INSIGHT IN SIGHT

Studying insight and the effects of giving hints on insight

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ABSTRACT

There are many ways to solve a problem. A unique way is insightful problem solving when the solution promptly comes into your mind. It is interesting to take a look inside one's brain to understand more about this intriguing phenomenon, particularly since brain responses appear to signal insight before subjects report it. The electroencephalogram of 20 participants was recorded during a verbal insight task. In part of the trials different types of hints were provided. The analyses of the EEG-data revealed more brain activity related to breaking one's mental impasse without providing the subjects with a hint and more activity related to the subjective aha-experience when no hint was given. The results suggest that giving a hint during insightful problem solving has an advantage when people can not proceed in solving a problem. On the other hand the actual experience of insight weakens when a hint is provided.
Keywords: insight, hints, EEG, 'aha-experience', mental impasse

SAMENVATTING

Er zijn vele manieren om een probleem op te lossen. Een unieke manier is inzicht waarbij de oplossing plotseling verschijnt. Het is interessant om een kijk te nemen in de hersenen om dit fenomeen beter te begrijpen. Elektro-encefalogram was gemeten bij 20 proefpersonen tijdens een verbale inzichttaak. In sommige trials werden verschillende hints gegeven. Uit de EEG-resultaten bleek dat er meer activiteit in de hersenen tijdens het breken van een mentale impasse plaatsvindt als geen hint werd aangeboden. Echter was er minder activiteit tijdens de subjectieve 'aha-ervaring' wanneer een hint wel werd aangeboden. De resultaten suggereren dat het geven van hints voordelig is als een probleem oplosser niet verder komt in het proces maar de subjectieve ervaring van inzicht wordt daarmee zwakker.
Sleutelwoorden: inzicht, hints, EEG, 'aha-ervaring', mentale impasse

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1. THEORY

1.1 Problem Solving and Insight

We are confronted with different kinds of problems every day. They can vary from small to great, from easy-to-solve to problems that don't seem to have a clear answer. Robertson's (2001) definition of a problem is when a person has a clear goal but the journey there isn't. Another definition of insightful problem solving is: "A problem exists when someone has a goal for which they are unable to generate a suitable sequence of actions either from memory or by applying a routine method. To solve a problem (it) requires representing the problem situation and goal, followed by search for an appropriate sequence of actions within the framework of the initial problem presentation" (Gilhooly & Murphy, 2005, p.279). Thus problems can come in many shapes and sizes. According to Robertson (2001) problems can also be 'knowledge-lean' or 'knowledge-rich' depending on the amount of necessary knowledge to solve the problem. They can also be ill or well defined and semantically rich or poor. According to Robertson there exists also a unique type of problem solving, namely insight. When Archimedes discovered a method for determining the volume of an object, he yelled "Eureka" and when Donald Duck gets a brilliant idea, a light bulb appears next to his head. These very different examples of insightful problem solving demonstrate the unique nature of insight that is recognizable throughout nations and cultures. The solution comes in mind suddenly, often after a period of not knowing how to proceed with the problem.

1.2 Insightful Problem Solving

Insight solutions are fundamentally different from the solutions without insight and are according to Sandkühler and Bhattacharya (2008) characterized by a number of properties: i) Impasse. When solving a problem the individual gets stuck and working towards an answer is not continued, ii) Restructuring of the problem is needed to get further in the problem solving attempt and iii) Probably the most recognizable feature of insight is the subjective aha-experience. The solution appears suddenly in mind and there is no doubt that it is not the correct answer. Metcalfe (1986) and Metcalfe and Wiebe (1987) studied the nature of sudden insight. They questioned how problems with and without insight differed from each other. In Metcalfe and Wiebe (1987) intuition on classic insight problems were compared to non-insight and arithmetic problems. They used warmth ratings where the subjects provide ratings on how close to the solution they think to be and this is often called feeling-of-warmth ratings. In algebra problems the subjects' ratings predicted their performance contrasting with the insight problems that showed a more sudden achievement of the solution. The subjects could also accurately predict which algebra problems they were going to solve which did not apply for the insight problems. According to the author this experiment shows 'an empirically demonstrable distinction' (p.243) between insight and non-insight problems and it is possible that solving insight problems qualitatively differs from solving non-insight problems.

As mentioned earlier, mental impasse is one of the characteristics of insight. It is when the thinker doesn't know how to proceed with the problem. According to Knoblich et al. (1999) impasses are caused by our past experiences that create constrains in our thinking by biasing the initial problem representation. Impasse can be resolved by constraint relaxation. They used the Matchstick Arithmetic problem, which is one of the classic insight problems. It consists of incorrect mathematical statements that are written in Roman numerals (I, II, VI) and mathematical operations (+, -, =). The solvers goal is to change the false statements into a correct one by moving only one matchstick. For example is the problem VI = VII + I and the correct solution is VII = VI + I. In this research there were three different constraints: i) in the 'Value Constraint' the numerical value within the statement can not be changed without compensating this in the other values, ii) in the 'Operator Constraint' the mathematical operator can not be altered without changes whether in the values or operators in the equation and iii) a 'Tautology Constraint' requires changes in the entire equation. Knoblich et al. (1999) tested three different types of problems. In the first type the problem was solved by moving a matchstick from one numeral to another as seen above. Here the 'Value Constraint' has to be relaxed. In the second problem type a 'Value' and 'Operator Constraint' had to be relaxed. The problem was I = II + II and the correct solution was I = III – II. In the third problem type an 'Operator' and 'Tautology Constraint' had to be relaxed. The problem (III = III + III) was solved by removing one matchstick from the plus sign and placing it vertically above or under the minus sign (III = III = III). Knoblich et al. (1999) discovered that the first problem type was easier to solve than the second type and that the second problem type was easier to solve than the third one. According to the authors it seems that some constraints are easier to relax than others. Ormerod, MacGregor and Chronicle (2002) argue that simply releasing the constraints preventing insight is not enough. Insightful problem solving might also require that the solver reaches a state of preparedness to be able to pay attention to the solution-relevant information.

According to Bowden et al. (2005) a major obstacle in the study of insight is that there are too little applicable insight problems that can be solved within a relatively short time. Moreover, the classical insight problems are often very complicated what results in very small number of useful trials and because of this the reliability of the received data is low. Bowden and Jung-Beeman’s (2003) solution was to create new problems that would not be time-consuming to solve. Mednik’s (1962) ‘Remote Associates Test’ (RAT) served as an inspiration for the ‘Compound Remote Associates' (CRA). CRA-problems consist of three problem words and a solution word that together form a phrase or a compound word. An example of the problems words is ‘cream’, ‘skate’ and ‘water’ with the solution word ‘ice’. Together the compound words ‘ice cream’, ‘ice skate’ and ‘ice water’ are formed. Another major advantage of CRA-problems is that they can be solved with or without insight (Bowden et al., 2005; Bowden & Jung-Beeman, 2007). The subjects give subjective ratings whether or not they have experienced insight and no special insight or non-insight problems are necessary. Processing and analysing data is easier because there are no different ongoing cognitive processes depending on the presence or absence of insight. According to Bowden and Jung-Beeman (2007) by using a 5-point scale (1= strong non-insight, 3=neutral, 5=strong insight) the participants tended only to use the middle values on the scale, namely 2 to 4. There also was a risk of participant using different values to indicate the same levels of insight. One the other hand with a 2-point scale there was no risk of getting confused but there also was no space for doubt. Because of this Bowden and Jung-Beeman (2007) advised to use the 3-point scale (insight, neutral, non-insight) for reporting insight.

1.3 Insight and the Brain

Although much is known about insightful problem solving, we still do not know what exactly happens inside one’s brain during an aha-experience. Because of the enormous development of methods for mapping the activity of the brain, it is now possible to cast a glance and see what exactly happens inside our head during insight. Electro cortical brain activity is one of the most frequently used methods of studying the neural correlates inside the brain.

Jung-Beeman et al. (2004) used the CRA-items created by Bowden and Jung-Beeman (2003) in their study. The sequence within trials began with the word ‘Compound’ presented in the middle of the screen for a variable time between 0.5 and 2.5 seconds. Next three problem words were shown for a maximum of 30 seconds and the subject indicated knowing the solution by a bimanual button press. Then the solution was verbalized within 2 seconds and the subjects rated whether or not they had experienced insight. Earlier Bowden and Beeman (1998) had found that while subjects were solving verbal problems and a potential solution word was presented to them, they read the actual solution word faster than an unrelated word. This “solution priming” was stronger when the stimulus was presented to the left visual hemi-field projecting to the right hemisphere (RH) in the brain than when it was presented to the right visual hemi-field (Bowden & Jung-Beeman, 2003). This finding along with supportive previous studies Jung-Beeman et al. (2004) expected to find components of insightful problem solving in the anterior temporal areas in the RH. Their study consisted of two experiments. In the first experiment they used 'functional Magnetic Resonance Imaging (fMRI) to identify the neuroanatomical location of insight processes. The changes in the blood flow in the brain, also called the hemodynamic response are measured. FMRI is a non-invasive method and no harmful radiation is used. One of the biggest advantages of fMRI is the great spatial resolution and signal from all areas of the brain can be recorded. Jung-Beeman et al. (2004) found that an area, namely anterior superior temporal gyrus (aSTG) in the right hemisphere of the brain, where the neural activity was significantly greater in insight solutions opposed to solutions without insight. In the second experiment the authors used 'Electroencephalogram' (EEG) to measure the precise time and frequency of the activity. It uses electrodes placed on the subject's scalp to measure the electrical activation of the neurons. EEG provides a great temporal resolution and can be used to measure the precise time course and frequency of the neural activation. The EEG-electrodes are often attached to a cap and are placed according to the International 10-20 System that describes the locations of the electrodes. Each location has been named with a letter and a number for identifying purposes. Jung-Beeman et al. (2004) found after analyzing the EEG-data a strong burst of gamma-band activity (39 Hz) associated with only insight solutions at or near the electrode T8 0.3 second before the participants had indicated to know the solution. A second finding in the EEG-experiment was a burst of alpha-band (8-13 Hz, estimated at 9.8 Hz) activity at or near the electrode PO8 starting from -1.4 to -0.4 second before the button press. After this burst the alpha-band activity declines (at least) until 0.2 second after the subject had pressed the button. Jung-Beeman et al. (2004) argue that this burst of alpha-activity in the right posterior parietal cortex calculated with difference waves (insight minus non-insight) might be an indirect correlate of unconscious processes that are related to solving the insight problem. The observed right temporal gamma-activity is according to the authors a direct correlate of the sudden transition to full awareness of the solution. In other words the change from mental impasse gives space to sudden insight.

There have been other attempts to map the neural activity during insight. Luo and Niki (2003) used Japanese puzzles in their experiment. They showed each subject 16 word puzzles based on a preliminary test. If the subject did not know the answer in the preliminary test, the correct solution was revealed to the subject for 2 seconds in the second test. Based on the results of the fMRI-analysis, Luo and Niki (2003) found that the right hippocampus was significantly activated after the subjects had seen the solution. According to the authors it is possible that the hippocampus facilitates the breaking of mental impasse. Noteworthy is that in the summary of a follow-up study (Mai et al., 2004) the authors only mention anterior cingulate cortex (ACC) to be associated with breaking the impasse as a result of previous research (Luo & Niki, 2003). The structure of experiment done by Mai et al. (2004) has many similarities with the research by Luo and Niki (2003). In subsequent research, the authors used Chinese riddles. The subject saw the riddle for 8 seconds, followed by a 2-second interval without the verbal stimulus. Next the solution was revealed for two seconds, followed by another 2-second interval. Then the subjects had to indicate whether they had understood the meaning of the riddle. After the analysis of ‘event-related potential's’ (ERP’s) the researchers found activity in insight solutions opposed to solutions without insight between 250 and 500 ms after revealing the correct answer. They measured strong activity near or in the ACC and the authors argue that it may reflect the breaking of mental impasse.

Also Sandkühler en Bhattacharya (2008) investigated in a complex study the four ‘salient features of insightful problem solving’, namely i) mental impasse, ii) restructuring of the problem representation, iii) deeper understanding of the problem and iv) the suddenness of aha-experience. Verbal remote associate problems were used. First no hint was given. If the participant experienced mental impasse a ‘hint or clue’ was presented consisting of the first letter or 60 to 75% of the letters of the solution word. A hint was also given if the initial 45 second time limit had passed. Sandkühler and Bhattacharya (2008) compared the percentual change of the task-related power with respect to the baseline power. The changes were called ‘Event-Related Synchronization’ (ERS) when the task-related power was higher than the baseline power. They found a strong alpha ERS (10-12Hz) at the right temporal regions when a hint was presented after a timeout from -0.2 to 0.3 second after presenting a hint indicating an inhibition in this region. This inhibition has been associated with integration of semantical or lexical information that is distantly related, for example problem words and possible solution words (Jung-Beeman et al., 2004). Sandkühler and Bhattacharya (2008) suggest that the found alpha-effect might be related to unconscious processing of the solution. They also found a strong gamma (38.00-44.00 Hz) effect at parieto-occipital areas from -1.5 to -1.0 seconds and from -0.75 to 0 seconds before pressing the button for a solution. Sandkühler and Bhattacharya (2008) argue that it is a correlate of the suddenness of the solution. They suggest that the gamma-activity reflects retrieval processes when the solvers retrieve the correct solution word from their memory. Discussing the differences in results between two experiments, Sandkühler and Bhattacharya (2008) claim that Jung-Beeman et al. (2004) measured the "aha-feeling" whereas their own results reflect a neural correlate of suddenness. Jung-Beeman et al. (2004) argue that the involvement of aSTG does not merely reflect the emotional response of insight solutions because the neural activity in this area is increased also when participants first see each problem.

Aziz-Zadeh, Kaplan and Iacoboni (2009) investigated the neural correlates of verbal insight solutions using anagrams in their fMRI-study. The participants' solutions were classified as insight solutions or search solutions depending on their subjective ratings and the response times. The trials with a response time of less than 4 seconds together with an insight rating were categorized as insight solutions and trials with a response time of 4 seconds or longer with a rating of search were categorized as search solutions. 70 % of the trials included to the study were insight solutions and 30 % search solutions. According to the authors this was due to the expert status of their participants. They found that areas such as the right insula, the anterior cingulate and Broca's area were activated by search solutions and insight solutions but more strongly by the latter. The anterior cingulate was also activated in the study by Mai et al. (2004) where riddles were used. Right prefrontal cortex and the pons were only activated by insight solutions. The right temporal pole and the bilateral angular gyri were the areas deactivated by search solutions and minimally activated by insight solutions. Aziz-Zadeh, Kaplan and Iacoboni (2009) found no areas that were significantly more activated in search solutions than in insight solutions. A more increased activation of the anterior cingulate was found in insight solutions and the authors argue the possibility of the area being a part of a network that focuses one's attention, executes control and it being a necessary component in insight processing. The activation of anterior cingulated cortex was also found by Mai et al. (2004).

Fink and Neubauer (2006) found that creative problem solving was generally accompanied by lower levels of cortical arousal. This was suggested by strong increases in alpha power (7-13 Hz) when the pre-stimulus reference power was compared to the activation levels during creative problem solving. Though the found alpha power just failed to reach statistical significance, it was more pronounced in anterior than in posterior regions of the brain. Jung-Beeman et al. (2004) also found an increase in alpha from -1.4 s until -0.4 s before the participant gave the response. Fink and Neubauer (2006) found that verbal intelligence and the sex of the participant may have effect on the measured alpha power activation. More specifically they found that females with high verbal IQ showed stronger increases in alpha power when compared with verbally average intelligent females. In males the opposite effect was found.

Reverberi et al. (2005) studied whether a group of patients with focal damage to the lateral frontal cortex would perform better on a classical insight problem in comparison with a group of healthy participants. In their hypothesis they combined the results of Knoblich et al. (1999) about breaking one's mental impasse that is caused by constraints acquired in past experiences and Frith's theory on the role of dorso-lateral frontal cortex. The latter theory claims that "the prefrontal cortex, particularly its dorso-lateral aspect, is crucial for defining a set of responses suitable for a particular task and biasing these for selection." (p.2882 in Reverberi et al., 2005). Reverberi et al. (2005) hypothesized that a group of patients with lesions in the lateral frontal cortex would perform better in the Matchstick Problem than a healthy control group because the constraints would not effect them as much as the controls. It is a surprising hypothesis because having a lesion to an area that is active in cognitive processing hardly ever improves a person's performance. Nevertheless the patients were significantly more successful in solving problems with strong constraints such as the 'Tautology' or 'Operator' constraints when compared to the healthy group. However the group with lateral frontal patients was as successful in solving problems with weak constraints as the healthy controls.

1.4 Differences in Research

The experiments of Luo and Niki (2003) and Mai et al. (2004) differ greatly from the research done by Jung-Beeman et al. (2004). First, the researchers have a different view of insight as a process. Luo and Niki (2003) and Mai et al. (2004) assume that breaking the mental impasse is the most defining feature of insight. "As a high-level cognitive process, 'insight' means to break the unwarranted 'fixation' and to form novel, task-related associations among the old nodes or cognitive skills." (p.316, Luo & Niki, 2003). Also Knoblich et al. (1999) see breaking one's mental impasse as the most important part of the process of insight. Nonetheless Jung-Beeman et al. (2004) prioritise another part of the process, namely the subjective aha-experience.

The second major difference in insight research is the use of hints. Luo and Niki (2003) and Mai et al. (2004) revealed in their studies the correct solution to accurately know the beginning of breaking the impasse. Sandkühler and Bhattacharya (2008) gave the subjects a hint consisting of the first letter or 60 to 75% of the letters of the correct solution if they had experienced impasse or were unable to discover the solution within the time limit. In stead of hints Jung-Beeman et al. (2004) let the subjects themselves discover the answer. This shows the different ways to handle "hints" in investigating insightful problem solving. In the article by Luo and Knoblich (2007) a conflict between 'internally vs. externally' triggered insight is discussed. Some researchers (including Ormerod, MacGregor & Chronicle, 2002 and Luo & Niki, 2003) argue that stimulating insight by a hint results in fundamentally the same insight-experience as without a hint, when a subject discovers the solution by himself. However one can not assume this without further research. According to Luo and Knoblich (2007) the dilemma is whether the researchers accurately want to time the beginning of insightful problem solving for their EEG or fMRI research using hints or to be able to conduct a more ecologically valid research. This conflict makes investigating the role of hints in insightful problem solving important.

1.5 Hypothesis

The research questions of this thesis are based on the uncertainties in the literature discussed above. First we wanted to replicate a part of the Jung-Beeman et al. (2004) research to be able to identify the aha-experience and to find the same behavior in the alpha and gamma band activity as Jung-Beeman et al. (2004) have found. The first hypothesis is that we find the same burst of gamma-activity and decline in alpha-activity approximately 0.3 second before the subject report having insight replicating the results of the EEG-experiment conducted by Jung-Beeman et al. (2004).

The second question concerns the unknown role of hints in insightful problem solving. We want to compare the insight-experience without a hint with an insight-experience that is stimulated by a hint, by pairing the aha-experience without a hint with aha-experience with different types of hints each time. Because no studies examining the effects of giving different kinds of hints have been conducted so far this experiment is explorative and no predictions on the possible effects can be given.

2. METHODS

2.1 Subjects

In total 20 persons volunteered to participate in this experiment. This group of 10 men and 10 females had an average age of 30.6 years (SD=1.91), varying from 20 to 50. All subjects except one were right-handed. They filled out a short survey with demographic data. All subjects were native Dutch and hadn't been living abroad for longer than 6 months at any time in their lives. All the subjects gave an informed consent and they were aware that they could stop the experiment at any given time.

Full anonymity was guaranteed and the experiment was approved by the Ethics Commission of the Department of Behavioral Sciences of the University of Twente.

2.2 Stimuli

2.2.1 List of Compound Words. To be able to conduct this experiment a Dutch list of compound words was generated. This was done with the help of the internet and several dictionaries. Only true compound words were used as opposed to Jung-Beeman et al. (2004) who used phrases as well. For the list of compound words see annex 1. A list of 140 word pairs was used in this experiment. A word pair consisted of a solution word and three problem words that could be placed in front of or after the solution word. For example the problem words are 'donder', 'boek' and 'licht' ('thunder', 'book' and 'light') and together with the solution word '*dag*' ('day') the words 'donder*dag*', '*dag*boek' and '*dag*licht' meaning 'Thursday', 'diary' and 'day light' can be formed. All solution words were common Dutch nouns and varied from 3 to 7 letters and the problem words were between 3 and 11 letters.

The word pairs were placed in one of the four conditions according to the alphabetic order of the solution word. The listing began with the pairs where the solution word was placed after the problem words, followed by the pairs where the solution word was before the problems words and at last the solution word where the problem words were on both sides of the solution word were placed into the list. This was done to create enough variety inside each condition. The actual testing program randomly chose the word pairs from the lists of each condition so the order on the list had no influence on the order of appearance during testing.

All four conditions consisted of 35 word pairs and the total amount of trials for each participant was 140. In the first condition no hint was given opposed to the remaining three conditions. In condition 2 the first letter of the solution word was revealed after 8 seconds and it was followed by dots representing the missing letters. For example c.. (cat). In the third condition 60 to 75% of the letters of the solution word were revealed. The revealed letters always included the first letter. For example c.t (cat) or t..le (table). Presenting the hints in the second and third condition was similar to the manner Sandkühler and Bhattacharya (2008) used in their research. In the fourth condition the whole solution word was revealed after 8 seconds. Luo and Niki (2003) also revealed the whole word in their study if the participant did not know the correct solution.

2.2.2 The Experiment. In order to investigate insight and the effects of giving different kinds of hints, it was necessary to generate a new testing program. This was done by using E-Prime (Schneider, Eschman & Zuccolotto, 2002) which is often used for programming in behavioral sciences.

The sequence of events in this experiment was inspired by Jung-Beeman et al. (2004). The time lines used in this experiment are presented in Figures 1 and 2. First the words 'Samengestelde woord' ('Compound word') were presented in the middle of the computer screen for 2 seconds (A). Then the three problem words were presented next to each other (B and B1). In condition 1 the words stayed in sight until the subject bimanually pressed the spacebar which meant that she or he knew the solution or until the 30 second time limit had passed (see Figure 1). In conditions 2, 3 and 4 the problem words were first presented alone for 8 seconds (B1) and then for 10 seconds together with the hint that appeared below the problem words (B2). In both cases if the subject had pressed the button or if the time limit was elapsed, the text 'Wat is de oplossing?' ('The solution?') appeared on the monitor (C). The solution was given verbally and if the subject did not know the answer, she or he was instructed to verbalize that as well.

Figure 1

The Time Line of Events in the Testing Procedure in Condition 1 without a Hint.

Figure 2

The Time Line of Events in the Testing Procedure in Conditions 2, 3 and 4 with a Hint.

The next event was 'Inzicht?' ('Insight?') and the participants were asked if they had experienced insight (D). The letters 'z' and 'm' on the keyboard were colored green, the letters 'a' and 'l' were yellow and numbers '1' and '0' were red. If the subjects had experienced insight, they were instructed to bimanually press the green buttons. If they were not sure to have experienced it, they pressed the yellow buttons and they were instructed to press the red buttons if they were convinced not to have experienced insight. Giving the buttons a color was supposed to make remembering the meaning of the buttons easier and to encourage the simultaneous bimanual button press. After the question about insight the subjects were notified that the trial was finished and that the next one would start as soon as the subjects pressed the spacebar (E). The subjects were instructed to ask questions or to have a drink at this time before beginning with the new trial to avoid noise in the EEG-data. In the study by Jung-Beeman et al. (2004) time limits in verbalizing the solution and giving a rating about the existence of insight were used but in this study the participants were given unlimited time to avoid hasty decisions. A pilot was conducted to test the program before the actual testing and we noticed that the fixed times would be too short, making the subjects hurry and not give enough time to make the decision. The data of the pilot is not included in the analysis.

2.3 Procedure

To start the actual experiment the subject’s head was measured and the right size cap was fitted. The experiment was first explained to the subjects with the help of pictures of the actual program. When the subjects had read the instructions they were able to practice the use of the program with four English trials, one for each condition. These trials were also used in de study by Bowden en Jung-Beeman (2003). The chosen problem words were ‘cream’, ‘skate’ and ‘water’ and the solution word ‘ice’. The other examples were ‘dream’, ‘break’, ‘light’ (‘day’), ‘boot’, summer’, ground’ (‘camp’) and ‘age’, ‘mile’, ‘sand’ (‘stone’). 44 to 90 % of the subjects in the experiment by Bowden en Jung-Beeman (2003) solved these CRA-items within 30 seconds. These selected items were considered to be familiar English words to the Dutch participants. At any time the participants were able to ask questions and when everything was clear, the experiment started. The experimenter told the participants to ask questions or take a sip of water only when they saw the text ‘Deze trial is afgelopen’ (‘This trial is finished’) on the screen in the end of each trial (see E in Figures 1 and 2). This was to avoid excess noise in the EEG-files. When the experiment was finished the subjects were given the opportunity to get their picture taken and they were able to wash their hair.

2.4 EEG-recording

A 64-channel electrocap was used in this experiment employing sintered Ag/AgCL electrodes which included all 10-20 locations (Oz, O1/2, Pz, P3/P4, P7/8, CPz, CP3/4, TP7/8, Cz, C3/4, FT7/8, Fz, F3/4, F7/8, FP1/2 plus POz, PO3/4, PO7/8, P1/2, P5/6, CP1/2, CP5/6, C1/2, C5/6, T7/8, FCz, FC1/2, FC3/4, FC5/6, F1/2, F5/6, AFZ, AF3/4, AF7/8, FPz). Eye blinks and eye movements were measured with four electro-oculogram (EOG) electrodes (VEOG; above and below the left eye) (HEOG; at the outer canthus of each eye). A ground electrode was attached on the subjects' forehead. The EEG was DC-recorded at 500 Hz/channel with 0.1-100 Hz filter settings and average referenced (Brainrecorder, Brainproducts, GmbH, Munich, Germany). Impedance was kept below 5 kO.

2.5 Behavioral Analysis

Behavioral data was converted to PASW Statistics 18 (SPSS Inc., Chicago, United States of America). The means and standard deviations for all conditions were calculated for the trials where the subjects had reported having experienced insight, no insight or neutral. Next within each condition means and standard deviations were calculated for trials with reported insight or no insight. Within the conditions the means and standard deviations of the non-contaminated trials were also calculated.

2.6 EEG-analysis

The data was analyzed using Brain Vision Analyzer (version 1.05.0001, Brain Products, GmbH, Munich, Germany). First the EEG-data was filtered. The upper cut off was set to be 70 and the lower cut off 1 with a slope of 48 in both. The notch filter was 50 Hz. Second, the data was segmented according to the condition and whether or not the subject had experienced insight and inspected for artifacts. The data containing the trials with neutral insight response were not included in this analysis. All groups of segments started 1500 ms before the subject pressed the button and ended 500 ms after that. When the subjects knew the solution in conditions with a hint already in B1 (see Figure 2) before the hint was presented and pressed the spacebar, the program first revealed the hint (B2) before the subjects could verbalize their solution. All trials wherein the subjects had not used the hint (e.g. subjects knew the solution before the hint was presented) were deleted. Also the trials wherein the reaction time between B2 and C was <0.2 second were deleted because we could not be certain whether the subjects actually had used the hint or discovered the solution without the hint. It was very important to have exclusively pure data for this research to be able to compare the different conditions with and without a hint. All trials with an incorrect solution were also deleted. If the subjects gave an alternative solution, the correctness was controlled and the alternative solution was approved. The correct alternative solutions are reported in Annex 1 alongside the correct solutions.

Next the T8 and PO8 channels were selected because Jung-Beeman et al. (2004) found differential neural activity for insight- and non-insight solutions at these locations. The power spectra in alpha- and gamma frequency bands were computed. However, because of uncertainty with respect to the precise alpha- and gamma frequency, it was decided to explore the following frequency bands : alpha-1 (9.50-10.50 Hz; mean 10 Hz, bandwidth 1 Hz), alpha-2 (9.00-11.00 Hz; mean 10 Hz, bandwidth 2 Hz), alpha-3 (8.00-12.00 Hz; mean 10 Hz, bandwidth 4 Hz), gamma-1 (38.00-40.00 Hz), gamma-2 (40.00-50.00 Hz) and gamma-3 (38.00-50.00 Hz). Jung-Beeman et al. (2004) have found an alpha-activity approximately at 9.8Hz and a burst of gamma-activity at 39Hz. That explains the choice of the first alpha- and gamma frequency. The following frequencies were explorative. Averages were scored to each power for each participant and grand averages for all subjects were calculated. Difference waves for insight minus non-insight averages like was done by Jung-Beeman et al. (2004, see Figure 3) could not be determined because there were not enough reliable non-insight solutions left after deleting possibly contaminated trials (in total 552 deleted trials out of 787 non-insight trials, compared to 568 deleted trials out of 1635 trials with insight). Therefore trials containing non-insight solutions could not be analyzed.

Inspecting the figure of alpha and gamma-power (see Figure 3) in the study by Jung-Beeman et al. (2004) learns that a certain turning point in the data lies approximately at -300ms, i.e., the point where the alpha decline in the gamma increase coincide. However, a similar point in the present study may differ from the observation by Jung-Beeman et al. (2004), therefore three different time windows were chosen for the analysis in this experiment. The first time window lasted from -400ms to -100ms (A) and from -100ms to +200ms (B), the second one from -300ms to -100ms (A) and from -100ms to +100ms (B) and the third window from -400ms to -200ms (A) and from -200ms to +/-0ms (B). In each case the mean power in the A part was compared to the mean power in the B part. In Figure 4 the time windows are presented together with the grand averages for the electrodes PO8 and T8. In the figure the first time window is colored green, the second one yellow and the third window red. Averages were calculated from the grand averages for the first sections (A's) and for the last sections (B's). These figures were converted to PASW Statistics 18 for the statistical analysis.

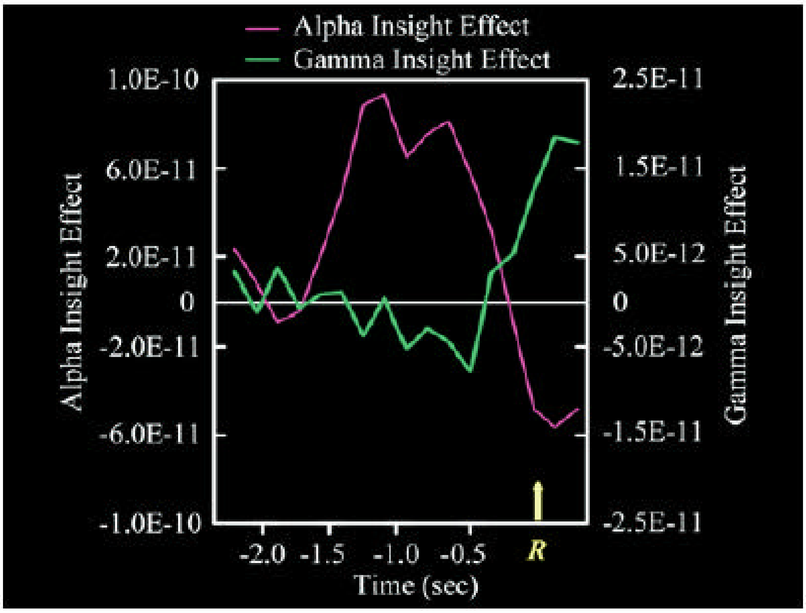

Figure 3:

The Fluctuations of the Alpha-power and Gamma-power calculated with the Difference Waves Iinsight minus Non-insight) in Jung-Beeman et al. (2004).

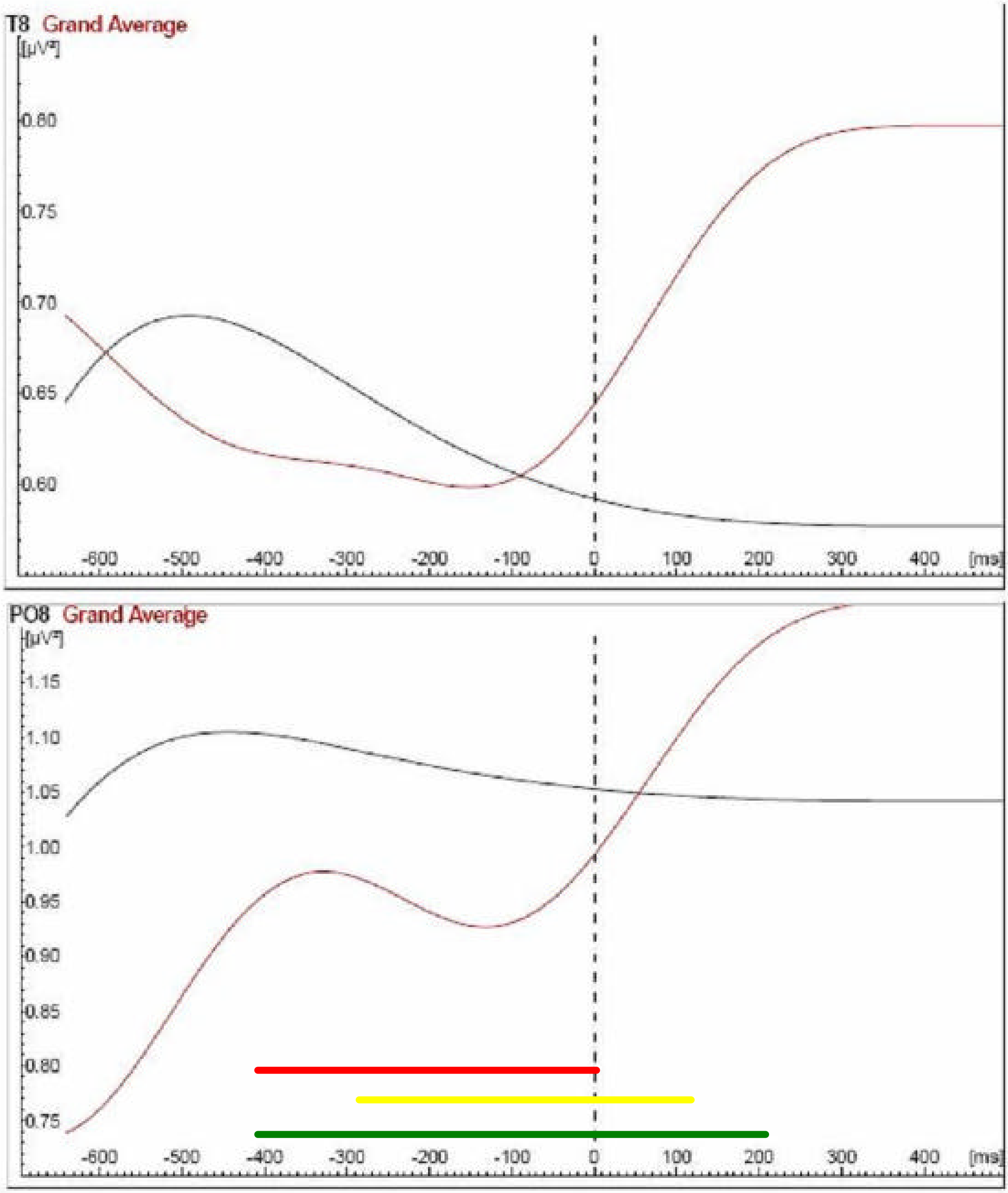

Figure 4

Grand Averages for Alpha-power (alpha-1, black line) and Gamma-power (gamma-1, red line) in T8 (upper figure) and PO8 (lower figure) with the three Time Windows. Green line (under) represents time window -400ms to 200ms, yellow Line represents the Time Window -300ms to 100ms and the red Line represents the Time Window -400ms to 0ms. All Time Windows are divided into two identically long Parts, the first (A) and second Part (B). At 0ms the Subjects indicated that they knew the Solution.

2.7 Statistical Analysis

First a Paired-Sample T-Test was performed with A and B as independent variables and power in a1, a2, a3, ?1, ?2 and ?3 as dependent variables. The analyses were performed at the electrode positions PO8 and T8 for each alpha and gamma-band in condition 1 to test the first hypothesis.

Second, General Linear Models (GLM) with Repeated Measures was calculated to test the second hypothesis. In the 2x2 design there was a Within-Subject factor AB with 2 levels, namely the first (A) and second (B) average of the grand averages. The second Within-Subject factor AHA had also 2 levels, namely condition 1 and a condition with a hint. Condition 1 was tested together with condition 2 (1&2), condition 3 (1&3) and condition 4 (1&4). The measured power in alpha (a1, a2 and a3) and gamma (?1, ?2 and ?3) at the electrodes PO8 and T8 were the dependent variables. The analyses were performed for each alpha and gamma-band separately.

3. RESULTS

3.1 Behavioral Performance

The subjects reported having experienced insight in 58% (M=81.75, SD=17.63, see Table 1) of all the trials in this experiment, no insight in 28% (M=39.35, SD=11.66) of the trials and reported 'neutral' (e.g. the subjects were not sure whether or not they had experienced insight) in 14% (M=18.90, SD=11.83) of the trials. The relevant means and standard deviations are presented in Table 1. The subjects gave an incorrect answer on average in 4% (M=5.30, SD=6.19) of the trials. 35% of the reported insight trials were deleted on grounds of possible contamination (e.g. the subject had not used the hint in conditions 2, 3 and 4) leaving 65% (M=53.35, SD=15.29) of the insight trials for the final analysis. As much as 70% of the trials where the subjects had reported having experienced no insight had to be deleted leaving only 30% (M=11.75, SD=12.2) pure trials. Because of the lack of enough reliable non-insight trials these were not used in the analysis.

In condition 1 there were on average 16.80 (SD= 5.13, see Table 1) trials solved with insight and after deleting the contaminated trials 15.00 (SD=4.83) trials left for the analyses. In the same condition there were 14.90 (SD=4.59) trials solved without insight and only 0.70 (SD=1.34) trials left after deleting the contaminated trials. In the second condition the subjects solved on average 20.15 (SD=4.39) trials with insight and after deleting there were 12.05 (SD=3.62) trials left. There were 11.95 (SD=3.10) trials solved without insight but only 0.80 (SD=2.02) left after deleting. In condition 3 there were on average 26.20 (SD=7.16) trials solved with insight and 3.20 (SD=5.85) trials solved without insight. After deleting the contaminated trials there were 18.20 (SD=7.25) insight and 1.30 (SD=4.90) non-insight trials left. In the fourth condition subject solved on average 18.60 (SD=8.09) trials with insight and 9.30 (SD=7.73) trials without insight. Without the contaminated trials there were 8.10 (SD=7.64) trials with insight and 8.95 (SD=7.44) trials without insight.

Table 1

The Means and Standard Deviations of the Subjects' Behavioral Performance. The total Number of Trials reported with Insight, Non-insight and 'Neutral'. The numbers of Insight- and Non-insight Trials after deleting the Contained Trials displayed according to the Condition.

	Mean	SD
Trials with reported insight	81.75	17.63
Insight trials after deleting	53.35	15.29
Condition 1	15.00	4.83
Condition 2	12.05	3.62
Condition 3	18.20	7.25
Condition 4	8.10	7.64
Trials reported neutral	18.90	11.83
Trials with reported non-insight	39.35	11.66
Non-insight trials after deleting	11.75	12.20
Condition 1	0.70	1.34
Condition 2	0.80	2.02
Condition 3	1.30	4.90
Condition 4	8.95	7.44
Incorrect solutions	5.30	6.19

3.2 EEG-results

The results of the Paired-Samples T-Test testing the first hypothesis are presented in Table 2 for each time window, electrode position T8 and PO8 and alpha- and gamma-bands. In Figures 5, 6 and 7 the increase and decline in power in alpha and gamma-band at the electrodes PO8 and T8 is illustrated for condition 1. The results for GLM Repeated Measures testing the second hypothesis are presented for each time window and for both electrode positions T8 and PO8 in Tables 3 to 8. All relevant results for main effects are presented for AB-main effects in Table 9 and for AHA-main effects in Table 10 according to the time window and power in alpha and gamma. Only results $P<0.10$ are presented. In

Figure 8 the relevant averages for A and B in the first time window are presented. In figures 9 and 10 the averages for the second and third time window are presented.

3.2.1 Results Paired-Samples T-Test. All results of the Paired-Samples T-Test are presented in Table 2. In the first time window (-400ms to 200ms) at the electrode T8 with alpha-1 is the difference between A and B almost significant (T=.054, see Figure 5). With alpha-2 at PO8 is B significantly greater than A (T=.014). In the second time window (-300ms to 100ms) is the difference between A an B with alpha-1 at T8 almost significant (T=.052, see Figure 6) and with alpha-2 at PO8 is B significantly greater than A (T=.047). In the third time window (-400ms to 0ms) at T8 with alpha-1 is A greater than B (T=.061, see Figure 7) but it fails to reach significance.

Table 2

T-values and Significance of the Differences between the First and Second Part of the Time Windows (A and B) at the Electrodes T8 and PO8 for each Power in Alpha and Gamma.

		-400ms to 200ms		-300ms to 100ms		-400ms to 0ms	
		T-value	Sig.	T-value	Sig.	T-value	Sig.
T8	a 1	2.052	.054	2.075	.052	1.990	.061
	a 2	-1.805	.087	-1.789	.090	-0.420	.679
	a 3	-0.039	.969	-1.086	.291	0.074	.942
	? 1	-1.547	.138	-1.273	.218	0.000	1.000
	? 2	0.190	.851	-0.342	.736	-0.053	.959
	? 3	-0.014	.989	-0.332	.744	-0.658	.518
PO8	a 1	1.139	.271	1.143	.267	1.081	.293
	a 2	-2.706	.014	-2.129	.047	-0.254	.802
	a 3	0.127	.900	0.795	.436	-0.984	.338
	? 1	-0.566	.578	-0.455	.661	0.168	.869
	? 2	-0.434	.669	-0.048	.962	-0.665	.514
	? 3	-0.376	.711	-0.141	.890	-0.929	.365

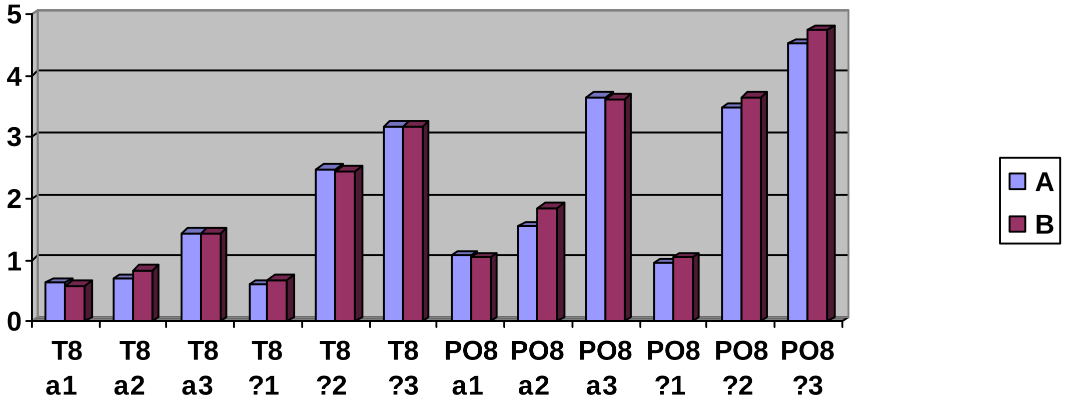

Figure 5

Averages for the First and Second Part of the Time Window (A and B) in condition 1 for each Alpha and Gamma-Band for Time Window -400ms to 200ms.

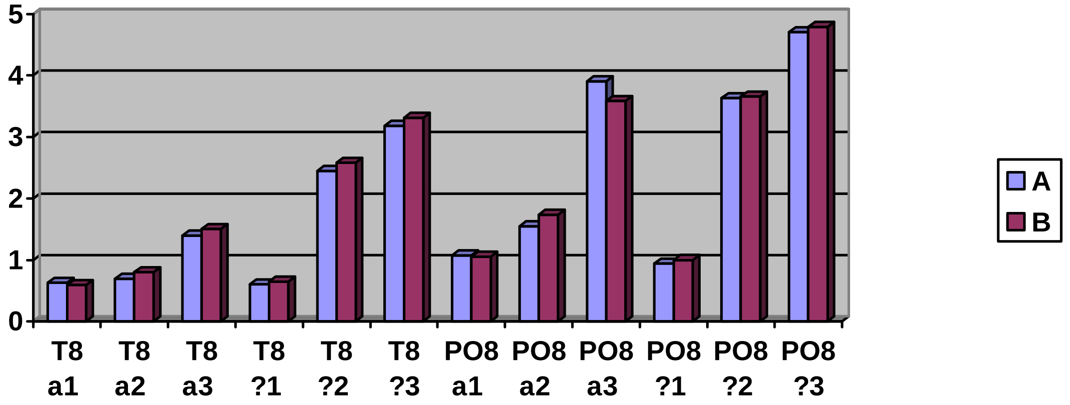

Figure 6

Averages for the First and Second Part of the Time Window (A and B) in condition 1 for each Alpha and Gamma-Band for Time Window -300ms to 100ms.

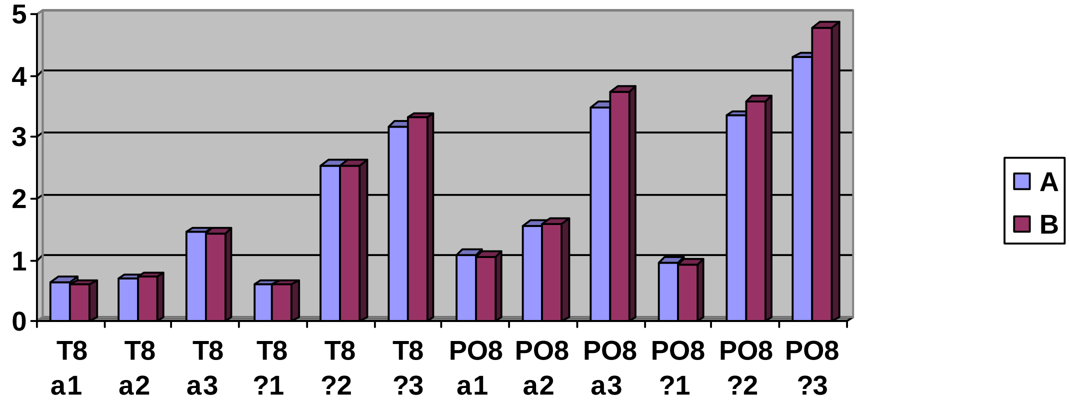

Figure 7

Averages for the First and Second Part of the Time Window (A and B) in condition 1 for each Alpha and Gamma-Band for Time Window -400ms to 0ms.

3.2.2 Alpha GLM-Results. In the first time window (from -400ms to 200ms) there was a significant main effect of AB at T8 with alpha-1 for 1&2 (F(1,19)=8.11, P=.010), 1&3 (F(1,18)=5.74, P=.028) and 1&4 (F(1,15)=12.18, P=.003, see Table 3). In all cases the power in alpha was declining (see Figure 8). At the PO8-electrode there was no main effect of AB with alpha-1 in 1&2 or 1&3 but in 1&4 there was an AB-main effect (F(1,15)=4.55, P=.050, see Table 4). The power was declining (see Figure 8). There was a main effect of AB in 1&2 at T8 with alpha-2 but it bordered on significance (F(1,19)=3.52, P=.076). With alpha-2 at T8 there was an AB-main effect in 1&3 (F(1,18)=6.77, P=.018, see Table 3) and there was no main effect of AB in 1&4. In both main effects of AB in 1&2 and 1&3 with alpha-2 the power in alpha was increasing (see Figure 8). In alpha-2 there was a main effect of AB at PO8 in 1&2 (F(1,19)=9.19, P=.007, see Table 4), 1&3 (F(1,18)=10.20, P=.005) and 1&4 (F(1,15)=8.13, P=.012). Here the power in alpha was increasing (see Figure 8). There were no main effects of AB with alpha-3 at either of the electrodes T8 or PO8. An AHA-main effect was found in alpha-1 at T8 in 1&3 (F(1,18)=4.48, P=.048, see Table 3). The activity in alpha was greater in condition 1 (see Table 3). There were no more main effects of AHA in this time window. At PO8 there was an AB*AHA-interaction effect with alpha-3 in 1&2 but it failed to reach significance (F(1,19)=3.37, P=.082).

Tabel 3

*The Significant Main Effects of the Averages (AB) and the Conditions (AHA) and the Interaction AB*AHA in the Time Window -400ms to -100ms and -100ms to +200ms at T8.*

		T8		
Condition		AB	AHA	AB*AHA
1&2	a 1	F(1,19)=8.105, P=.010 (A>B)		
	a 2	F(1,19)=3.522, P=.076 (A<B)		
	a 3			
	? 1			
	? 2			
	? 3			
1&3	a 1	F(1,18)=5.742, P=.028 (A>B)	F=4.484, P=.048 (1>3)	
	a 2	F(1,18)=6.768, P=.018 (A<B)		
	a 3			
	? 1			
	? 2			
	? 3			
1&4	a 1	F(1,15)=12.184, P=.003 (A>B)		
	a 2			
	a 3			
	? 1			
	? 2			
	? 3			

Tabel 4

*The Significant Main Effects of the Averages (AB) and the Conditions (AHA) and the Interaction AB*AHA in the Time Window -400ms to -100ms and -100ms to +200ms at PO8.*

		PO8		
Condition		AB	AHA	AB*AHA
1&2	a 1			
	a 2	F(1,19)=9.185, P=.007 (A<B)		
	a 3			F=3.371, P=.082
	? 1			
	? 2			
	? 3			
1&3	a 1			
	a 2	F(1,18)=10.197, P=.005 (A<B)		
	a 3			
	? 1			
	? 2			
	? 3			
1&4	a 1	F(1,15)=4.554, P=.050 (A>B)		
	a 2	F(1,15)=8.128, P=.012 (A<B)		
	a 3			
	? 1			
	? 2			
	? 3			

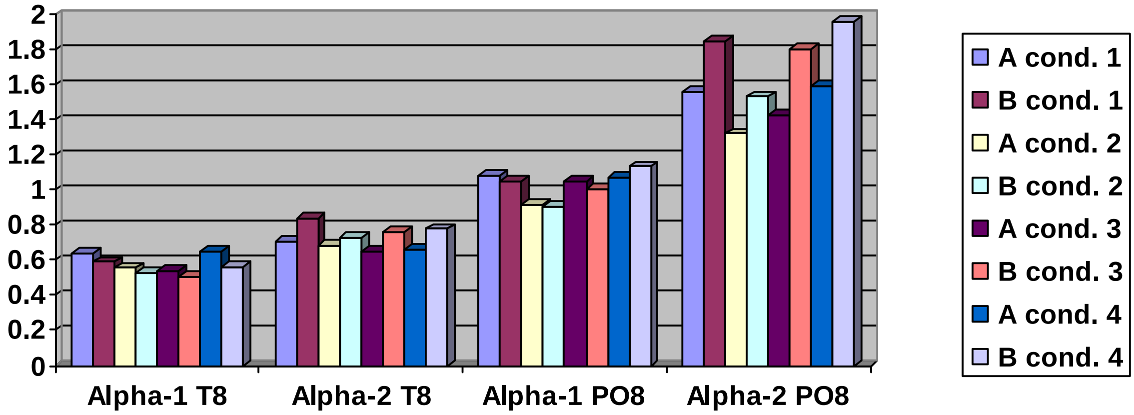

Figure 8

The relevant Averages of the First and Second Part (A and B) for Alpha-1 and Alpha-2 for Time Window -400ms to 200ms

In the second time window (from -300ms to 100ms) at the T8-electrode there was a main effect of AB with alpha-1 in 1&2 (F(1,19)=8.24, P=.010), 1&3 (F(1,18)=5.83, P=.027) and 1&4 (F(1,15)=12.46, P=.003, see Table 5). In all cases the alpha-power was declining (see Figure 9). There were no significant main effects of AB with alpha-1 at PO8 in 1&2 or in 1&3 but in 1&4 we found a main effect of AB with alpha-1 (F(1,15)=4.77, P=.045, see Table 6). The power in alpha was declining (see Figure 9). The main effect of AB in 1&2 at T8 with alpha-2 bordered on significance (F(1,19)=3.50, P=.077). In 1&3 there was a main effect of AB found at T8 with alpha-2 (F(1,18)=7.30, P=.015, see Table 5). The power in alpha was increasing (see Figure 9). There were no significant results in 1&4. A main effect of AB was found at PO8 with alpha-2 in 1&2 (F(1,19)=6.90, P=.017), 1&3 (F(1,18)=8.05, P=.011) and 1&4 (F(1,15)=5.54, P=.033, see Table 6). In all cases the alpha-power was increasing (see Figure 9). There were no results for a main effect of AB with alpha-3. There was a main effect of AHA at the electrode T8 with alpha-1 in 1&3 (F(1,18)=4.44, P=.049, see Table 5) and condition 1 was larger than condition 3 (see Table 5). There was also an AHA-main effect at PO8 with alpha-3 in 1&2 (F(1,19)=3.65, P=.071, see Table 6) but it was not significant. There were no more main effects of AHA in this time window. An AB*AHA interaction effect was found at PO8 in 1&2 with alpha-3 (F(1,19)=3.847, P=.065) but it failed to reach significance.

Tabel 5

*The Significant Main Effects of the Averages (AB) and the Conditions (AHA) and the Interaction AB*AHA in the Time Window -300ms to -100ms and -100ms to +100ms at T8*

			T8	
Condition		AB	AHA	AB*AHA
1&2	a 1	F(1,19)=8.239,P=.010 (A>B)		
	a 2	F(1,19)=3.498, P=.077 (A<B)		
	a 3			
	? 1			
	? 2			
	? 3			
1&3	a 1	F(1,18)=5.826, P=.027 (A>B)	F=4.443, P=.049 (1>3)	
	a 2	F(1,18)=7.301, P=.015 (A<B)		
	a 3			
	? 1			
	? 2			
	? 3			
1&4	a 1	F(1,15)=12.459, P=.003 (A>B)		
	a 2			
	a 3			
	? 1			
	? 2			
	? 3			

Tabel 6

*The Significant Main Effects of the Averages (AB) and the Conditions (AHA) and the Interaction AB*AHA in the Time Window -300ms to -100ms and -100ms to +100ms at PO8*

			PO8	
Condition		AB	AHA	AB*AHA
1&2	a 1			
	a 2	F(1,19)=6.901, P=.017 (A<B)		
	a 3		F=3.651, P=.071 (1>2)	F=3.847, P=.065
	? 1			
	? 2			
	? 3			
1&3	a 1			
	a 2	F(1,18)=8.047, P=.011 (A<B)		
	a 3			
	? 1			
	? 2			
	? 3			
1&4	a 1	F(1,15)=4.773, P=.045 (A>B)		
	a 2	F(1,15)=5.539, P=.033 (A<B)		
	a 3			
	? 1			
	? 2			
	? 3			

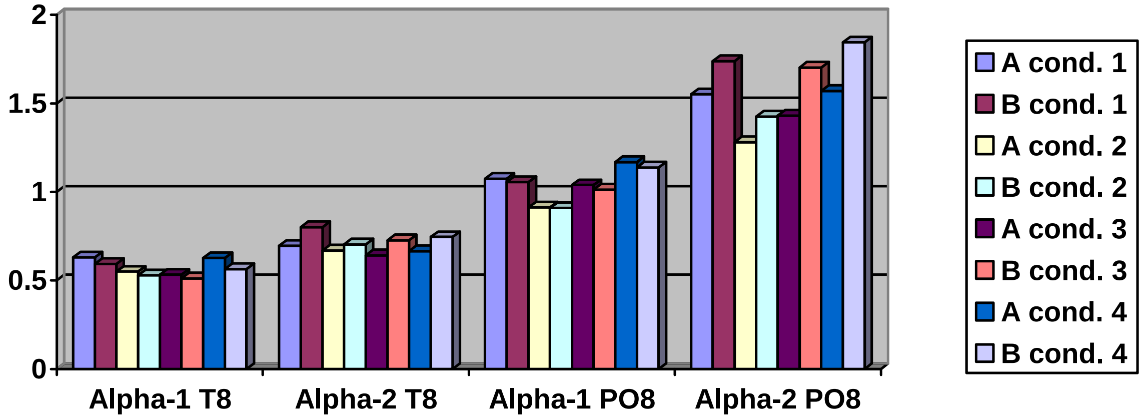

Figure 9

The relevant Averages of the First and Second Part (A and B) for Alpha-1 and Alpha-2 for Time Window -300ms to 100ms

In the third time window that lasted from -400ms to 0ms at the T8-electrode a main effect of AB with alpha-1 was found in 1&2 (F(1,19)=7.67, P=.012), 1&3 (F(1,18)=5.46, P=.031) and 1&4 (F(1,15)=11.58, P=.004, see Table 7). In all cases the power in alpha was declining (see Figure 10). A main effect of AB was found at PO8 in 1&4 with alpha-1 (F(1,15)=3.967, P=.065, see Table 8) but no main effects were found in 1&2 or in 1&3. There were no main effects of AB in alpha-2 or alpha-3. There was a main effect of AHA found at PO8 with alpha-3 in 1&2 (F(1,19)=3.699, P=.070, see Table 8) and also an AHA-main effect at T8 with alpha-1 in 1&3 (F(1,18)=4.46, P=.049, see Table 7). In both cases the power in condition 1 was greater than in the second or third condition.

3.2.3 Gamma GLM-Results. There were no significant results in the gamma-power in the time windows -400ms to 200ms and -300ms to 100ms. In the time window -400ms to 0ms there was a main effect of AB with gamma-1 at the electrode T8 in 1&4 (F(1,15)=3.92, P=.066, see Table 7). The power in gamma was declining and it also bordered on significance (see Figure 10). At PO8 a main effect of AHA (F(1,19)=4.18, P=.055, see Table 8) was found with gamma-2 in 1&2. Here the gamma-power in condition 1 was greater than in condition 2. There were no more significant results in the gamma-band.

Tabel 7

*The Significant Main Effects of the Averages (AB) and the Conditions (AHA) and the Interaction AB*AHA in the Time Window -400ms to -200ms and -200ms to 0ms at T8*

			T8	
Condition		AB	AHA	AB*AHA
1&2	a 1	F(1,19)=7.670, P=.012 (A>B)		
	a 2			
	a 3			
	? 1			
	? 2			
	? 3			
1&3	a 1	F(1,18)=5.456, P=.031 (A>B)	F=4.463, P=.049 (1>3)	
	a 2			
	a 3			
	? 1			
	? 2			
	? 3			
1&4	a 1	F(1,15)=11.581, P=.004 (A>B)		
	a 2			
	a 3			
	? 1	F(1,15)=3.923, P=.066 (A>B)		
	? 2			
	? 3			

Tabel 8

*The Significant Main Effects of the Averages (AB) and the Conditions (AHA) and the Interaction AB*AHA in the Time Window -400ms to -200ms and -200ms to 0ms at PO8*

			PO8	
Condition		AB	AHA	AB*AHA
1&2	a 1			
	a 2			
	a 3		F=3.699, P=.070 (1>2)	
	? 1			
	? 2		F=4.178, P=.055 (1>2)	
	? 3			
1&3	a 1			
	a 2			
	a 3			
	? 1			
	? 2			
	? 3			
1&4	a 1	F(1,15)=3.967, P=.065 (A>B)		
	a 2			
	a 3			
	? 1			
	? 2			
	? 3			

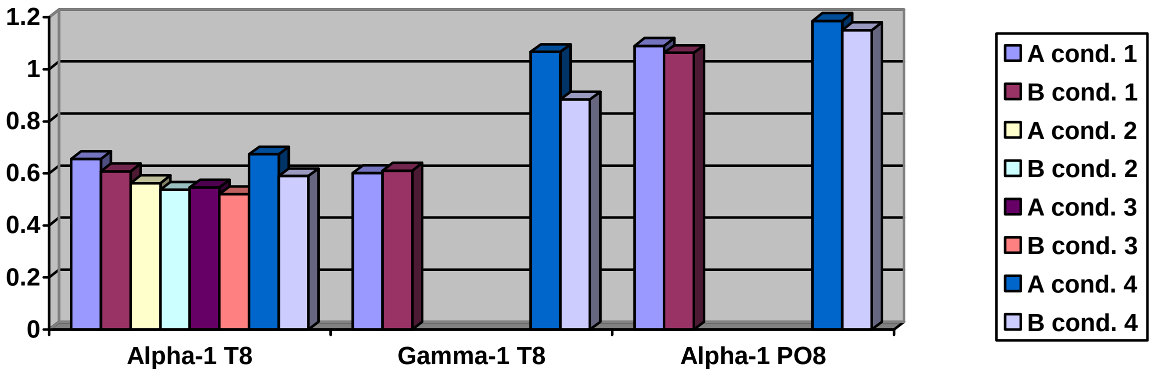

Figure 10

The relevant Averages of the First and Second Part (A and B) for Alpha-1 and Gamma-1 for Time Window -400ms to 0ms

Table 9

Summary of Significant Main Effects of the Averages (AB) in all Time Windows

	-400ms to 200ms	-300ms to 100ms	-400ms to 0ms
Alpha-1			
AB at T8	1&2 A>B	1&2 A>B	1&2 A>B
	1&3 A>B	1&3 A>B	1&3 A>B
	1&4 A>B	1&4 A>B	1&4 A>B
AB at PO8	1&2 A>B		
	1&4 A>B	1&4 A>B	1&4 A>B
Alpha-2			
AB at PO8		1&2 A<B	
	1&3 A<B	1&3 A<B	
	1&4 A<B	1&4 A<B	
AB at T8	1&3 A<B	1&3 A<B	
Gamma-1			
AB at T8			1&4 A>B

Table 10
Summary of Significant Main Effects of the Condition (AHA) in all Time Windows

	-400ms to 200ms	-300ms to 100ms	-400ms to 0ms
Alpha-1 AHA at T8	1&3 1>3	1&3 1>3	1&3 1>3
Alpha-3 AHA at PO8		1&2 1>2	1&2 1>2
Gamma-2 AHA at PO8			1&2 1>2

4. DISCUSSION

In this experiment we investigated a unique way of solving problems, namely insight. Insightful problem solving is characterized by a number of properties (Sandkühler & Bhattacharya, 2008). In mental impasse the process of solving a problem does not proceed and it can be caused by different constraints created by our past experiences biasing the problem representation (Knoblich et al., 1999). When the impasse is broken after relaxing the constraints, the solution appears suddenly and the solver experiences an illuminating aha-experience (Jung-Beeman et al., 2004).

In the literature the breaking of one’s mental impasse has been associated with alpha-band activity. Jung-Beeman et al. (2004) argued that they had found an indirect correlate of unconscious solution-related processes in the alpha-band activity. Sandkühler and Bhattacharya (2008) found differences in the alpha-activity that indicated an inhibition in the right temporal regions of the brain. They also suggest that the found alpha-effect might be related to unconscious processing of the solution. Whereas the breaking of mental impasse has been associated with activity in the alpha-band, the subjective aha-experience has been associated with activity in the gamma-band. Jung-Beeman et al. (2004) argue that the burst of gamma-activity is a direct correlate of the sudden awareness of the solution. Sandkühler and Bhattacharya (2008) suggest that the observed gamma-activity at parieto-occipital areas is a correlate of the suddenness of the solution. They suggest that the gamma-activity reflects retrieval processes when the solvers retrieve the correct solution word from their memory.

The subjects in this experiment completed a verbal insight task and now the behavioral results are compared with the results of a similar experiment by Jung-Beeman et al. (2004). In the fMRI-experiment of Jung-Beeman et al. (2004) 59 % of the presented problems were solved correctly. The participants rated having experienced insight in 56 % of the problems, no insight in 41 % and ‘other’ in 2 %. In the EEG-experiment 46 % of the problems were correctly solved. The percentage of problems solved with insight was higher (56 %) than problems solved without insight (42%). In our experiment the subjects reported having experienced insight in 58% of all the trials, no insight in 28% and 'neutral' in 14% of the trials. The subjects gave only 4% incorrect solutions. Because of different methods used in these two studies it is difficult to compare the data from these two experiments with each other but it seems that in our experiment there were less insight trials and more non-insight trials deleted when compared to the data presented by Jung-Beeman et al. (2004). The subjects also reported more 'neutral' trials in the present study than in the study by Jung-Beeman et al. (2004).

Next, we turn to the EEG-results of this experiment. The first main goal of this experiment was to replicate a part of the experiment done by Jung-Beeman et al. (2004) to identify the neural correlates of insightful problem solving. We expected to find an increase in the gamma-activity and a decline in the alpha-power approximately 0.3 second before the subjects have reported having experienced insight when no hint was provided. We tested this in the condition without a hint. In all time windows, the power in alpha (a1; 9.50-10.50 Hz) was declining over time at the electrode T8. Jung-Beeman et al. (2004) also found a decline in the alpha-band. In an other alpha-band (a2; 9-11 Hz) we found increasing power at the electrode PO8 in the time windows exceeding the moment the subjects had indicated that they knew the solution (-400ms to 200ms and in -300ms to 100ms), suggesting that the power in this frequency band of alpha keeps rising. This was unexpected because Jung-Beeman et al. (2004) did not find an increase in the alpha-band activity. On the other hand Fink and Neubauer (2006) found lower levels of cortical arousal that was shown by increases in alpha-power (7-13Hz) when a pre-stimulus reference interval was compared to an activation interval 1250ms to 250ms before their subjects had indicated to have a creative idea. Though the results bordered on significance "the alpha-power was more pronounced in the anterior than posterior regions of the brain." (p.50, Fink & Neubauer, 2006). They argue that it might reflect a reduced state of active information processing. In this experiment there were no significant results found in the gamma-band activity in either of the electrode positions or time windows in the condition where no hint was provided suggesting that we were not able to find gamma-band activity reflecting the suddenness of the solution similar to which was found by Jung-Beeman et al. (2004). We were however able to replicate the decline in alpha-band activity reflecting the breaking the mental impasse that was also found by Jung-Beeman et al. (2004) and Sandkühler and Bhattacharya (2008).

The second goal of this experiment was to explore the role of giving different types of hints on the breaking of one's mental impasse and the subjective aha-experience. In the literature different types of hints have been used while the effects of providing hints have never been investigated so far. Sandkühler and Bhattacharya (2008) provided the subjects a hint if they had encountered mental impasse or if the time limit had passed. Two types of hints (only the first letter or 60 to 75% of the letters of the solution word were revealed) were given randomly and no distinction was made which type was used. Other authors (Luo & Niki, 2003; Mai et al., 2004) have revealed the correct solution for 2 seconds. Using this type of hint can result in a different insight-experience than when the solution is not or only partly revealed. Ormerod, MacGregor and Chronicle (2002) argued together with Luo and Niki (2003) that insight stimulated by a hint results in the same kind of insight-experience as without one. This is an important reason to investigate the differences providing a hint can have on the functioning of the brain. Because no studies have been conducted comparing trials with a hint to trials without one, there was no certainty in which trials the activation in the brain is stronger.

Exploring the effects of giving different types of hints, the main effects of the condition (AHA) reflect the differences between the conditions that are not time related and the main effects of the averages (AB) reflect the time-related differences within the conditions that are compared. First we discuss the main effects of the condition. We found a significant main effect of the condition (AHA, see Table 10) in the alpha-band (a1; 9.5-10.5Hz) at the electrode T8 in conditions 1 and 3 in all time windows. The average power in alpha in the condition without a hint was greater than the average power in the condition wherein 60 to 75% of the letters of the solution word were revealed after 8 seconds. The measured activity in the alpha-band was affected whether a hint was given or not suggesting that there is a noticeable difference in the brain states related to breaking the mental impasse. There was more activity related to breaking the impasse when no hint is given. Besides the main effect in the alpha-band there was also a significant main effect in the gamma-band activity reflecting the suddenness of the solution. Because of the lack of previous research it was possible that the experience of insight would be stronger without a hint because the person does not get any help acquiring the correct solution. On the other hand it could have also been be possible that the experience of insight is strengthened by unconscious processes that are reinforced by seeing the hint. In the third time window, from -400ms to 0ms, we found at the electrode PO8 that the average power in gamma (40-50Hz) was greater in the condition without a hint than in a condition wherein the first letter of the solution was revealed after 8 seconds. One's brain is more activated during the aha-experience when no hint is provided. According to our results giving a hint affects insightful problem solving and insight stimulated by a hint is fundamentally different than insight-experience without a provided hint in contrast to what was argued earlier (Ormerod, MacGregor & Chronicle, 2002; Luo & Niki, 2003).

Next the main effects of the averages are discussed revealing the time-related differences that can be found in both conditions that are compared. We found that the power in alpha (a1; 9.5-10.5 Hz) was declining at the electrode T8 in all time windows whether the condition without a hint was tested together with any of the conditions wherein a hint was provided (see Table 9 for an overview). It suggests thus that the state in the brain changes irrespective of whether or not a hint was given. We also found in all time windows a significant main effect of the averages at the electrode PO8 when the first condition, without a hint was tested together with the fourth condition wherein the correct solution was revealed after 8 seconds. The power in alpha (a1; 9.5-10.5 Hz) was declining which corresponds with the results of Jung-Beeman et al. (2004) who also found a decline in the alpha-band activity at the same electrode. With an other alpha-band frequency, alpha (a2; 9-11 Hz) at the electrode PO8 the power in alpha was significantly increasing instead of declining when the condition without a hint (condition 1) was tested together with conditions wherein 60 to 75% of the letters of the solutions word were revealed (condition 3) and wherein the correct solution was completely revealed (condition 4) after 8 seconds. These increases were significant in the first two time windows that exceeded the moment the subjects had indicated knowing the solution (at 0ms). We also found that the power in alpha-2 (9-11Hz) was significantly increasing at the electrode T8 when condition 1 was tested together with condition 3 in the time windows that exceeded the moment the subjects had pressed the button. These two results suggest that the power in alpha (a2; 9-11 Hz) keeps rising at PO8 and at T8 after the subjects have pressed the button because it was not significant in the time window that did not exceed 0ms. Fink and Neubauer (2006) found also an increase in the alpha-activity. Noteworthy in our results are the differences between the two alpha-frequencies. The power in alpha (a1; 9.5-10.5Hz) declines at the electrode T8 in all time windows and conditions and at the electrode PO8 in all time windows when conditions 1 and 4 are tested together. The power in alpha (a2; 9-11Hz) increases in the first and second time window, that both exceed the moment the subjects have pressed the button (at 0ms) at the same electrodes with only a slightly broader alpha-band (see Table 9).

The differences in the results between the different time windows are noticeable. In the time windows that went beyond the moment when the subjects had pressed the button (at 0ms) there were more significant main effects of the averages, reflecting the time-related similarities between the conditions than in the time window that lasted from -400ms until 0ms (see Tables 9 and 10). On the other hand the third time window had the most main effects of the condition reflecting the differences between the conditions.

After discussing the results of this experiment an interesting question raises. Does the insight in every day situations differ from the ’verbal insight’ as studied in this experiment. According to Jung-Beeman et al. (2004) it is possible that non-verbal insightful problem solving makes use of different cortical networks compared to a verbal task. Are the same patterns found in a more ecological valid experiment? This question could be studied in a way that the experience of insight resembles more the experience in real life. The challenge in more ecologically valid insight research is developing suitable materials into an artificial environment that often are used in neurological research. A required amount of measurement points are needed to get reliable results. Also the way of presenting the insight problems and the contents have to be recognizable to people with different education status, age and background. Materials resembeling the CRA-problems have to be created in order to investigate insight in alternative ways.

Insight can be used in the field of education in several ways. According to Bowden en Jung-Beeman (2007):“ A better understanding of the mechanisms of insight might allow people to develop their creativity to a fuller extent or to improve methods of education by allowing teachers to design lessons so that students are more likely to have insights.” (p.98). It has also been shown that in succesfull problem solving the ”aha-experience” can change one’s attitude towards learning into a more positive one (Liljedahl, 2005).

4.1 Conclusions

Our results reveal a declining alpha-band activity at the electrode T8 but no increasing gamma-activity replicating the results of Jung-Beeman et al. (2004) only partly. On the other hand we found several differences in the activation of alpha and gamma-band activity depending on whether or not a hint is provided during insightful problem solving. The alpha-band activity, that is associated with breaking one’s mental impasse, is stronger when no hint is given. It appears when people can not proceed in solving a problem and a hint is provided, there is less activity in the brain related to breaking one’s mental impasse than without a hint. We also found that experiencing insight is related to more activation when no hint is provided than when a hint is given. It suggests that the experience of insight is stronger when no hint is given. The results of this experiment show that providing people with hints have an effect on insightful problem solving. Knowing the advantages and disadvantages of giving hints during problem solving might in the future be implemented in the learning sciences to increase the progres in teaching and learning.

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ANNEXES

1. Compound words

Annex 1: Compound Words

Condition	Solution word (Problem words)
3	Aard (-beving, -gas, -appel)
4	Appel (-boor, aard-, -sap)
1	Auto (-baan, model-, speelgoed-)
4	Bad (-pak, -laken, -jas,)
2	Bak (zand-, -steen, -fiets)
2	Band (hals-, enkel-, -opname)
3	Bank (toon-, school-, -rekening)
4	Bar (-code, -kruk, koffie-)
1	Beeld (boeg-, -buis, -scherm)
2	Bel (deur-, zeep-, -toon)
1	Berg (-plaats, -kom, -pas)
3	Bier (-buik, tap-, -glas)
4	Blad (tafel-, schouder-, -zijde)
1	Blik (-schade, -voer, ogen-)
2	Bliksem (-actie, -bezoek, -flits)
3	Bloed (-druk, -suiker, -bank)
2	Bloem (boter-, -pot, -kool)
3	Blok (-letter, -fluit, ijs-)
4	Boek (studie-, -deel, -handel) (also possible: dag)
1	Boom (spoor-, -stam, -grens)
2	Bos (-bes, naald-, -bouw)
4	Boter (-ham, -koek, -vloot)
1	Bouw (-pakket, -jaar, -tekening)
3	Brand (zuur-, -weer, -stof)
4	Brief (ketting-, poeder-, -papier)
1	Bureau (politie-, -stoel, -blad) (also possible: auto, werk)
2	Cel (-deur, stam-, bloed-)
3	Dag (donder-, -licht, -boek,)
4	Deeg (brood-, pasta-, -rol)
2	Deel (-teken, -staat, -tijd)
1	Deur (klap-, -mat, -bel)
2	Dienst (avond-, -plicht, -jaar) (also possible: school)
3	Doel (eind-, -groep, -punt)
3	Draai (-tafel, -boek, -molen)
4	Druk (bloed-, -werk, -knop)
4	Dwang (-buis, -bevel, -arbeid)
1	Fiets (-band, -pad, -pomp)
2	Feest (-tent, -varken, -dag)
3	Fruit (-boom, -sap, -salade) (also possible: appel)

1	Gas (-stel, -pedaal, traan-)
2	Glas (wijn-, -bak, -wol) (also possible: steen)
4	Golf (-plaat, -lengte, -breker)
1	Groente (-boer, -soep, -tuin)
2	Hand (-rem -schoen, -schrift)
3	Ham (boter-, -vraag, -ster)
3	Hart (-slag, -aanval, -operatie)
4	Hoofd (-rol, -doek, -letter)
1	Hooi (-wagen, -koorts, -vork)
4	Huis (huur-, -dier, -arts)
2	Ijs (-blok, -baan, -beer)
3	Jaar (-rekening, -beurs, -gang)
1	Kast (meter-, kleding-, vitrine-)
1	Kamer (huis-, -plant, hotel-)
4	Kern (-energie, -wapen, -bom) (also possible: atoom)
2	Ketting (hals-, -brief, -roker)
1	Kijk (-cijfer, -doos, -operatie)
3	Klok (-huis, -slag, avond-)
3	Koffie (-kop, -pad, -filter)
4	Kom (soep-, vis-, -pas)
1	Kool (zuur-, -stof, -zaad)
2	Kop (-rol, -lamp, koffie-)
3	Kraam (markt-, -visite, kermis-)
4	Kroon (-steen, -kurk, -prins)
1	Kruis (-bes, -punt, -vogel)
2	Kunst (-werk, -schaats, -stof)
3	Land (-macht, -bouw, -schap)
4	Leiding (pijp-, -water, -gever)
4	Licht (-jaar, -val, -punt)
1	Lid (-staat, -maat, -woord) (also possible: werk)
2	Lijf (-rente, -spreuk, -wacht)
1	Lijn (bus-, spoor-, -vlucht)
3	Lucht (-ballon, -bel, -druk)
2	Maat (kleding-, -staf, -regel)
3	Melk (kokos-, -weg, -gebit)
4	Meter (gas-, kilo-, -kast)
4	Mis (-daad, -handeling, -verstand)
1	Moeder (-vlek, -taal, -dag)
1	Moes (appel-, -tuin, aal-)
2	Molen (koffie-, water-, wind-)

2	Nacht (-dier, -werk, -hemel)
3	Natuur (-talent, -monument, -ramp)
2	Net (vis-, -vlies, -werk)
3	Nood (adem-, -rem, -zaak)
3	Noot (muziek-, palm-, wal-)
4	Olie (olijf-, -bol, -verf)
4	Oog (-klep, -getuige, -schaduw)
1	Oor (-deel, -bel, -sprong)
1	Paal (flits-, lantaren-, -danser)
2	Pak (-ijs, -huis, -bon)
4	Pad (fiets-, gang-, loop-)
2	Pedaal (gas-, -emmer, -rem)
3	Peper (-molen, -noot, -munt)
3	Pijp (kachel-, water-, -leiding)
4	Pijn (hoofd-, -bestrijding, -boom) (also possible: luis)
1	Plak (tand-, -band, -boek)
2	Post (-kantoor, aftrek-, deur-)
3	Pot (spaar-, -vis, -lood)
4	Proef (-dier, -persoon, -tijd)
4	Punt (-dak, -komma, hoogte-)
1	Recht (kies-, -bank, -hoek)
2	Rol (behang-, deeg-, -gordijn)
1	Rug (-zak, -pijn, -klacht)
3	Schaal (fruit-, -model, -dier)
4	School (basis-, -bank, -bord)
1	Slag (veld-, -ader, -room)
1	Spel (bord-, woord-, kans-)
2	Spoor (-lijn, -boek, -weg)
2	Suiker (poeder-, -pot, -klont)
3	Stam (boom-, -gast, -cel)
2	Steen (bak-, molen-, natuur-) (also possible: water)
4	Stoel (strand-, -gang, klap-)
1	Stof (brand-, -doek, -zuiger)
3	Stop (-teken, -contact, -licht)
4	Straf (-blad, -bank, -punt)
1	Tafel (-zout, -kleed, -poot)
2	Tand (-plak, -pasta, -arts)
3	Teken (-tafel, vraag-, -film)
4	Tennis (tafel-, -bal, -elleboog)
3	Tijd (-perk, -bestek, -stip)
4	Tuin (-bouw, -broek, -man) (also possible: klus)

1	Veld (-sla, -werk, slag-)
2	Vloer (-tegel, dans-, werk-)
3	Voet (koe-, -bal, -noot)
4	Vogel (trek-, -nest, -griep)
1	Vraag (-prijs, -teken, -stuk) (also possible: hoofd)
1	Vuur (paas-, -toren, -pijl)
2	Water (-val, -stof, regen-)
3	Was (-machine, -rek, hand-)
2	Weer (-haak, -stand, -woord) (also possible: werk)
4	Wereld (-stad, -winkel, voetbal-)
3	Werk (-plaats, -woord, -tijd)
4	Wind (-kracht, -streek, -vlaag)
1	Winter (-slaap, -maand, -sport)
1	Zak (-geld, -doek, slaap-) (also possible: kamer)
2	Zand (-bak, -steen, -pad)
3	Zee (-hond, -man, -zout)
2	Zeil (grond-, -boot, -plank)
3	Ziekte (slaap-, -wet, infectie-)
4	Zout (tafel-, -molen, keuken-)
2	Zuur (kool-, maag-, -stof)