05$, $t(39) = -0.27$, $p = .79$, did not. These results indicate that the effect of irrelevant speech on reading comprehension was larger for participants with poor updating ability. However, there is no evidence of relationship between the effect of irrelevant speech on updating and the effect of irrelevant speech on reading comprehension. In order to investigate if the effect from irrelevant speech on reading comprehension is larger for participants who tend to allow irrelevant information to become too active in working memory, an additional hierarchical regression analysis was calculated. Reading comprehension with irrelevant speech was selected as dependent variable, reading comprehension in silence was selected as independent variable in the first step and immediate intrusions in silence and with background speech was selected as independent variables in the second step. Both models were significant, $R = .57$, $F(1, 38) = 18.14$, $MSE = 5.95$, $p < .001$; and, $R = .67$, $F(3, 36) = 9.63$, $MSE = 5.14$, $p < .0001$, respectively. Reading comprehension in silence, $\beta = .53$, $t(39) = 4.21$, $p < .001$ (in the second step), and immediate intrusions in silence, $\beta = -.36$, $t(39) = 2.81$, $p < .01$, added significantly to the prediction, while immediate intrusions with background speech did not, $\beta = .03$, $t(39) = 0.24$, $p = .81$. Hence, immediate intrusions made in silence were found to moderate the effect of irrelevant speech on reading comprehension. The more immediate intrusions the participants made in the updating task in silence, the more were they disturbed by irrelevant speech while reading. As the number of immediate intrusion errors made with irrelevant speech did not contribute to the prediction, the moderating role of immediate intrusions must be interpreted with caution.

DISCUSSION

This study aimed to investigate the relationship between updating and the effect of irrelevant speech on reading comprehension. The experiment revealed four major findings. First, irrelevant speech disrupted updating performance; second, irrelevant speech disrupted reading comprehension; third, participants who performed poor on updating also performed poor on reading comprehension, specifically those who made a lot of delayed intrusion errors; and forth, the effect of irrelevant speech on reading comprehension was larger for participants with poor updating abilities, specifically for those who made a lot of immediate intrusion errors.

The relationship between updating and reading comprehension found in the present experiment is consistent with previous research (Carretti et al. 2005; De Beni et al. 1998; Palladino et al. 2001) and provide further support for the assumption that poor comprehenders lack efficient updating abilities. Specifically, poor comprehenders made more delayed intrusion errors than good comprehenders did, which supports the assumption that poor comprehenders exhibit a general problem with suppressing activated information in working memory (e.g., Gernsbacher 1993). The effect of irrelevant speech on reading comprehension was larger for participants with poor updating abilities. This finding is in line with investigations that have proven people with poor working memory capacity to be more hampered by noise (e.g., Elliott et al. 2006; Kjellberg et al. 2008) and have a stronger tendency to report words heard in task-irrelevant speech (Beaman 2004; Conway et al. 2001) than people with good working memory capacity. Specifically, the effect of irrelevant speech on reading comprehension was larger for participants who made a lot of immediate intrusions errors in the updating task in silence. This finding suggests that the degree of disruption from irrelevant speech on reading comprehension is determined by people's ability to inhibit irrelevant information from becoming too active in working memory. A similar result was not found, however, with immediate intrusions made in the updating task with background speech. One possible interpretation is that the number of immediate intrusion errors made in silence is a more valid measure of participant's failure to inhibit information from gaining access to working memory, than the number of immediate intrusions made when participants are engaged in trying to inhibit both potential immediate intrusions and the irrelevant speech from gaining access.

A close analysis of the type of errors made in the updating task revealed that more innovations were made in the irrelevant speech condition, while no difference was found on order errors, delayed intrusions and immediate intrusions. These findings indicate that irrelevant speech does not have an immediate effect on inhibition mechanisms. If, for example, the participants had made more delayed intrusions with background speech, this would have reflected a disrupted ability to suppress irrelevant information in working memory and would probably have contributed to the explanation of the effect of irrelevant speech on reading comprehension given the relationship between delayed intrusions and reading comprehension. As it is, the present investigation found no evidence of a relationship between the effect of irrelevant speech on reading comprehension and the effect of irrelevant speech on inhibition mechanisms. In conclusion, people with poor updating ability are not only less able to comprehend what they read, but also more susceptible to the disruptive effect from irrelevant speech while reading.

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