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Isolating general task processes using EEG

Bachelor's Project Thesis

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Abstract: In this experiment we studied the cognitive processes involved in problem solving. Using EEG we examined brain activation involved in two tasks that seem to be very different on the surface to discover if these tasks rely on the same underlying mechanisms. The hypothesis was that both tasks rely on the same declarative and working memory system. This was done by manipulating retrieval and transformation in an algebra task and in a word swapping task. Analysis of the behavioural data showed significant differences in accuracy and reaction time when retrieval and transformation were manipulated in both tasks. Analysis of the EEG data also showed similar patterns in activation between tasks, supporting the hypothesis. While this is a step towards understanding how these task processes function in the brain, a more in depth comparison of the underlying mechanisms of two seemingly different tasks is needed using the power of a statistical model.

1 Introduction

The brain is our control centre, it processes all incoming information and determines the actions needed to be taken to achieve goals. We of course use our brain for every single task we do, from playing a sport to reading a book. While some tasks like reading can be examined in a scanner, others cannot. This makes it harder to find the general mechanisms used for executing tasks. The tasks we perform always involve information processing and problem solving to some degree. In soccer for example, we must process information to get the ball in the goal from the current position, which is the problem. It seems reasonable to assume that we do not have task-specific areas. There is no area of the brain solely dedicated to playing soccer for example. This would mean that tasks must rely on the same mechanisms. Because executing tasks can be seen as a form of problem solving, such as in the soccer example, we will focus on problem solving as the shared mechanism for our research.

Previous research has also focused on problem solving, however, the focus has been on the processing of a single task (Anderson et al., 2004, 2007; Danker and Anderson, 2007). This does not allow for a direct comparison of mechanisms used for different tasks. This gives us reason to focus on the similarities between tasks. In order to do this we will look at two tasks that appear to be profoundly different on the surface. The first task is an algebra task and the second tasks is a word swapping task, both explained in detail in section 1.2. This will allow us to discover to what extent different tasks are relying on the same underlying cognitive processes. By underlying cognitive processes we mean that there is a single working memory system that different tasks rely on instead of having their own working memory system. As well as a single declarative memory system for a variety of tasks. In order to do so we will be using EEG as the tasks we will be looking at are fast paced tasks. EEG is a brain imaging technique that provides excellent temporal resolution. This is ideal for comparing the basic brain activation at a given moment during these fast tasks. This allows us to compare activation for different levels of difficulty within a task over time. We can then compare how the tasks were effected by manipulating difficulty in similar ways within the task. We will change difficulty by manipulating retrieval and transformation, which is explained in more detail in section 1.1.

1.1 Problem Solving

Problem solving has been found to function in the fronto-parietal network of the brain (Figure 1.1)(Molko et al., 2003; De Smedt et al., 2011). The fronto-parietal network is responsible for cognitive control (attention control and goal maintenance). Both working memory and declarative memory have been linked to the prefrontal cortex and the posterior parietal cortex (Berryhill and Olson, 2008; Cabeza et al., 2008; D'Esposito and Postile, 2009; Hutchinson et al., 2009) which are both in the fronto-parietal network. Problem-solving relies on declarative memory to retrieve facts and rules from memory needed to solve the problem. In working memory facts are maintained and manipulated to solve the problem. We will refer to use of declarative memory and working memory as retrieval and transformation, respectively. Retrieval and transformation have been found to occur in both the prefrontal regions and in the parietal cortex (Anderson et al., 2008, 2007; Danker and Anderson, 2007; Rugg and Henson, 2002; Sohn et al., 2005; Stocco and Anderson, 2008).

We consider manipulation of retrieval and transformation as changing the difficulty of a problem (Newman et al., 2011). A task that requires retrieval of multiple facts and requires transformations is more difficult than a task that does not require this. Using algebraic equations we can visualize this quite easily, when we have to solve for x and the equation is $x = 4$ we do not need to retrieve or transform any information, but when the equation is $8x - 2 = 30$ we need to retrieve arithmetic facts and transform the equation to find that $x = 4$.

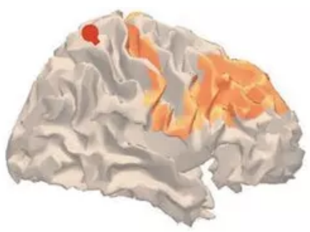


Figure 1.1: The fronto-parietal network (Smith, 2016)

1.2 The Tasks

1.2.1 Algebra task

The first task is solving algebraic equations. To vary the levels of retrieval and transformation the task consists of five different categories of equations. The first category is equation type $x = 5$, this requires no retrieval and no transformation. The second kind of equation is in the category $x - 2 = 4$, here a transformation is required to get $x = 4 + 2$ and minimal retrieval is need for the addition. This is classified as minimal retrieval as addition has been found to require less retrieval than multiplication (Imbo and Vandierendonck, 2008). The third type of equation is $x = 32/8$, this involves retrieval of the division rule and no transformation. The fourth equation category is $8x = 32$, this requires a transformation to $x = 32/8$ and retrieval for the division. The final equation is one in the category of $8x - 2 = 30$. This requires two transformations and two retrievals. The first equation is, therefore, classified as the easiest equation to solve and the fifth equation is classified as the most difficult equation.

1.2.2 Names task

The second task is an information swapping task, referred to as the names task. This task has been used in previous experiments (Anderson et al., 2004, 2007) and has been proven to be susceptible to retrieval and transformation manipulation. There are four different swapping instructions, they can be found in Table 1.1.

Participants are shown three names, one by one; they must swap the names depending on the given instruction. The instruction is a two digit number or a two letter word. For number instructions with a 4 the participants have to give the names in the same order as shown, this requires no retrieval and no transformation. Number instructions without a 4 mean that names in the associated position to the number have to be swapped; in the example in Table 1.1 (instruction: 23) the participant would have to swap the second name shown (Dick) with the third name shown (Fred), this requires a transformation but no retrieval. When a word instruction is shown participants have to retrieve the two digit number that belonged to the word, which they had learned prior to the experiment. When a word instruction is shown that is associated with a number containing a 4, participants have to give the names in the same order as shown. This requires retrieval of the associated number, but no transformation. A word instruction with a word associated with a number without a 4 requires the participant to retrieve the associated number and swap the names accordingly. In the example in table 1.1 (instruction: BE) participants would have to retrieve the associated number to BE, which is 31 and swap the third name (Fred) with the first name (Tom). This requires retrieval and transformation. The easiest task in this case is a number instruction containing a 4 and the most difficult task is a word instruction associated with a word not containing a 4.

It is expected that manipulation of retrieval and transformation will result in a similar general effect for both tasks. General effects would be that the easiest conditions (low retrieval and transformation requirements) in both tasks will elicit the least amount of activation and the most difficult conditions (high levels of retrieval and transformation) the highest amount of activation, while conditions in between will not be significantly different. Conditions relying on working memory may show strong significant effects as working memory (transformation) has been found to have a significant effect on problem solving (Imbo and Vandierendonck, 2008; Lee et al., 2009). Effects of condition are expected in the left parietal region for transformation (Anderson et al., 2004, 2008). Language processing has been found in the frontal lobe of the brain as have mathematics functions, this could elicit similar effects of activation in the frontal regions of the brain for both tasks. Taking previous research of the fronto-parietal network into consideration it is also expected that these regions will show similar effects for both tasks as both tasks should rely on working memory and declarative memory.

Table 1.1: The four conditions of the name task, AT is associated with 14 and BE is associated with 31. The names shown in order are: Tom-Dick-Fred

	No Retrieval	Retrieval
No Transformation Correct answer:	**14** Tom-Dick-Fred	**AT** Tom-Dick-Fred
Transformation Correct answer:	**23** Tom-Fred-Dick	**BE** Fred-Dick-Tom

2 Methods

As mentioned, the testing of the experiment consisted of two tasks, an algebra task and a names task. The experiment started with a training phase. In the training phase participants had to learn 12 word to number associations for use in the names task.

2.1 Participants

Participants were students at the University of Groningen. Twenty-five students participated in the experiment, 14 females and 11 males aged 20-30 (mean age of 23). All participants were right-handed. The session lasted 3 hours and there was a monetary compensation of eight euros per hour. Six participants were excluded from the analysis due to noise in the EEG recordings.

2.2 Materials

The experiment was conducted using OpenSesame (Mathot et al., 2012) on a normal PC monitor, using a normal mouse. Windows operating system interrupted the experiment occasionally, when this occurred in a block the trials in the block of the interruption were removed.

2.3 Procedure and Tasks

The experiment started with the training phase for the names task, which consisted of two parts. Participants received instructions explaining what they had to learn but not what the specific task was going to be. On this page were 12 word-number combinations, for example AT belongs to 14 and BE belongs to 31 (Appendix A). Participants were also given 2 pages to write on to learn the combinations any way they wanted to. They were given 10 minutes to do this. The second phase of the training was training with a program that consisted of 4 blocks. Use of the instructions or the practice sheets was not permitted. In each block all of the words were presented one by one and participants were asked to give the correct number that belonged to the shown word. The block ended when the participant had answered all combinations correctly, incorrectly answered trials were repeated.

Once they had completed this, the EEG cap was installed and they were given the instructions for the test phase. The installation time for the EEG cap was half an hour. The test phase started with a practice session (1 block for each task) to familiarize the participants with the tasks. The test phase consisted of eight blocks (four algebra blocks and four names blocks). The task was alternated each block. Both tasks started with an initial fixation and ended by giving feedback (wrong, correct, too slow) followed by fixation.

2.3.1 Algebra task

The algebra task consisted of five conditions as already mentioned. Examples of the five conditions can be seen below:

- condition 1: $x = 5$
- condition 2: $x - 2 = 4$
- condition 3: $x = 32/8$
- condition 4: $8x = 32$
- condition 5: $8x - 2 = 30$

One block of the algebra task consisted of 100 trials (20 trials per condition) with a total of 400 trials in the entire experiment. After the initial fixation the equation was shown, participants were instructed to click when they knew the answer, there was a timeout of 10 seconds. Then a keypad with the numbers 1-9 in a circular dial was shown and participants had two seconds to click on the correct number.

2.3.2 Names task

The names task consisted of 4 conditions:

- condition 6: 14
- condition 7: 23
- condition 8: AT *(14)*
- condition 9: BE *(31)*

One block of the names task consisted of 48 trials (12 trials per condition), a total of 192 trials in the entire experiment. An illustration of the task can be seen in Figure 2.1. After the initial fixation the names (Tom, Dick, Fred) where shown one by one, each for half a second, ending with another fixation stimulus. The names were shown in a random order each trial. Then the instruction was given. The participants had 10 seconds to click once they knew the answer, then the three names were shown and the participant had to click the names in the correct order within four seconds.

2.4 Behavioural Analysis

For analysis of reaction time, incorrect trials and trials three standard deviations above the mean were removed. A pairwise paired t-test was used to analyze the accuracy and reaction time for the algebra task. Holm-Bonferroni (Holm, 1979) was used as correction for multiple tests. A two-way ANOVA with repeated measures was used to analyze the accuracy and reaction time for the names task, the factors used were retrieval and transformation with a control for between participant variation. A two-way ANOVA was used for the names because there was either retrieval and/or transformation per condition whereas the algebra task had varying levels for retrieval and transformation (condition 5 8x-2=30, has two retrievals and two transformations).

2.5 EEG

2.5.1 Recording

The EEG was recorded on 130 electrodes using software and EEG cap from BioSemi (see Appendix B). Electrodes were also attached to the face (above and below the left eye and the outside of both eyes) and mastoids. The channel's potentials did not fall below -30mV or exceed 30mV. The data was recorded at 256Hz.

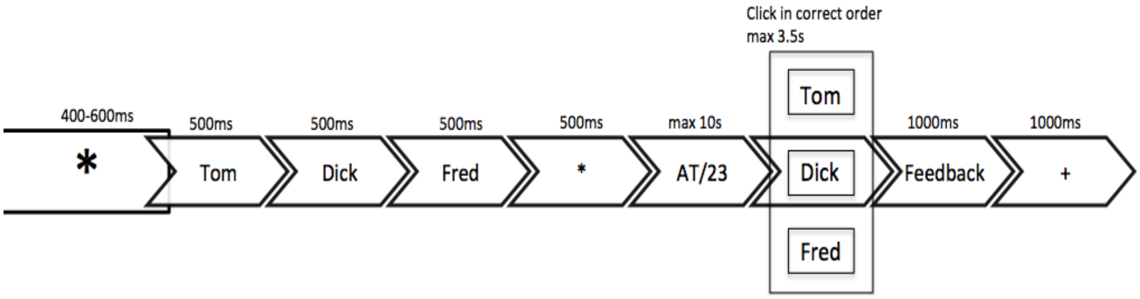


Figure 2.1: Illustration of the names task showing that the instruction can be either a word or a number

2.5.2 Analysis

The EEG analysis was done using EEGLAB (Delorme and Makeig, 2004). The data was first decomposed into epochs from the trial onset. For the algebra task the epochs began at 0.2 seconds before the trial onset and ended 8 seconds after. The epochs for the names task began 0.2 seconds before the trial onset and ended 11.5 seconds thereafter. The name epochs were longer because it took participants longer to solve the problem. The epochs contained the moment the instruction was shown, the moment the response keypad was shown and the feedback.

The data was then divided into independent components using the ICA algorithm in EEGLAB. Components that were associated with eye blinks were removed manually. Epochs containing artifacts were first excluded from the data sets using built in functions in EEGLAB. After each function was applied, the epochs containing artifacts exceeding the limits were removed. First the 'find abnormal values' function was used with an upper standard deviation limit of 50 and a lower standard deviation of -50. Then the 'find abnormal trends' function was applied with a max slope of 15 standard deviations per epoch and an R-squared limit of 0.05. Finally artifacts were found and trials were marked for rejection visually. Participants were excluded from further analysis if more than 30% of the trials were removed.

Stimulus and response locked epochs were made, stimulus locked epochs were baseline-corrected by -200-0ms seconds and response locked epochs by 0-200ms. For the algebra task the stimulus locked epochs started 0.2 seconds before the trial onset and ended two seconds after it. For the names task the stimulus locked epochs started 0.2 seconds before the trial onset and ended four seconds after. Response locked epochs ran from 0.7 seconds before the response keypad was shown to 0.2 seconds thereafter. Epochs containing trials where an incorrect answer was given or no answer was given were removed from further analysis.

ERPs were calculated for both tasks per condition and were plotted for stimulus and response locked epochs. All conditions per task were plotted onto one graph. An ANOVA was used to analyze the effects of the conditions with a statistical threshold of 0.05 and an FDR correction for multiple tests.

3 Results

3.1 Behavioural Data

The behavioural analysis examined accuracy and reaction time. The average accuracy per condition can be found in Figure 3.1. Here we see that condition 1 was on average close to always being correctly answered and that condition 5 was correctly answered about 85% of the trials. We also see that conditions 2-4 are very close to each other in accuracy. Condition 9 has the lowest accuracy at about 0.5. Condition 6 has the highest accuracy for the names task, and condition 7-8 are close in accuracy.

There was a significant difference between algebra conditions as determined by a one-way ANOVA ($F(1,24) = 31.45$, $p < 0.001$). Therefore, further

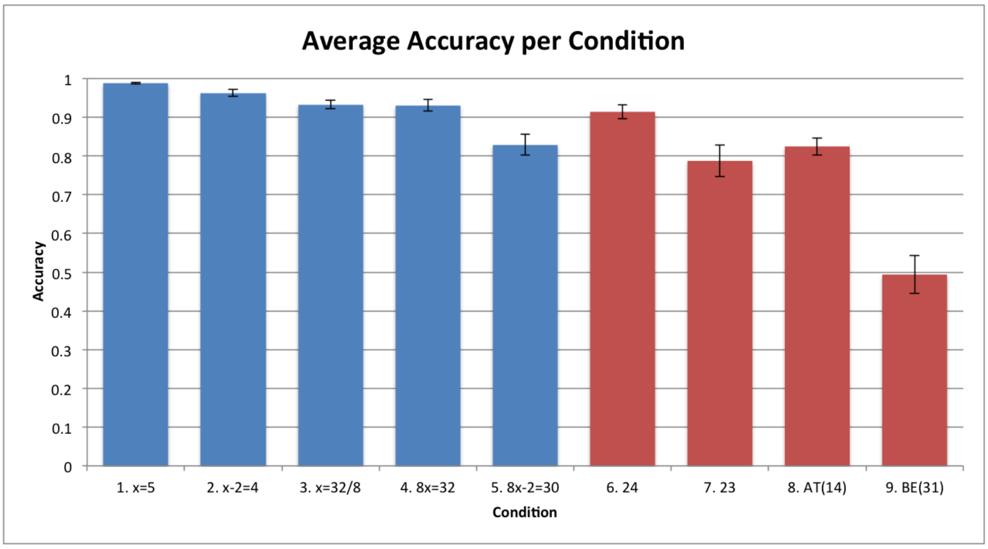


Figure 3.1: Graph of the average accuracy per condition over all participants with the standard error. 1 is correct and 0 is incorrect. The algebra task is represented by the blue bars and the names task by the red bars.

analysis was done using a paired pairwise t-test. All conditions for the algebra task showed a significant difference between each other (conditions 1 & 2 p=0.012; conditions 1 & 3 p<0.001; conditions 1 & 4 p=0.004; conditions 1 & 5 p<0.001; conditions 2 & 3 p=0.010; conditions 2 & 4 p=0.016; conditions 2 & 5 p<0.001; conditions 3 & 5 p<0.001; conditions 4 & 5 p<0.001) with one exception; between conditions 3 and 4 there was no significant difference in accuracy (p=0.821). The exact p-values for accuracy in the algebra task using a paired t-test can be found in table 3.1. For the names task a repeated measures two-way ANOVA was used, as explained above. There was a significant difference for retrieval ($F(1,24) = 67.04$, $p < 0.001$). There was also a significant difference for transformation ($F(1,24) = 47.42$, $p < 0.001$). There was a significant interaction between retrieval and transformation ($F(1, 24) = 34.84$, $p < 0.001$).

The average reaction time per condition can be found in Figure 3.2. Condition 1 took on average less than 1000ms to answer, whereas condition 6 took 3000ms. Once again we see that conditions 2-4 are close to each other in their values. Looking at the names task we see that condition 6 also took less than 1000ms to answer and that condition 9, the hardest condition for the names, took more than 3000ms to answer. Condition 7-8 are also close in value to each other again.

A one-way ANOVA determined that there was a significant difference between algebra conditions ($F(1,24) = 253.8$, $p < 0.001$), therefore, a pairwise paired- t-test was used to find differences between conditions. There was a significant difference between all algebra conditions (conditions 1 & 2 p<0.001; conditions 1 & 3 p<0.001; conditions 1 & 4 p<0.001; conditions 1 & 5 p<0.001; conditions 2 & 4 p=0.016; conditions 2 & 5 p<0.001; conditions 3 & 5 p<0.001; conditions 4 & 5 p<0.001) with two exceptions. There was no significant difference between conditions 2 and 3 (p=0.387) and conditions 3 and 4 (p=0.229). The exact p-values for reaction times in the algebra task using a paired t-test can be found in Table 3.2. In the names task there was a significant difference for retrieval as determined

Table 3.1: Algebra task p-values for accuracy from paired t-test

Condition	1	2	3	4
2	0.01201	-	-	-
3	0.00019	0.01010	-	-
4	0.00402	0.01606	0.82134	-
5	3.8e-05	3.8e-05	0.00019	8.4e-06

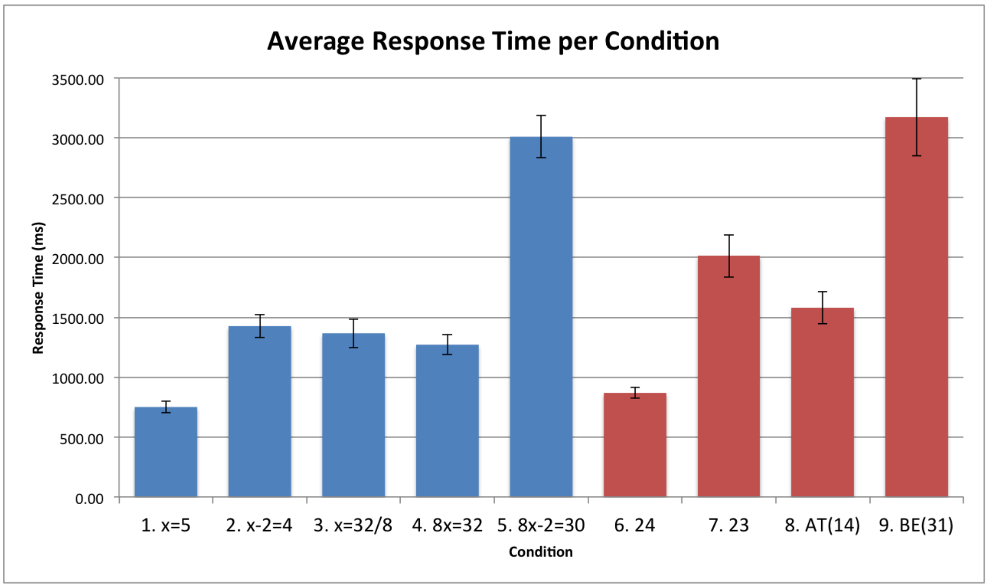


Figure 3.2: Graph of the average reaction time per condition over all participants with the standard error. The algebra task is represented by the blue bars and the names task by the red bars.

by a repeated measures two-way ANOVA ($F(1,24) = 35.98$, $p < 0.001$). There was also a significant difference for transformation ($F(1,24) = 64.75$, $p < 0.001$). There was a significant interaction between retrieval and transformation ($F(1,24) = 6.903$, $p = 0.0148$).

We can see a similar effect between the algebra task and the names task for both accuracy and reaction time. In other words, the manipulations of transformation and retrieval had similar effects in both tasks, for example that the conditions in both tasks that require the most retrieval and transformation (conditions 5 and 9) have noticeably slower reaction times.

Table 3.2: Algebra task p-values for reaction time from paired t-test

Condition	1	2	3	4
2	8.9e-11	-	-	-
3	8.0e-07	0.387	-	-
4	5.5e-09	0.016	0.229	-
5	2.1e-13	2.7e-12	1.2e-14	2.9e-12

3.2 ERP Data

To analyze the EEG data stimulus- and response-locked ERP's were made for both tasks. The ERP examines the brain activation at a given moment in time. The grey areas in the graphs are areas of significant difference of the means using an ANOVA. The channels used for the purpose of analysis were A23, A19, A1, C21, C17 (Oz, Pz, Cz, Fz, Fpz electrodes, in the 10/20 system) and D4, C4, A7 B4. The locations on the scalp of these channels can be found in Figure 3.3.

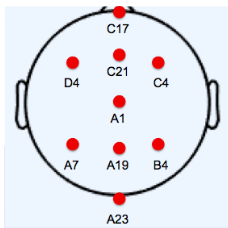


Figure 3.3: Scalp map for channels A23, A19, A1, C21, C17, D4, C4, A7 B4. C17 is located on the frontal area of the head and A23 is located on the occipital area, the channel name is located under the corresponding red circle.

3.2.1 Stimulus-locked Analysis

Analysis of the algebra task ERP showed areas of significant effects of conditions in all channels (Figure 3.4). At the moment the stimulus was recognized (at the peak level of potential) activation for condition 3 was the highest. After the peak (at about 700ms) we see that activation for condition 1 was the lowest and activation for condition 5 was the highest. Activation for conditions 2-4 fluctuated around each other. The effect for condition 1 ended before 1000ms. For all channels there was a significant difference between conditions at the peak level of activation. For all channels, there was a significant difference in conditions from 500-800ms. There was an effect of retrieval in all channels, although not very pronounced. There was no clear visible effect of transformation.

The ERP results for the names task can be found in Figure 3.5. The instruction for the names task was presented at 2000ms. Before 2000ms there are three peaks in potential in the frontal electrodes, this occurred at the moments the names were shown. There are significant differences in conditions after the instruction was recognized in the frontal electrodes. Rear electrodes showed a significant difference at the moment the instruction was shown but not after recognition of it (after 2500ms). All electrodes showed significant differences between conditions 500ms before the instruction was shown up until it was shown (2000ms). We see clear effects of retrieval in channel D4, where activation for condition 8 and 9 is the highest after stimulus recognition (about 2300ms). There are also clear effects of transformation in channels A1, B4, C4 and C17, where activation for condition 7 and 9 is highest after stimulus recognition. The transformation effect is less pronounced than the retrieval effect.

3.2.2 Response-locked Analysis

In the response-locked ERPs for the algebra task (Figure 3.6), condition 1 exhibited the highest activation at the moment of response, while condition 5 was closer to 0μV. Conditions 2-4 showed similar activation. There were areas of significance at the moment of response for channels A7, A19 and B4. There were large areas of significance in channels A23, A19, A1, C21, D4, A7 and B4 in from 700ms-200ms before the response.

For the names task, condition 6 exhibited the highest activation (Figure 3.7). Condition 8 had the lowest activation, although conditions 7, 8 and 9 had activations close to each other. Channels A19, A7 and B4 had areas of significance at the moment of response.

4 Discussion

In this experiment we evaluated the effects of declarative and working memory for two tasks that seemed to be very different on the surface. We did this by manipulation of retrieval and transformation. By doing this we aimed to discover if these different tasks rely on the same underlying processes.

We will start by discussing the behavioural results. For accuracy of the tasks we can see that the algebra and the names task show similar patterns. Accuracy for the algebra task is higher, which can only be attributed to the fact that algebraic equations are heavily practiced, especially because all participants were university level students. The names task is arguably, explicitly in this form not practiced at all before participating in this experiment.

Accuracy for condition 9 (BE *(31)* - retrieval, transformation) is on average below half. This is most likely due to participants forgetting what number belonged to the given word instruction resulting in it not being able to be retrieved anymore to give correct answers. Chance level is 0.33, the swap options are 1 and 2, 1 and 3, or 2 and 3, if the instruction is reversed (2 and 1, 3 and 1, 3 and 2) then the resulting answer is still the same as the reversed instruction. Of course we cannot assume that all participants forgot all the associations which is why the accuracy is still above chance level. This would not explain why condition 8 (AT *(14)* - retrieval, no transformation) has an accuracy higher than 0.8. An explanation for this could be that participants did not actually need to remember the entire number that belonged to the word because these words were all associated with

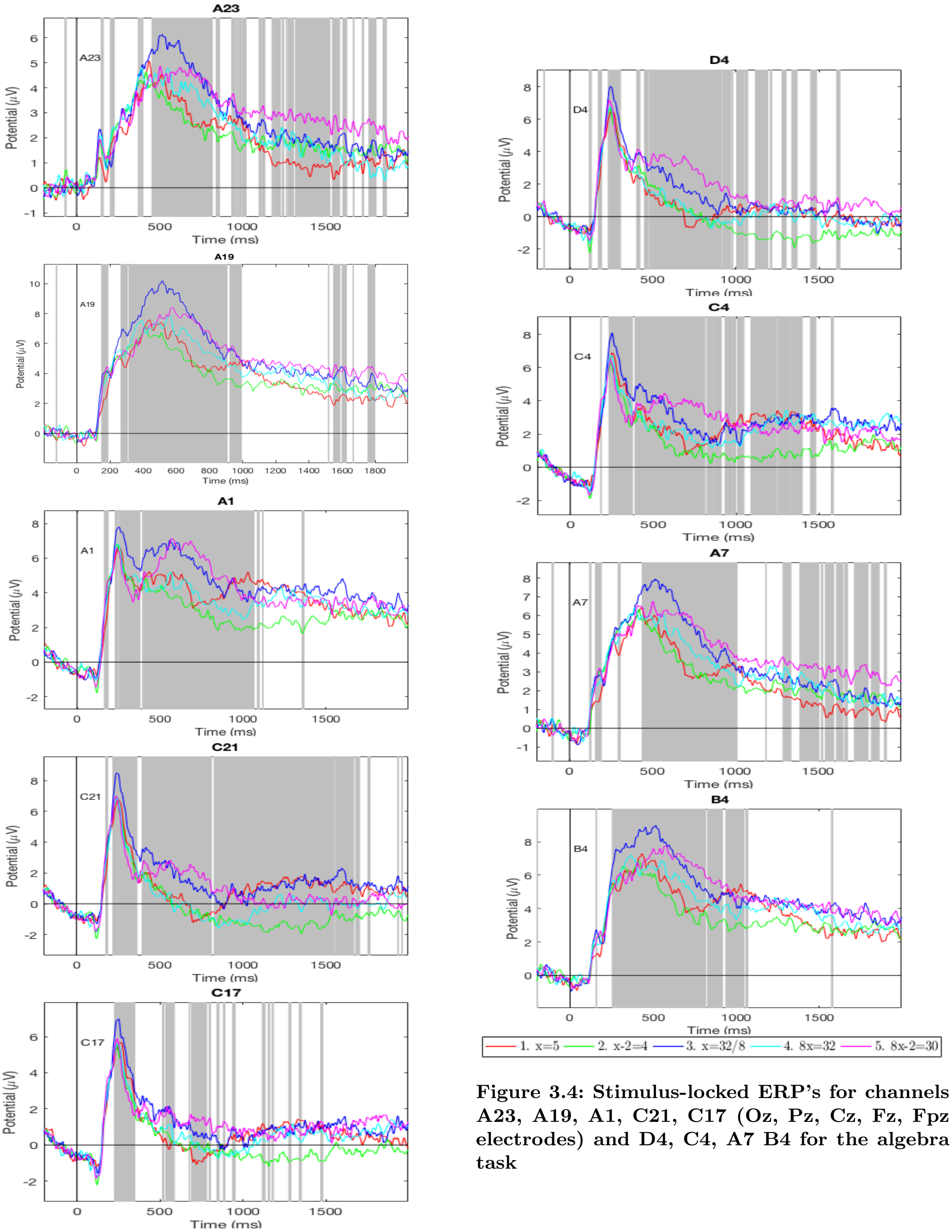


Figure 3.4: Stimulus-locked ERP's for channels A23, A19, A1, C21, C17 (Oz, Pz, Cz, Fz, Fpz electrodes) and D4, C4, A7 B4 for the algebra task

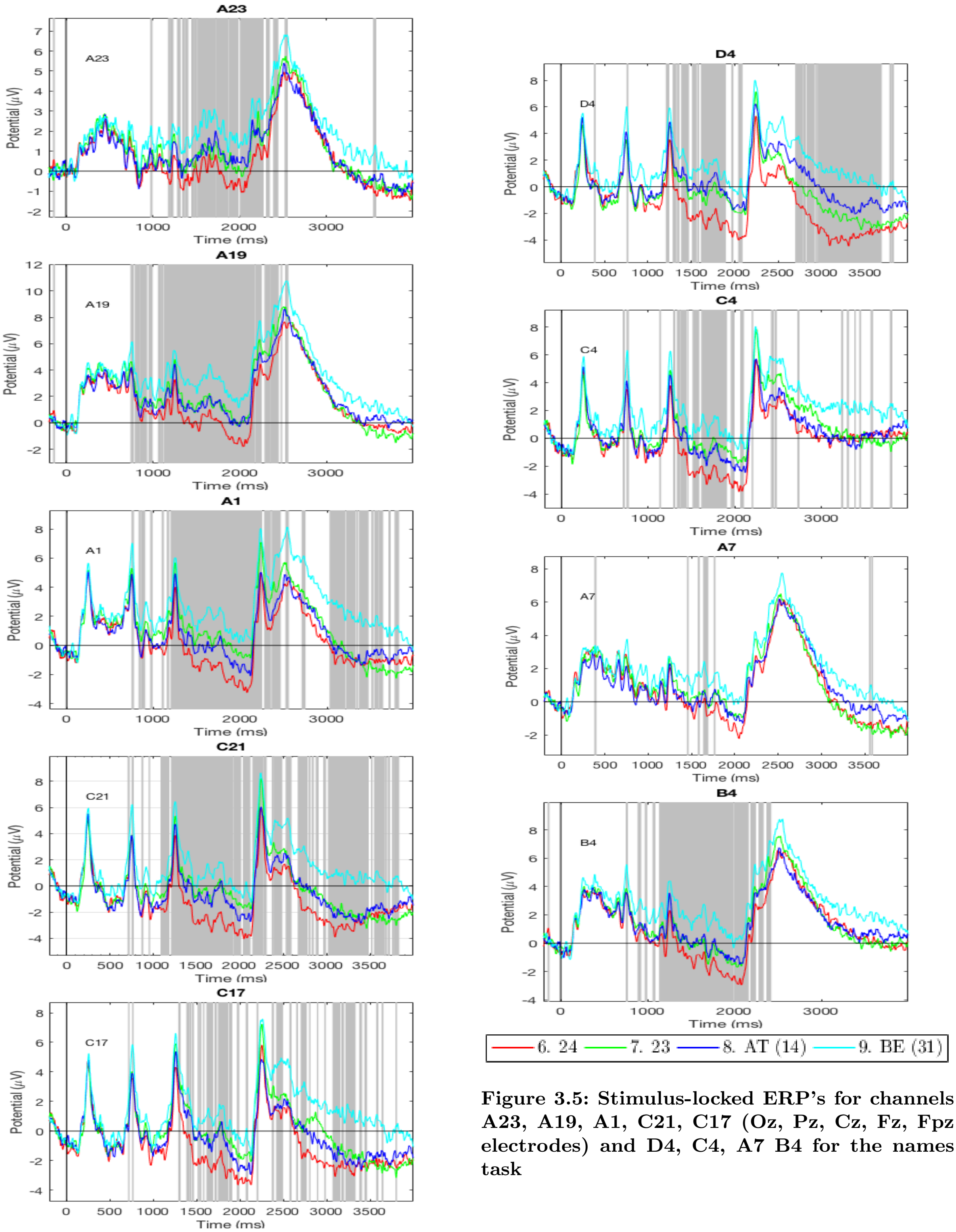
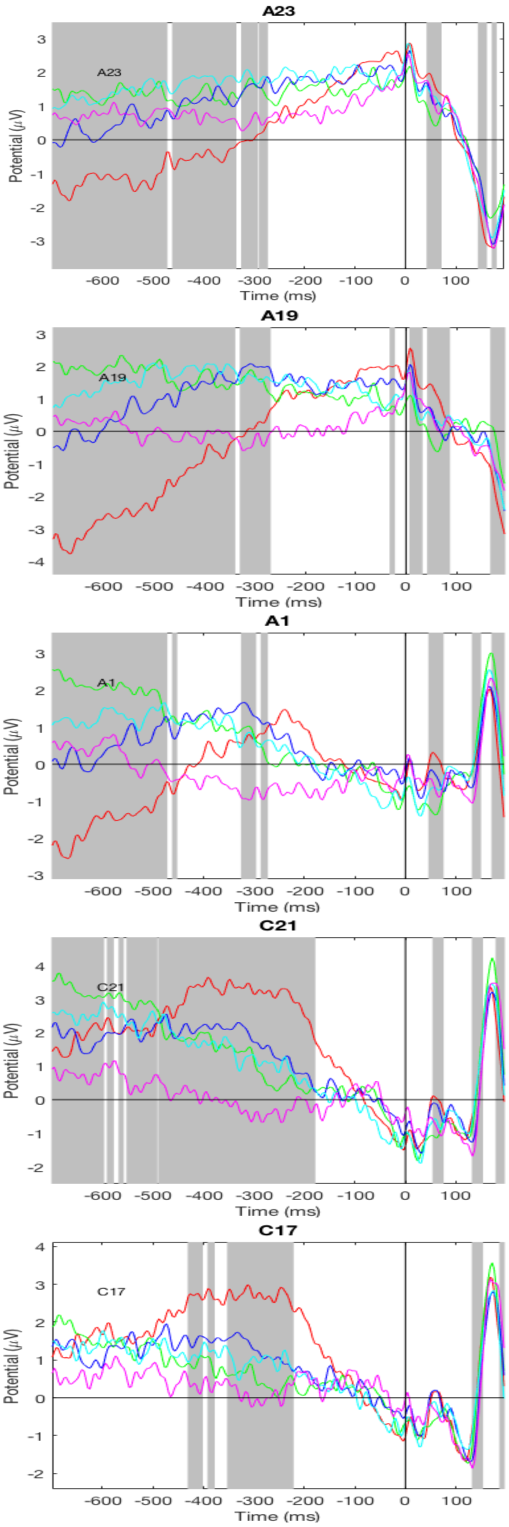


Figure 3.5: Stimulus-locked ERP's for channels A23, A19, A1, C21, C17 (Oz, Pz, Cz, Fz, Fpz electrodes) and D4, C4, A7 B4 for the names task



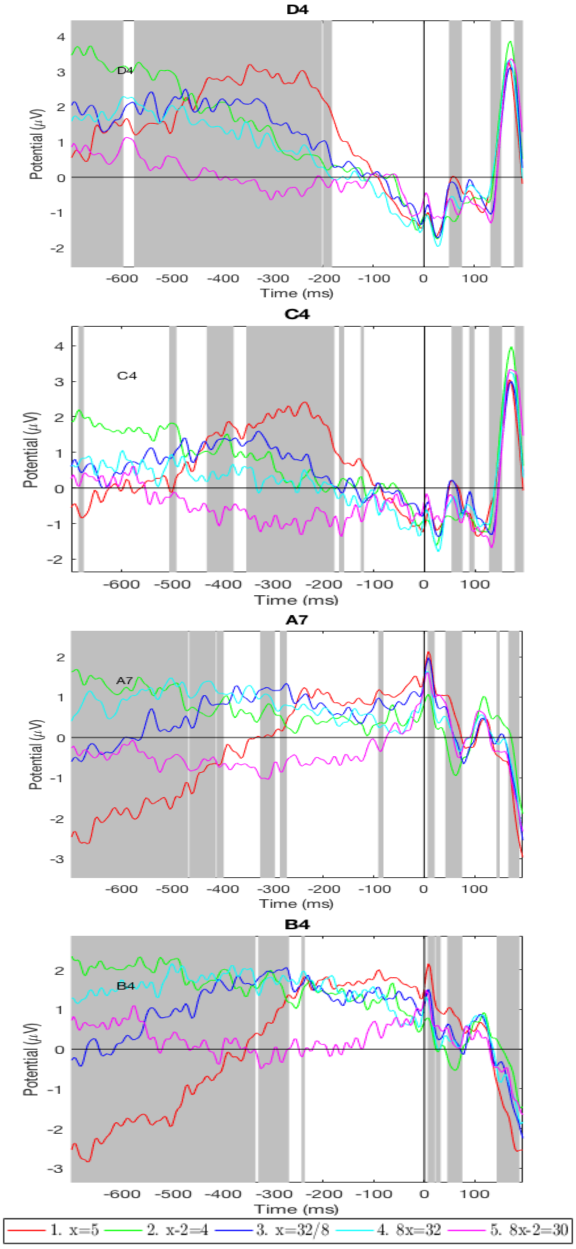


Figure 3.6: Response-locked ERP's for channels A23, A19, A1, C21, C17 (Oz, Pz, Cz, Fz, Fpz electrodes) and D4, C4, A7 B4 for the algebra task

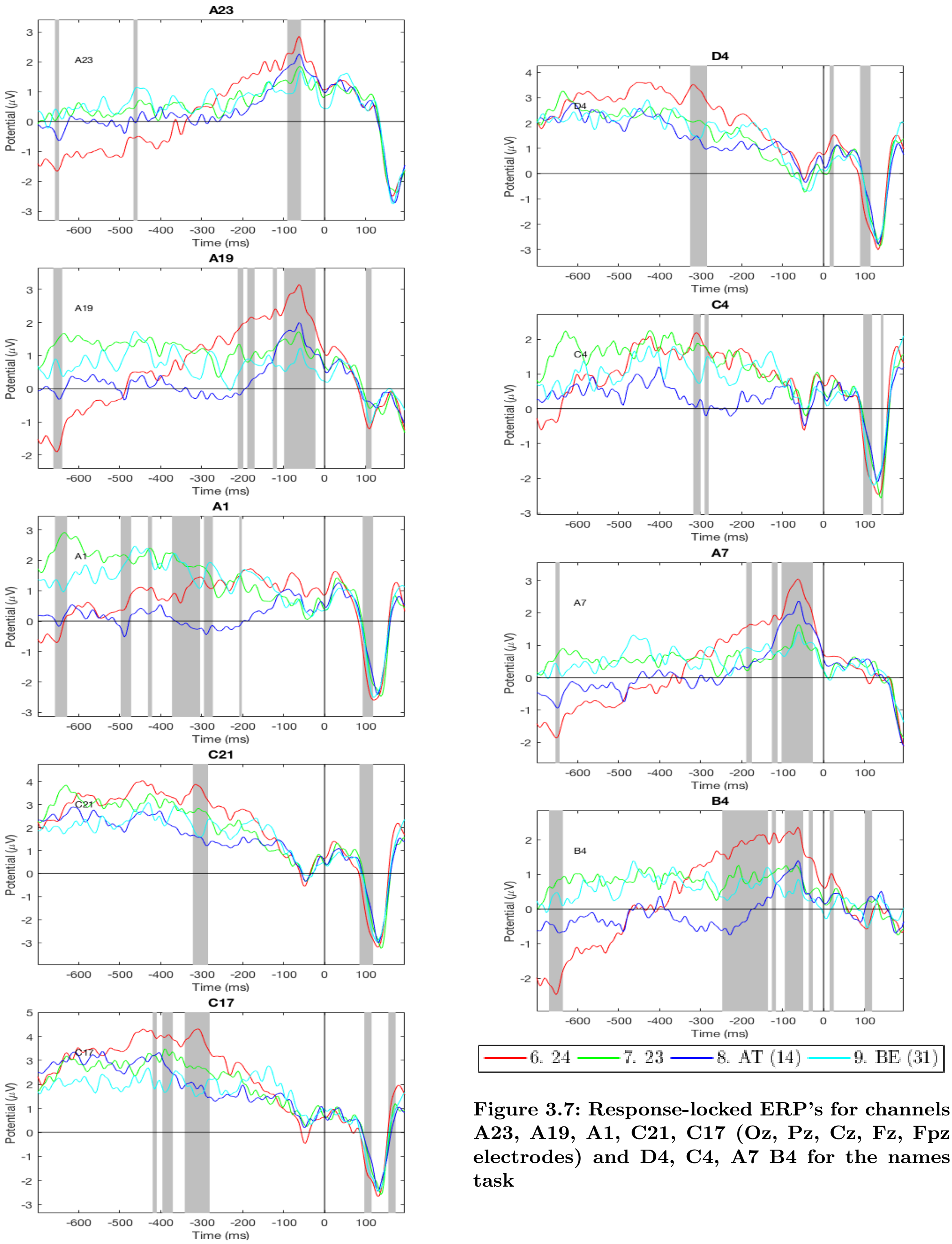


Figure 3.7: Response-locked ERP's for channels A23, A19, A1, C21, C17 (Oz, Pz, Cz, Fz, Fpz electrodes) and D4, C4, A7 B4 for the names task

a number with the digit 4. Participants would have been able to correctly solve this condition just by knowing the word was associated with the digit 4; whereas in condition 9 participants would have to actually retrieve the complete number in order to give the correct answer.

Interestingly, looking at the reaction times condition 9 does not take much longer to solve than condition 5 ($8x - 2 = 30$ - 2 retrievals, 2 transformations). This could possibly be because while algebra is a more practiced task condition 5 requires two retrievals and two transformations to solve. This could be seen as twice as difficult compared to condition 9 using our definition of difficulty in the terms of retrieval and transformation. Previous research has found that retrieval takes longer when there are more facts, which is the case here (Anderson, 1974; Sohn et al., 2005).

Remarkably, the reaction time is shorter and accuracy higher for condition 4 ($8x = 32$ - retrieval, transformation) compared to condition 3 ($x = 32/8$, retrieval, no transformation), even though condition 4 requires both a transformation and retrieval. We could assume that condition 3 is purely division and condition 4 could also be solved by thinking in multiplication terms (what multiplied by 8 equals 32?). If this is the case it would be in line with the conclusions of Campbell, which are that division relies on the multiplication system so division is checked by multiplication (Campbell, 1997). It would then make sense that condition 4 would be seen in multiplication, whereas condition 3 would be handled as division but checked by multiplication causing the longer reaction time.

Contrary to previous research using the names task (Anderson et al., 2003, 2007), we found an interaction between retrieval and transformation. This discrepancy is most likely due to the small pool of participants in our experiment.

Looking at Figures 3.1 and 3.2 we see that the algebra and the names task show a similar shape between conditions. We can assume that this similar pattern is initial evidence towards at first sight seemingly different tasks relying on the same network as the pattern occurs when we manipulate the same variables within tasks.

Now we will take the ERP results into consideration. Effects from the response-locked ERPs seem to be an effect of reaction team instead of retrieval or transformation. The reaction time between conditions differed considerable which resulted in the response-locked results reflecting the total duration of processing. For this reason it is challenging to interpret any effects of retrieval or transformation, therefore, we will focus on the stimulus-locked ERPs.

Interestingly, condition 3 ($x = 32/8$ - retrieval, no transformation) has the highest activation when being recognized. It is as if participants were surprised to see this as an equation. This resulted in less clear effects of retrieval or transformation in the algebra task as we would expect low activation for condition 3 in areas susceptible to transformation and moderate activation for retrieval areas. While it could be expected that condition 3 would require higher activation than condition 4 ($8x = 32$ - retrieval, transformation) because condition 4 occurs more naturally in day to day life it is somewhat unexpected that there is more activation for condition 4 than condition 5 ($8x - 2 = 30$ - 2 retrievals, 2 transformations). This may have to do with the suggestion made earlier about the effects of division and multiplication (Campbell, 1997).

Before the instruction is shown in the names task we see in most stimulus-locked ERPs three peaks in activation, these peaks occur most strongly in frontal channels, suggesting that these are the names being maintained in working memory (D'Esposito and Postile, 2009; Nagel et al., 2013). What we also observe during the names task is quite interesting, there seems to be an effect of condition before the stimulus is shown; as if participants already know in which condition they are before the instruction is given. Possibly the most plausible explanation is that there was a pattern in the order the instructions were shown depending on the order the names were shown that participants became unconsciously aware of, despite using randomization. This could have led to knowing in which condition they were before the instruction was shown.

In channel D4 of the names task there is an effect of retrieval. Conditions 8 (AT *(14)* - retrieval, no transformation) and 9 (BE *(31)* - retrieval, transformation), conditions that both require retrieval, cause the most activation. Channel D4 sits on the left frontal regions of the head, which would suggest that declarative memory is located in the left frontal lobe, which is in concurrence with previous research (Lepage et al., 2000). This effect is not present in channel C4 which is the channel for the right frontal lobe, this would suggest that declarative memory is lateralized to the left side of the frontal lobe. This effect of memory can also be seen in the algebra task, although less pronounced, possibly due the varying levels of retrieval.

Comparing the algebra task with the names task we once again observe similar patterns in activation, now between channels. The same channels for both tasks show similar peaks in activation for the stimulus, for example in channel D4 we see a sharp peak in both tasks and in channel A7 we observe a wider more prolonged peak. This is more evidence pointing towards these tasks relying on the same network as we see that manipulating retrieval and transformation results in similar patterns of activation between tasks.

The results we present here suggest that the two tasks we evaluated are relying in some part on the same systems. This is in concurrence with research done by Newmann et al. who found that word and number tasks were relying on the same network using fMRI (Newman et al., 2011). The active brain areas during problem solving discovered by Newmann et al. were the parietal cortices as well as the left prefrontal cortex and the basal ganglia. These areas are analogous with the fronto-parietal network that we suggested was the system different tasks could be relying on.

5 Conclusion

The results found in this experiment demonstrate that tasks that seem very different can be affected by manipulation of retrieval and transformation in a similar manner. This would suggest that these tasks are relying on the same underlying mechanisms to process information to solve the problem presented in the task. Furthermore, the processing of both tasks seem to occur in the same general areas of the brain, the frontal and parietal area. This is a step towards understanding how the brain functions for tasks that appear to be altogether different. The results of this experiment suggest that we do not have a specified area in the brain per task. Instead it suggests that tasks rely on the same cognitive processes to produce appropriate results.

EEG is an excellent brain imaging technique for temporal resolution, but cannot provide the entire picture by itself. Further research needs to be done using different brain imaging techniques to acquire a more complete compilation of data. But even then, brain imaging techniques deliver a substantial amount of data and it quickly becomes difficult to compare the results of two different tasks. Therefore, the next step towards analyzing the results of these tasks would be to use a statistical model. A statistical model would allow for a detailed analysis showing just how much different tasks rely on the same cognitive processes.

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Appendix A: Word number combinations

- IN - 12
- OR - 13
- AT - 14
- DO - 21
- OF - 23
- BY - 24
- BE - 31
- AN - 32
- WE - 34
- TO - 41
- HE - 42
- IT - 43

Appendix B: BioSemi EEG cap scalp map (BioSemi)