The Role of Working Memory in Creative Insight: Correlation analysis of working memory capacity, creative insight and divergent thinking

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Abstract

There is an ongoing debate about the components and processes of creativity. Within the subfield of creative insight, which is often considered to be the first measurable part of creativity, the role of working memory is discussed. Since creative insight appears to happen without conscious planning, the involvement of working memory appears to be limited; a hypothesis supported by several studies. However, there are several studies that support an opposing hypothesis. Namely, that creativity, including creative insights, is a form of divergent thinking and that working memory is needed for divergent thinking.

This study investigated the role of working memory in creative insight through correlation analyses between working memory capacity, the frequency of insight and divergent thinking ability. The study was performed using Operation Span to test working memory capacity, Compound Word Association to assess the frequency of insight, and a part of Torrance Test of Creative Thinking to assess the ability for divergent thinking.

The result show that working memory have little involvement in creative insight, but that it is involved in divergent thinking. This indicates that the nature of insight is different from divergent thinking.

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1 Introduction

Creativity, which at least to some part resides in the field of the unconscious, is a difficult research area. From the early days of psychology, scientists have struggled to agree on a definition of creativity that would satisfy all aspects. This in turn makes it difficulty to dive deeper in the concept. [1] [17] Another problem that creativity research has to deal with is not only that of how creativity should be defined but also what it consists of.

The research has undergone several shifts of focus throughout history, dependent on available research methods and trends in similar research areas. Today modern imaging technology allow us to find areas in the brain that are active during creative tasks, but more traditionally, creativity research was performed either by investigating extraordinarily creative people or through conducting creativity experiments that results in a quota for the creative ability.

The more traditional way to investigate creativity focused on individual differences, on the foundation that creative ability was one measurable cognitive function. Today most scientist agree that creativity is not a single cognitive function located in one brain area, but rather a combination of several different cognitive abilities that together creates different types of creative modes. [17] This is often refered to as *the Creative Cognition Approach* [21]. It is therefore not common today to investigate creativity by determining how creative a person is by using a quota. Modern creativity research focus on trying to find which cognitive functions that are important for creative abilities, rather than measuring creativity in individuals.

Since creativity is partly an unconscious phenomenon, the first problem is to define creativity. This in turn makes it more difficult to determine which cognitive functions play a part. Creative ability is not one single ability and it takes on different personalities in different fields; artistic creativity differs from scientific creativity, some forms of creativity needs previous knowledge and other forms seems to be more basic and appears without any deeper knowledge.

Creativity has traditionally been considered to be composed by divergent thinking, or associate thought. There is, however, a lot of discussion regarding the nature of creativity, since it is found to be both difficult to get good test data due to its flowing and seemingly varied structure. Divergent insight, or creative insights, is something that can easily be tested in what is called insight problems, which gives a creative dimension to more traditional problem solving.

Creative insight is often considered to be the first manifestation of creativity and is therefore one of the easiest parts of creativity to test with cognitive psychology methods. Creative insight, also called the *Aha!-experience*, is when the solution strategy is not obvious, but rather when an answer to a problem suddenly appears. In history many great ideas are suggested to be discovered by insights. Most famous is perhaps Archimedes who supposedly shouted "Eureka!" (translated: I found it!) when he realised how to measure the volume of an irregular object. He noticed that the volume of water pushed away of his body in the bathtub, was equal to his own body size. This immediate moment of clarity supposedly send him running naked through the streets. Even though

this might not be the real story, the phenomenon of instant clarity is very common even though it does not always have to be the solution to a grand problem such as that of Archimedes. A moment when a forgotten word suddenly comes to mind, may equally be an insight.

Insight is a small portion of creativity that it is possible to give a working definition and, therefore, researchable. There are plenty of tests and procedures in insight problem solving and the research is slowly mapping the cognitive functions underlying its nature. One of the most debated areas is the role of working memory in creative insight. The focus of the debate is that creative insight appears without conscious planning. Therefore, the involvement of working memory should be limited and other processes should be the contributing factors. On the other hand, it could also be the case that since creativity, insight included, is a phenomenon of divergent thinking, working memory is essential in order to create new concepts and combinations to solve the problem at hand.

It is this ongoing debate and the diverse research results on the role of working memory in creative processes, that underlie the purpose of this study.

1.1 Purpose

The purpose of this study is to investigate the possible correlation of working memory capacity(WMC) with the performance of creative insight and creative ability in the form of divergent thinking. The study is based on two fundamentally different hypotheses in order to determine which one provides a more probable explanation for the role of working memory in creative insight.

The first hypothesis is that working memory capacity is not a key component in creative insights. This is due to the fact that insights emerge as the result of unconscious and automatic processing and therefore does not need the conscious benefits from working memory.

The second, opposing hypothesis, is that insights are a form of divergent thinking and divergent thinking needs working memory. The first part of the hypothesis assumes that insight is a creative process, and creative processes are traditionally considered to involve divergent thinking. The second part of the hypothesis is motivated by the argument that, since divergent thinking, based on its defined nature, tries to combine concepts in new constellations and uses, it should be in need of working memory to store these concepts and relationships.

In order to investigate these hypotheses three tests will be performed. One test to determine the WMC, one to test the frequency of insights and finally one test to assess the ability for divergent thinking. The last test will be performed with the purpose of validating the divergent thinking nature of the insight test, as well as confirming that working memory is needed for divergent thinking.

2 Theory

2.1 Brief History of Creativity Research

There are a large number of questions to consider when performing studies in the field of creativity. Somehow, we have moments of insight and we also have a rather fixed idea of what creativity is on a conceptual level. For example, if a computer application is programmed to create a poem by randomly selecting words and order them based on semantic and linguistic rules, or if a web camera is set to take a photograph at a random moment most of us are unwilling to define either of these processes as creative, even if the result would pass a Turing test. Conceptually the human intuition seem to state that creative performance is a biological phenomenon that cannot be programmed.

Another example of our fixed idea of the nature of creativity is that if an insect walks in a highly advanced pattern in the sand, leaving an artistic painting, regardless of our astonishment, it is unlikely that the insect would be ascribed any creative talent. Apparently there are more limitations to the perceived concept of creativity than that of biology.

The first important note is intelligence. We are unwilling to give the insect creative ability because we perceive the pattern in the sand as a mere coincidence. It is not intelligent enough to produce creative results. It is suggested that, in order to be able to create something we would perceive as creative, the intelligence needs to exceed a certain threshold. This is referred to as *the Threshold Theory* [13]. In the separation between animals and humans this would be a satisfactory distinction, however, in humans it is found that high intelligence does not actually correlate with high creative ability when the threshold has been exceeded. Clearly there is more to the creative process than intelligence.

The role of consciousness is another interesting and rather controversial question that seems to be involved in creativity. On the one hand, creativity is very much defined by unconsciousness. In creative environments, you often here *we shall sleep on it* or *it came to me in a dream*, expressions that clearly indicate that creativity and the moment of insight is not a moment that we analytically prepare for, at least not in a conscious way. In fact, it rather seems that the preparations for a creative performance is done somewhat without our conscious effort and awareness. On the other hand, it is clearly something that requires consciousness at some level since we are so unwilling to ascribe this talent to computer applications and animals that, to our knowledge, act on programmed rules or instinct rather than by what we traditionally would call conscious thought.

How are we then to observe something as multidimensional and seemingly contradictory as creativity? Despite often being considered to be an unscientific area of study, much research has been conducted in the field.

Within creativity studies a lot of focus has been put in the field of studying people of extraordinary creativity. Several points has been made on all kinds of levels about these people both from pure research in the form of early intelligence test, where the goal was to assess individuals with a creative correspondent to

IQ, that determined how creative different people were. Studies in this field is referred to as *Creative People* that focuses on individual differences in the creative ability. [1] Even though much can be learned from studying particularly gifted people, the research method has been rather unsuccessful. This thanks to new research results that indicate that creativity is not a single process but rather a combination of several subprocesses. Hence, making it difficult to assess a persons creative ability in contrast to other people.

Today, there is not much thought put into research trying to determine a creative quota since creativity does not appear to be a constant variable that can be measured in that particular sense. Instead creativity appears to be more flexible and context dependent. As briefly mentioned in the introduction, it is now widely hypothesised that creativity is not one process but a network of several processes in the brain that are in charge of different processes.

Hence, the modern approach to creative studies has been made with more theoretical cognitive psychology.In which focus has lies in trying to explain and map the different processes that are involved in the creative process. This has been made both by studying people that show more than normal levels of creative performance as well as more theoretical approaches where the different cognitive aspects of creativity is analysed and put together into different models. Often referred to as *the Cognitive Creative Approach*, it is with underlying cognitive abilities that we should try to explain creativity. Creative ability is therefore the combination of different mental abilities. [21] This hypothesis also conclude that creativity is not only one process, but it also takes into account the whole brain, inviting to discover more about the phenomenon through the advancing neuroscience. [17]

Thanks to modern neuroimaging techniques, there is now a possibility to study how the brain is activated during creative tasks, something that can easily be correlated with other cognitive task. This is thought to be one way to figure out the different processes that are involved in creative thinking. However, the neuroscience of creativity is far more complexed than what might have been hoped. For example, it is reasonable to differentiate between visual creativity, as in painting, and literal creativity, as in story telling. However, both of these can be considered as a form of artistic creativity. There is also the consideration of scientific creativity, should this be analysed in the same way? A final distinction, many left unmentioned, is the difference between everyday creativity, those moments of insights and solutions that comes to us either without planing or perhaps as a consequence to something we are faced with everyday, and expert creativity, that requires knowledge and where the solution can take years of effort to be reached. All of these forms of creative thinking results in different activation in the brain, providing further support of creativity being a multidimensional process.

On a more fundamental level, there are a lot of studies that try to isolate different parts of the creative process, all in order to determine what might be important for novelty and innovation. Some of these studies, as well as pure speculations, have created a wast number of different theories of how creativity work, and which cognitive functions are important. Even though most of these

theories have their foundation in the creative cognition approach, they tend to focus on different internal processes. Commonly agreed upon cognitive processes that takes part of creativity is *conceptualisation, imagery* and *metaphors*. [13]

In line with this is the more traditional way to look at creativity. That of creativity as divergent thinking. It has long been thought that there are two modes of thinking, divergent and convergent thinking. Divergent thinking is referred to as *associative thought* and it deals with finding relationships and similarities between items and concepts in which there previously have not been any. Convergent thinking is also called *analytical thought* in which the thoughts are focused on things that are already known, in order to retrieve knowledge about something at hand. [8]

When creativity is considered to be a form of divergent thinking it is called *the Associate Theory*. Mednick [15] is one of the followers and he explores this view of creativity. He makes the following definition of the creative process:

> ... we may proceed to define creative process as the forming of associative elements into new combinations which either meet specified requirements or are in some way useful. [p. 221]

The focus lying in creating new combinations through associations, that turn out to be useful to the given situation. Adding not only the need to create original thoughts, because they may come to be completely useless given the situation, but also to appropriately assess the solution to the situation.

Mednick continues by saying that creative thought occurs in three way; serendipity, similarity and lastly mediation. The first one deals with the finding of new combinations of elements that does not otherwise come to mind, the second with combining elements within a particular field, meaning that the concepts are already somewhat combined, and the last one Mednick describe as being the form of the creative process that tries to find the closeness or correlation between different elements. [15]

In his article Mednick also mentions a phenomenon he calls *Associative Hierarchy*. The idea is that the deeper a persons associate hierarchy is given a situation, the more related are the associations, the flatter the hierarchy, the more flexible are the associations. However, in accordance with what has been stated as the associate theory, there is no value of how creative a person may be, given his associative hierarchy, rather which type of creative process is at hand. [15, p. 221]

Creative people therefore usually have flat associative hierarchies. The steeper the associative hierarchy the more restricted the categories of association become. If an individual have flatter hierarchy, then more unusual associations can be made. A good test for this is a word associations test. In such a test the participants are ask to think of as many application areas for a particular object. [8] This study used a simple version of this, see the Torrance Test of Creative Thinking in section 3.3.2.

In the associative theory of creativity, is working memory essential to the creative process, since working memory helps bring out information from the associate memory. [10, p. 114] There is also significant biopsychological evidence

pointing towards working memory being connected to associate thoughts(e.g. Sarnthein et al. 1998 [18]) further suggesting that working memory is an essential part of associations, and consequently also creative thought.

In line with this presented Vandervert [24] a theory of creativity that directly links working memory to creativity, namely *the Cerebellar/Working Memory Theory of Novelty and Innovation.* The theory connects the feed-forward models of the cerebellum to working memory, and how working memory is connected to the pre-frontal cortex and other areas that has been found to be particularly active during creative performance. Due to the complexed nature of the Cerebellum, few studies has been made to satisfactory support this theory, but it does indicate the desire to investigate the role of working memory in creative performance.

Even though divergent thinking is what traditionally has been considered the foundation of creativity, there is a growing support for there being a need for both divergent and convergent thinking. Gabora [8] claims that there is substantial evidence for the hypothesis that creativity involves the capacity to spontaneously shift back and forth between these two modes of thinking. Hence, attention becomes an important part of creative ability, divergent thinking is about defocusing, and convergent thinking is to focus the attention to the problem at hand. Other studies (e.g. Kasof 1997 [11]) also support the need for attention and attention shifting in the creative process, further indicating that creativity is a complexed phenomenon that perhaps is not exclusively of a divergent nature.

2.2 Creative Insight

As suggested above, it is clear that creativity is a difficult research area, partly due to the difficulty in finding a proper and satisfactory definition. The moment of insight provides an area of creativity that can both be defined and is easier to research. In the same way as we intuitively seem to have an idea of what is creative and what is not, there seems to be a fixed idea of what an insight is. Most can relate to that aha!-moment that is the creative insight. This intuition is both a strength and a weakness for experiments testing insights. Even though this results in many definitions, most of them say similar things only put in different words. All seem to focus on that an insight does not have a conscious solution strategy and that the solution, or the moment of clarity, simply appears.

Bowden [4] defines the creative insights with these words:

> The term "insight" designates the clear or deep perception of a situation, a feeling of understanding, the clear(and often sudden) understanding of a complex situation, or grasping the inner nature of things intuitively. [p. 88]

Dominowski and Dallob say it is a form of understanding a problem and its solution. That it is the product of a process of restructuring, and it is

dependent on the features of the problem situation. [20, p. 38] Interesting is they add context as an important factor of how insights occur and how they manifest.

Schooler and Melcher [19] defines it as:

> ... the sudden solution to a problem that one has been working on without any sense of progress. [p. 98]

This is most in line with the definition that has been used in this study, since it is simple and short. In this study the following definition has been used: *An creative insight is when the solution strategy is not obvious, but rather that the answer suddenly appears.*

The interesting question for this study is: what relationship does creative insight have with working memory?

2.3 Creative Insight and Working Memory

Initially, it should be stated that in the same sense as there might be several different kinds of creativity and creative insights, several studies differentiate between different kinds of working memory, and also different kinds of problems. They are often divided into subsections, such as spacial working memory and verbal working memory. This is not difficult to apply to insight problems which often also deals with one particular field of study. For simplification, the terminology will always remain to working memory and insight problems regardless of which subsection they might be part of.

There is really not much to say against there being a connection between working memory and associative thought. Several studies points toward association cortex being activated during working memory tasks (e.g. Sarnthein et al, 1998 [18])

For creative insight there is instead, a great deal to say. Several studies points toward there being a significant difference in how insight problems and analytical problems are solved, with an emphasis on the what role working memory has. The question is how large is the difference in for working memory involvement?

Fleck [7] comes to the conclusion that there is a difference in the need for working memory in analytical problem solving and insight. Problem solving, without doubt, needs working memory, but for insight problems the importance of working memory was not significant. Lavric et al. [14] came, by using an ERP study, to the same conclusion, that the need for working memory in insight problems is limited, or unknown.

On the opposite side, Ash and Wiley [2], as well as Gilhooly and Murphy [9], argues that certain components of working memory are important for insight problem solving. The focus lie in how working memory supports the allocation of attention in order to solve the problems at hand. This is an interesting perspective that working memory contributes by providing attention. Kasof [11] presents an idea that creativity is enhanced when the attention can be focused and one is not distracted.

Murray and Byrne [16] came to the conclusion that people with good working memory perform better on insight problems than people with less WMC. They also come to the conclusion that people who are good at insight problem solving are also better at switching attention. De Dreu [6] performed several studies that all indicated that a high WMC correlated with an increase in a range of different creative tasks.

This in turn, support the hypothesis presented by Gabora [8], that creativity is the product of focusing attention, in convergent thought, and defocusing attention, in divergent thinking, and that it is this combination that constitute the creative process. This indicate that creativity is more than divergent thinking. She argues that the defocusing may result in the initial parts of the insight with searching for appropriate associations, but it is the focusing of attention that results in the evaluation and, therefore, also the final product of an insight.

This taken into account, is creative insights truly divergent? Much point toward more emergent theories, that combine divergent and convergent thinking.

3 Method

3.1 Participants

Test subjects were gathered using a convenience sample. Most of the participants were undergraduate students at the cognitive science program at Linkping University, Sweden. However, in order to get a broader sample concerning age, socio-economic status, and cognitive strain in everyday life, at least a third of the participants were not allowed to be students. A demand that was fulfilled. This provided a wider range of performance in the different tasks, and made it possible to generalize more about the results.

In the study 23 people participated, but due to insufficient performance, see section 3.3.1 for explanations for elimination criteria, and lack of understanding for the task at hand, five participants was eliminated from the analysis and results. The remaining sample consisted of eighteen participants, which was equally divided between males and females. Due to the samples heterogeneity the age range of the participants were rather large, ranging from eighteen to fifty-three years of age(M age=27.06, SD=8.40).

3.2 Ethics

At the introduction of the experiment the participants were informed of their rights. This included that they would remain anonymous throughout the experiment, and that no information about their participation, or their results, could be connected to them either from the study, or the report. They were also informed that they at any time during the experiment could end their participation without having to give any explanation, but if they finished the experiment their result could not be withdrawn from the study, due to the anonymous nature of the study.

It was also emphasised during the introduction, that even though they were implored to do their best, there was no value put in the individuals performance on the tests. The only exception was pointing out that the mathematical part of the working memory test had to be calculated after the best of the participant ability. On the creativity test, it was instructed that there was no value difference in solving the problems with an insight or by an analytical solution strategy. A high creativity score was not to be considered better, or worse, than a lower score on the creative tests.

3.3 Procedure

The experiment was made individually with one participant at a time. The experiment was calculated to take roughly one hour, which also turned out to be the case for most participants. During a short introduction they where informed of their rights, the overall structure of the experiments and potential questions were answered.

The experiment was performed in a small laboratory room without windows and other distractions at Linkpings University, Sweden.

All information needed for the test was presented on a computer screen and the experimenter was placed behind the participant, in order to be able to visually monitor what went on on the computer screen. The participants were not allowed to use any kinds of cognitive aid, e.g. pen and paper. Instead, they were instructed to answer out loud, so that the experimenter could record their answers. The only exception was the second creative task, see section 3.3.2, in which the test subjects themselves wrote their answers.

The experiment was divided into two categories, a creative part and a part for working memory. The part that the subjects were to start with, was alternated so that half of the subject performed the working memory test first and the other half performed the creative test first. This was done in order to avoid having particular results due to fatigue, or perhaps the desire to finish quickly. Whether this might have been an issue or not, t-test was performed afterwards testing the performance of the participants who started first with one part against the performance of the participants who started with the other part, see section 4.1.

Before each test the participants were given clear instructions on the computer screen of the task at hand, meaning what they were expected to do and how they should do it. The experimenter asked if the instructions had been understood and if not, they made additional explanations to make sure that the subjects knew what was expected of them.

Before the official experiments was initiated, a small pilot study was made to test whether the layout of the experiment would work properly. Since the tests used in the study are well used, and found to give reliable results, a large pilot study was not considered needed. Therefore, the pilot study was executed with one single participant. The purpose of the pilot study was not to evaluate the quality of the tests, but to make sure that this study was made in accordance with previous ones, and to measure the time consumption needed to preform the experiment.

During the pilot study, it became clear that the experiment would take about one hour. It also became apparent, due to the performance of the participant, that there was room for yet another level of difficulty in the working memory test. The difficult level of the working memory test was increased from six to seven, see section 3.3.1 for details.

3.3.1 Working Memory Test

The part testing working memory capacity (WMC), consisted of one test called *Operation Span* [23] [22](OSpan). OSpan is a common test for calculating a score of WMC.

It has been shown that OSpan has both good reliability and good validity, and it is found to correlate with several other working memory tests. [22] Hence it provides a good measurement of WMC. The test presented by Unsworth was slightly moderated in that the part to remember was changed from words to letters. This was done in order to minimize potential confusion between the

working memory test and the creativity test, which was filled with words, see section 3.3.2 for the execution of the creative tests. It also differs in how the WMC score was calculated. Unsworth and Engle [22] calculated the score when the entire sequence is correctly recalled. However, in order to have a more flexible WMC score, this study used a more forgiving way of calculating the WMC, see section 3.4 for detailed account on how the score was calculated.

The OSpan test provides a WMC score by asking the participants to memorize a letter, and at the same time make simple arithmetical calculations in order to distract the test subjects from remembering it too easily.

The test has the following appearance:

$$2 * 4 - 3 = 5 \ ?$$
$$\text{L}$$

This picture is then repeated in sets, with new equations and letters. The sets increase in length, meaning the number of pictures per set, to increase the difficulty. When the image is displayed the participants are told to immediately answer whether the arithmetical equation is true or false, and at the same time remember the letter presented underneath. When the set is finished the participant is asked to list the letters in the correct sequence. The sets started with two letters to remember stepping up to seven letters at the most difficult level. It was important that the participants not only remembered the letters, but also in which order they were presented, since sequence mistakes lowered the score. For each difficulty level there was five sets, resulting in 35 letter sequences and all together 135 letters to remember.

Even though the letters to remember were organized to simulate a random distribution, an effort was made to make sure that Swedish or English words never appeared, and that acronyms were kept to a minimum, in order to not give any unintentional aid.

The arithmetical part of the test was done with simple mathematics so that even persons with limited mathematical ability should be able to solve the problems. The equations were always presented with three numbers that had relations to each other using the mathematical functions *addition, subtraction, multiplication* and *division*. However, there was only one multiplication or division per equation. The equations were also constructed so that the numbers never exceeded the number nine. This was done on both the numbers presented, and the numbers resulting from the internal calculations, in order to keep the calculations distracting but still manageable during the time limit.

The time limit was five seconds per equation and letter, after which the test continued automatically with a brief pause consisting of a blank page for a quarter of a second to make sure that the participants notice that there is a new equation to be solved and another letter to be remembered.

In the OSpan test the participants had an threshold of 85 percent accuracy of the arithmetics [22], however, in order to increase the number of valid participants the threshold was reduced to 75 percent. It is believed that this has little or no effect on the resulting WMC score, see section 5.2.1. The purpose

of having to make arithmetical calculation is that working memory is activated through remembering the letters and at the same time focus on the equation. It does not effect the WMC whether the participants are correct in their calculations or not. The important factor here is not that the answer is correct, but rather that the participants make a serious effort to answer correctly. However, to prevent the participants from cheating on the test and only answer true or false to the equations at random, the threshold at 75 percent accuracy was still enforced.

3.3.2 Creativity tests

To test creativity, as divergent thinking, two tests were performed. The first one is a well used test called *Compound Word Association test*, which has been used in different versions in several studies (e.g. Kounios and Beeman, 2010 [12]). The benefits of having this type of test is that the insight problems often are solved immediately or within ten seconds. This creates a test that is quick to perform without damaging the quality of the test. [12])

The second test is a part from the Torrance test of Creative Thinking(TTCT), which has been found to have high reliability and high predictive validity [5]. Both tests examine the individuals ability for divergent thinking. The former in the form of measuring the frequency of divergent insights, and the latter in a more concrete way to measure the depth of the associates hierarchies.

Since the study was performed in Sweden, the Swedish language was used in all tests. This effected the nature of the compound word associates test in a most beneficial way. The Swedish language allows for compound words to be created very easily. The test was constructed in the following manner. The participants are shown three words on the screen. All of these words can together with a mutual forth word produce three compound words derived from the original words. Below is an example.

life - fishing - house

The task here is to think of a new word that with the three words create compound words. In the example "boat" would be a sufficient answer, since it creates the following compound words:

life boat - fishing boat - boat house

However, the task is not to find the word that solves the problem. The word in itself is unimportant. In fact, there might be several solutions to the problems that would be satisfactory. The important part of the test is to determine whether the concluding answer was found through an insight or through a more analytical strategy. In order to explain these concepts to the participants, the test subjects were presented with the definitions, found in section 2, both on the screen before the test began, on a paper that remained in front of the participants throughout the entire experiment and lastly the experimenter made sure that the participants had understood what should be considered an insight and

what should be considered analytical. See section 5.2.2 for discussion regarding the method of the tests.

When the test subjects made it clear that they had understood the concepts and had read the instructions, two examples were demonstrated to ensure that they had understood what was asked of them. Since the participants were asked to think out loud, if they so desired, the experimenter could monitor the flow of thought which provided another dimension to the test. The participants were asked to say the solution word out loud, so that the test personal could write it down, as well as define their solution as either an insight, also referred to as an aha!-experience, or a more analytical solution. In cases of doubt a middle option could be chosen.

In the case that the participant could not find an appropriate word for the problem at hand, the participants were shown a solution alternative, and were once again asked if they felt like they had an insight when the solution was presented to them. This was done in order to create a higher possible score on the test, see section 3.4 for how the test was scored.

This procedure was repeated for twenty-four compound word problems.

The second creativity test is, as mentioned above, an association test from TTCT which tests divergent thinking. Here the participants are asked to think of as many unique uses for one particular object. In the classical test this object is a brick, which also was used in this experiment.

The participants were first instructed how the test is performed, namely that they are to write down as many uses for an object as possible under three minutes. The are informed of what would be sufficient answers, namely that the object in question must be used with a purpose and that it has to be somewhat reasonable. Unapproved suggestions would be for a brick: "to lift it" and "to live in it". The first one, since it is irrelevant that it is a brick, meaning that it being a brick serves no purpose and the second one because it greatly violate the possible uses for a brick. Approved suggestions would be instead: "to use as a weight in weightlifting" and "house for insects".

It was also important that they understood that the applications for the object had to be unique. If the suggestions "build house" was given, it gave no further points to state that one could also use it to "to build a wall", since both indicate the same use for the brick. However, when the usage was changed even though the verb remained the same, the suggestions were approved. An example of this would be to add "build garden path", to the already suggested "build house". Since the nature of building a house in bricks is very different from using bricks as a material for constructing a garden path, both would be considered unique applications.

The answers were to be written on a piece of paper, with one application per row. The participants were informed that they need not to write complete sentences, it was enough to write down key words to explain what they meant. Examples of this would be to simply write "build house" and "weightlifting weight".

When the test subject reported that they understood the instructions, see section 5.2.2 for discussion, the test was initiated with the examiner revealing

the object, *brick*, and starting an alarm clock. During the three minutes the test personal remained quiet, unless there was some direct questions, and let the participants write down their answers.

3.4 Scoring of Data

In order to have a quantitative value of the performance and results from the tests the following methods were used to evaluate the performance.

Mathematical Score Evaluation: On the mathematical part of OSpan the score was derived from the numbers of correct equations. Each participant which stated that an equation that was false, when it was false, was given one point and the same for the true equations. This resulted in a score stretching from zero to a maximum of 135. Since the limit was 75 percent correct assessments, the score was calculated into a percent value, which is the value presented in the results.

WMC Score Evaluation: The WMC was evaluated in a similar way. Each participant received a value ranging from zero to 135 based on the same limitations as found on the mathematical part. However, the scoring was calculated in a slightly more sophisticated manner. In order to have a more flexible score than that presented in the classic test [22], the participants received points even if they did not get all the letters in a sequence right.

The score was calculated using the following system: For each correctly recalled letter that was placed in the right position, one point was given. For correctly remembered letters that was placed at most one place from the correct spot $\frac{1}{2}$ point was given, and for any correctly remembered letter that was placed more than one spot away $\frac{1}{5}$ points were rewarded. This way of assessing value to the WMC made sure that people who remember the letters in correct sequence is rewarded better results than people who remember them in the wrong order. But it also takes into account that it is better to remember them wrongly than not to remember them at all.

Creativity Test Evaluations: For the creative tests the performance were much more difficult to assess. For the compound word associates test the aha!-qouta, as it is referred to throughout the thesis, was calculated as follows: The participants were asked to say whether they found the solution based on an insight, or a more analytical strategy or, in difficult cases, in between. For each indicated insight they where rewarded three points, for each analytical solution strategy they were rewarded one point, and for solutions that were somewhere in between, two points were rewarded. In the case that the subjects could not find an appropriate word, the participants were, as mentioned in the method section, offered a second chance to have an insight when the solution was shown to them. If they reported having an insight at this second opportunity, two points were rewarded. The sum of all these awarded points resulted in the aha!-quota.

In order to see if there was a qualitative difference in whether people solved the problems with insights or analytical strategies, and simply receiving aha!-experiences when the solution was presented, another score was also calculated from the compound word associates test. This was a percent of insight from the solved problems. The "in between" option was calculated as half an insight in this score. This created two different scores on the compound word associates test that stands by themselves as a point of measurement in the result section.

In the final test, namely TTCT, the score was simply calculated by counting the number of application areas that was approved given the mentioned criteria.

Table 1: WMC and Aha!-quota for groups starting with working memory resp. creativity tests

	Starting condition	N	Mean	Std. Deviation	Std. Error Mean
WMC	Working Memory	9	104.92	24.44	8.15
	Creativity Tests	9	98.47	22.08	7.36
Aha!-quota	Working Memory	9	54.11	5.99	2.00
	Creativity Tests	9	53.56	6.78	2.26

4 Results

The results of the study are divided into first a section devoted to determine if there where any biases due to which test was initiated first. Followed by two section concerning the results, and their normal distribution, for the working memory test and the creative tests. Lastly is a section devoted to the correlated results from the latter two sections.

All results are then discussed further in section 5.

4.1 Elimination of Possible Starting Bias

In order to make sure that there was no difference in performance between the groups starting with testing WMC or the group that started with testing creative ability, independent samples t-test of the groups was conducted on both the WMC and the aha!-quota, see table 1. The motivation for this conduct was that several of the participants expressed that they became very tired after the mental effort of OSpan. This might have had an impact on the level of creative thinking the participants could express.

Regarding the WMC the t-test resulted in no significant difference in the performance for the group that started with OSpan(M=104.92, SD=24.44), and the group starting with the creative part(M=98.47, SD=22.08); t(16)=0.58, p(two-tailed)=0.57. These results indicate that there is no reason to consider that WMC have been affected by being either first, or second, during the experiment.

It was the more reason to be concerned if there was a difference in the performance in the creative part, since the possible fatigue from the working memory test may influence the performance. Independent-sample t-test was conducted on the results from the compound word associates test as well, see table 1. Here the quota of aha!-experiences (M=53.83, SD=6.21) were tested for both groups, in which the working memory test was performed before, and after, the creativity tests.

The results show that there was no significant difference between the group that started with working memory(M=54.11, SD=5.99), and the group starting with creativity tests(M=53.56, SD=6.78); t(16)=0.86, p(two-tailed)=0.40.

There is once again no reason to consider that the order of the tests might have had any effect on the performance.

See section 5.2 for deeper discussion regarding the discarded starting biases.

4.2 Working Memory Test

The WMC results are very varied with some participants performing very well and others not so well. Figure 1 show the distribution on WMC based on five classes. It is unfortunately not in line with a normal distribution but rather titled toward better performance than normal. Under section 5.1.1 data transformations was performed hoping to find a normal distribution through squaring the data and using the 10-logarithm, this was not found. The tilt in the distribution may have had an impact on how the results should be interpreted, see the results discussion for further investigation.

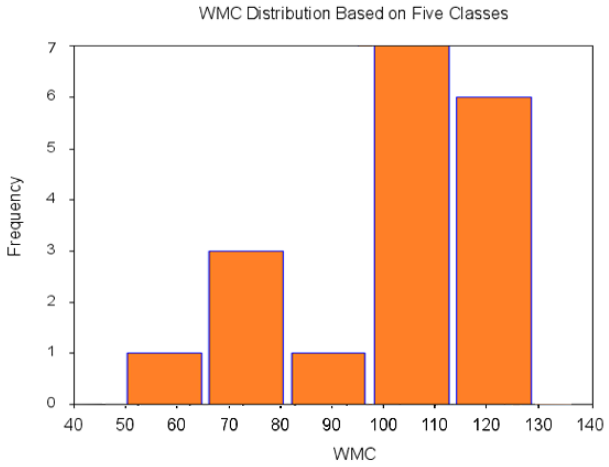

Figure 1: WMC distribution based on five classes

Even though there was no actual value put in the performance on the mathematical part of the test, since its only purpose was to distract the subjects from remembering the letters, it felt interesting to investigate the correlation between correctly assessed equations and the WMC. It could be relevant if the subjects focused less on the mathematics in order to perform better on the working memory test, and therefore, could the subjects with high WMC perhaps have lower scores on the mathematical part. It might also be so that a high mathematical ability creates the opposite effect, since good mathematicians needs less time

to solve the equation and consequently have more time to focus on the letter. Figure 2 show the scatter plot of mathematical performance as it correlates with WMC. The experiment was conducted with an open discussion after each test, in which the participants could comment on their performance and their thoughts about the test. Some of the better mathematicians in the test group expressed that they did not actually need to solve the equations, instead it was sometimes sufficient to simply look at the numbers and determine whether or not the solution should be an even or odd number, if it was the wrong one, they could very quickly determine that the equation was false. On the other hand, the participants struggling with the mathematical part expressed that they did not have time to look at both the equation and the letter, leaving the letters completely unobserved in order to try to correctly assess the equations.

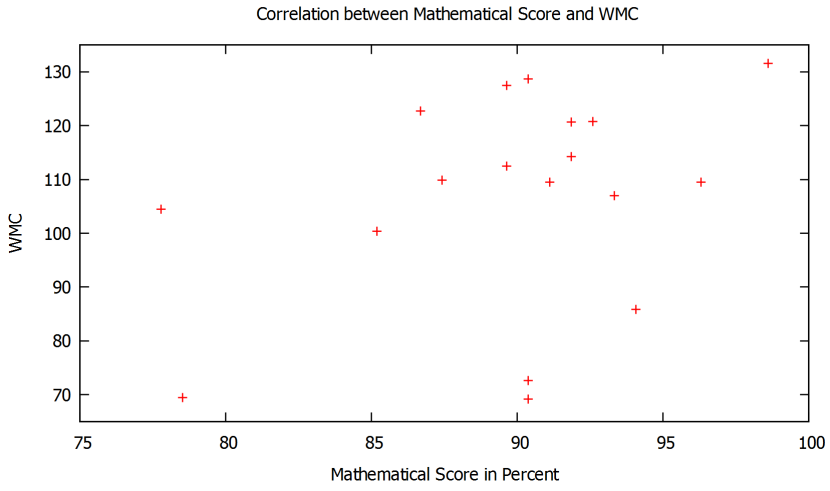

Figure 2: WMC and mathematical percent score in Operation Span

At a significance level of p=0.05 the correlation efficient of the correlation of WMC and arithmetic performance was r=0.65. This in turn results in a p-value of p(two-tailed)=0.0035, which is lower than the probability level. Hence, the null hypothesis can be rejected and there is a significance in the correlations between WMC and the arithmetic performance. See table 3 for all correlation results and section 5.2.1 for discussion.

4.3 Creativity Tests

To present the results from the compound word associations test both the Aha!-quota and the percent of insight was used, see section 3.4 for details regarding calculating the scores.

All together this created a distribution on the Aha!-quota between 41 and

Table 2: Creativity test statistics

	N	Mean	Std. Deviation	Std. Error Mean
Aha!-quota	18	53.83	6.21	1.46
Percent of Insight	18	69.19	14.98	3.53
Nr of Brick Applications	18	9.50	3.45	0.81

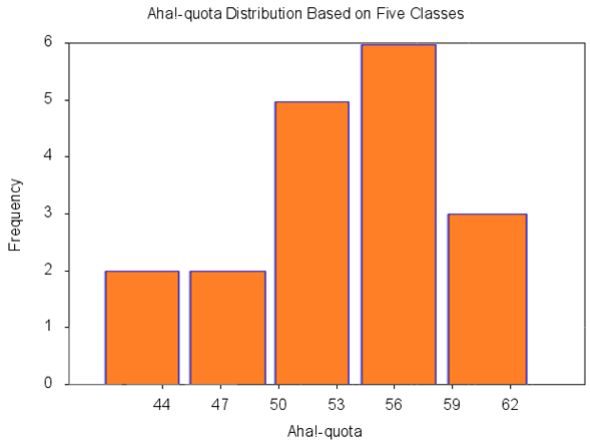

Figure 3: Aha!-quota distribution on five classes

63(M=53.83, SD=6.21). Based on five classes is slightly titled toward higher score than at a normal distribution. Since it is also interesting to isolate the insights given when the subjects had when they managed to solve the problem another value was calculated. This was the percent of insight of the solved problems(M=18.67, SD=1.71). Here only the number of insights(M=12.94, SD=3.19) was taken into account and it generated another distribution laid between 36.84 percent and 94.12 percent(M=69.19, SD=14.98). There was an abnormal distribution and therefore a higher value was put into the aha!-quota in relation to the percent of insight value.

It seemed interesting to determine whether or not the aha!-quota correlated with the percent of solved problems that was solved using insights. To give further support to use both of these measurements. The results showed a correlation coefficient of r=0.88 (df=16), which resulted in a two-tailed p-value of p¡0.0001, hence it is clear that the null hypothesis may be rejected and it is safe to assume that a higher aha!-quota also infer a higher percent of the solutions being insights. This linear correlation is visualized in figure 5.

The Torrance Test of Creative Thinking resulted in the following: With a

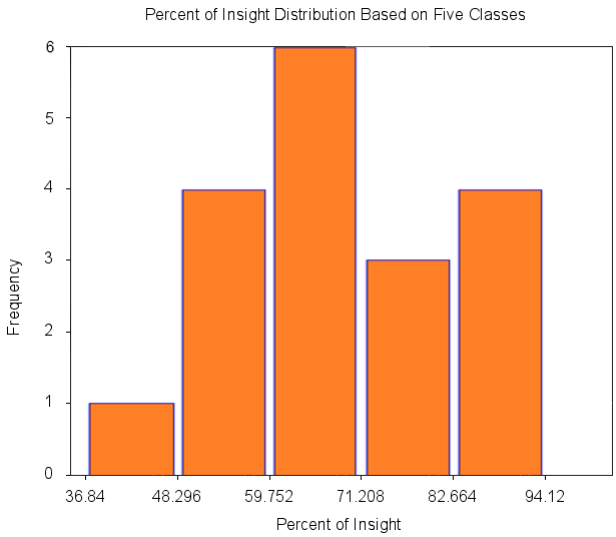

Figure 4: Percent of Insight distribution

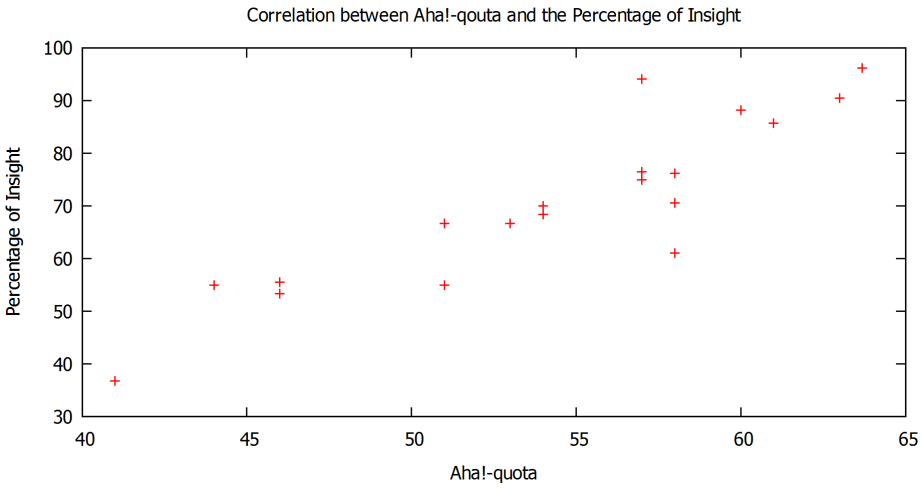

Figure 5: Aha!-quota and Percent of Insights

few ideas that most participants thought of, such as "building a house", most participants were rather diverse in their ideas of what the item could be used for. The participants that had the most suggestions often thought of things that the brick in itself was a mere tool to accomplish, and not something that it is

usually made for. Hence, they were more "creative" in the test since they did not limit themselves but used the full ability of divergent thinking to think of as many areas as possible. The range of application areas that the participants thought of spanned from three to sixteen(M=9.50, SD=3.45). See the discussion under section 5.2.2.

It felt interesting to see whether there were any correlation between the results from the compound word associates test and TTCT. If there was, it would be stronger to assume that the aha!-experience is in fact to be considered connected to divergent creative ability. The correlation efficient is r=0.35 and the two-tailed p-value is p=0.15. Somewhat surprisingly, there was no correlation found, meaning that the null hypothesis can not be rejected and the relationship between aha!-quota and the number of thought out application areas for the brick is uncertain.

However, if one looks at the scatter plot, see figure 6, there is a slightly leaning trend of the more ideas for bricks the higher aha!-quota. If one were to remove the outlines, it is not impossible that there in fact would be significant correlation. This non-significant result is further discussed in section 5.1.2.

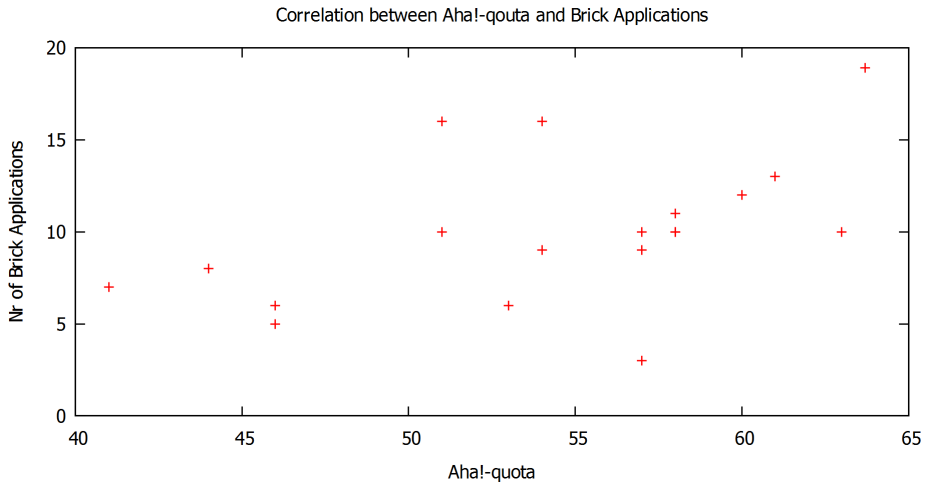

Figure 6: Aha!-quota and Nr of Brick Applications

4.4 Correlation between Working Memory Capacity and Creative Ability

As the purpose of this thesis was to determine whether there were any truth behind working memory and creative capability to correlate, the following section present the results from the correlation analysis between the working memory capacity and the creative results.

Table 3: Correlation Matrix

Variables		1	2	3	4	5
1. WMC	Pearsons corr	1	.65	.30	.14	.64
	Sig. (2-tailed)	-	.0035	.23	.58	.004
	N	18	18	18	18	18
2. Mathematical score	Pearsons corr	.65	1			
	Sig. (2-tailed)	.0035	-			
	N		18			
3. Aha!-quota	Pearsons corr	.30		1	.88	.35
	Sig. (2-tailed)	.23		-	<.0001	.15
	N	18		18	18	18
4. Percent of insights	Pearsons corr	.14		.88	1	
	Sig. (2-tailed)	.58		<.0001	-	
	N	18		18	18	
5. Nr of brick applications	Pearsons corr	.64		.33		1
	Sig. (2-tailed)	.23		.15		-
	N	18		18		18

The correlation between WMC the aha!-quota is r=0.30 and the p-value calculates to p=0.23. This is more than the significance level of p=0.05 and therefore the null hypothesis may not be disregarded. It is not possible to make any conclusion about the correlation between WMC and creative ability, at least not in the form of the aha!-quota derived from the compound word association test performed in this study. This result is reasonable when one looks at the scatter plot over the WMC and the aha!-quota, see figure 7, which clearly demonstrate that there is no trends in performance to be found.

Then the percent of insight from the solutions was correlated with the WMC. Once again there is no significance to be found. In fact the correlation efficient is less than half than that of the correlation with the aha!-quota. The correlation efficient is r=0.14, resulting in a p-value of p=0.58, a number far greater then that of the significance level of p=0.05. Hence, the correlation is not statistically significant and the null hypothesis may once again not be rejected. However, again it is interesting to look at the scatter plot, see figure 8, as it reveals more than the calculations. With the exception of two test subjects there is a linear trend towards the conclusion that a high working memory capacity might result in a high number of insights.

Regardless there is no significant results from either of the scores from the insight test and the working memory test.

Finally there was a correlation test made between the WMC and the number of brick applications. Unsurprisingly, this results showed a significant correlation, indicating that working memory capacity is involved in divergent thinking. With a correlation coefficient at r=0.64 the p-value was calculated to p=0.004

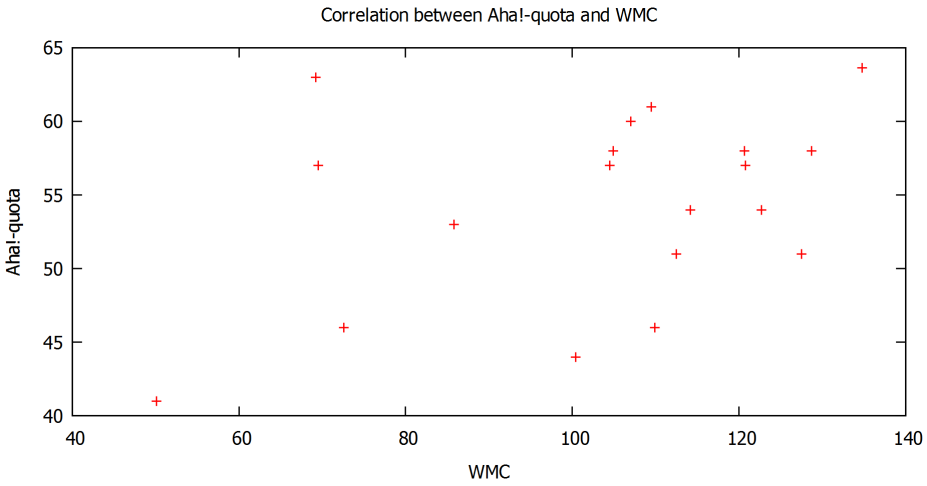

Figure 7: Working Memory Capacity and Aha!-quota

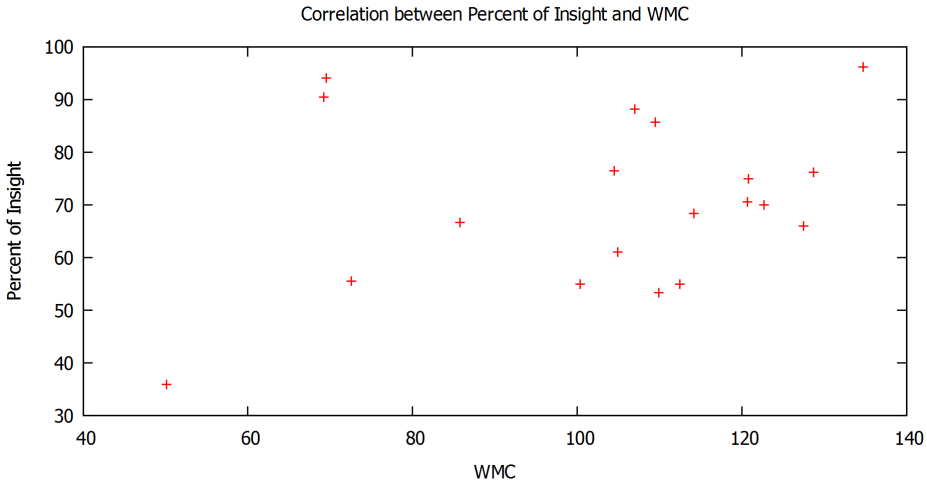

Figure 8: Working Memory Capacity and Percent of Insight

which is indeed smaller than the significance level of p=0.05. Hence, it is significant that WMC and the results from TTCT are correlating with each other.

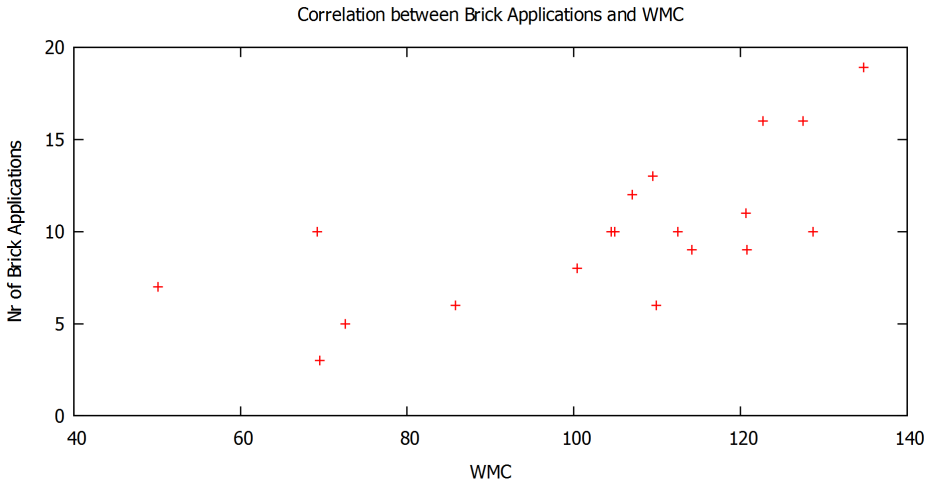

Figure 9: Working Memory Capacity and number of applications for a Brick

5 Discussion

Below are several sections in which corresponding discussions regarding the results and the method of the study.

5.1 Results Discussion

The study was made in order to give further support to one of two opposite hypothesis regarding the role of working memory in creative insights, see section 1.1 for the hypotheses. The results show that there is no correlation between high WMC and the insight problem solving frequency, supporting the hypothesis that creative insight is a product of primarily unconscious processes and not in need of working memory. Below is a more detailed discussion regarding the results and the conclusions that can be derived from them.

5.1.1 Working Memory Test Results

Distribution of WMC: The results reported in section 4.2 on WMC, diverged from a normal distribution. This problem remained even through data transformation with both squaring the WMC score and using the 10-logarithm. This further indicate that either the sample used in the experiment was not satisfactory representative, or the results was influenced by other factors than that of simply working memory, see section 5.2.1 for possible influencing factors.

Since the sample that was selected to a large part were students and post-graduates, despite attempts to broaden the sample, the performance may not represent the normal distribution in society. This of course creates the problem

that the results concerning the correlation studies may not be as reliable as desired.

To have more reliable results it would be advisable to have a larger and more heterogeneous sample. It would also be a good idea to establish the WMC by not one single working memory test, but by a series of different tests.

5.1.2 Creativity Test Results

The interesting point to make here is that the two test designed to test the frequency of insights and the ability to divergent thinking, did not correlate. The purpose of this correlation test was to give support to whether the creative insight, as tested in this study, was a form of divergent thinking. If there had been a correlation it would have been more reliable to say that the results from the creative insight test was a form of divergent thinking. Since this was not the case, a problem emerges. The second hypothesis infer that the creative insights is a form of divergent thinking, and that divergent thinking is in need of working memory. If the creative insight can not be determined as divergent thinking, the second hypothesis cannot be discarded which is an important remark.

Distribution of Aha!-quota and Percentage of Insight: It is a rather interesting finding that the Aha!-quota is more normally distributed than the percent of insight value. This could be a result based on the aha!-quota taking an overall aha!-experience into account and not exclusively the solved problems as with the percent of insight. It could also be a result that the people who had a high percent of insight may have overestimated the number of aha!-experiences in the solved problems, leaving it a higher value rather than good representation of the actual aha!-experiences. Due to the slightly superior distribution of the aha!-quota, it has been regarded as the most reliable value and it is the one that has been used as the primary value in the correlation analyses.

5.1.3 Correlation Between WMC and Creative Ability Results:

As mentioned, there was no correlation between WMC and the creative insight frequency. The result between WMC and both the Aha!-quota and percent of insight were both non-significant. This indicate that the creative insights is not dependent on working memory, and that insight problem solving is dependent on processes that in turn is not in need of working memory. This supports the first hypothesis.

However, in order to be able to reject the second hypothesis, that of creative insights being a part of divergent thinking, which in turn is in need of working memory, it needs to be established that creative insights is in fact a form of divergent thinking. Since the results from the correlation between the number of brick applications and the insight frequency did not correlate it is reasonable to assume that insights may not be of a divergent thinking kind.

In order to test this further yet another correlation analysis was conducted, testing the correlation between WMC and the number of brick applications in

the TTCT test. The found correlation indicate that it would be reasonable to assume that working memory is needed for divergent thinking, supporting the second hypothesis. This creates a conflict in the two hypothesis since both has been somewhat confirmed. It is therefore presumed that either the results is not sufficient to make any correct analyses, or the creative insight is not a form of divergent thinking.

5.2 Method discussion

In retrospect there is a lot that can be said about the different test made during the experiments. One problem is the size of the sample, which might be the cause of the results not being normally distributed.

The biggest issue however, is that OSpan gives a quantitative value at the actual performance, whereas the creativity test, primarily the compound word association tests, gives a highly subjective qualitative value. To make comparisons and trying to find out correlations between these two values might prove to be not only difficult, but also indicate false correlations, since it is neither entirely qualitative nor quantitative.

An interesting point to note here is that since the t-test conducted on the performance, based on the order of the tests did not result in any significant result, at least this was not a problem in the experiments.

5.2.1 Discussion around the Working Memory Tests

WMC correlation with mathematical ability: Initially it is important to discuss how OSpan establish a WMC, due to the correlation results between WMC and mathematical performance.

How should the results from the correlation between WMC and mathematical part be explained? The correlation is most disturbing for the interpretation of the results. Because there is a correlation, it indicates that the WMC either is connected to good mathematical ability or OSpan, as used in this study, does not show a good representation of WMC. Why is that? Well because the mathematically excelled participants expressed that they made *mental short cuts* in order to work faster on the mathematical part, and because they more rapidly could determine whether the equations were correct or false, had more time to focus on the letters and could consequently get a better WMC score. The subjects who instead reported that they struggled with the mathematical part, often did not have time to solve the equations properly and sometimes ended up guessing whether it was true or false, taking no time to look at the letter.

It would seem that operation span does not exclusively test working memory, but both WMC and the speed of mental calculation.

Another problem that arose, is that several of the participants expressed that the five seconds to determine the equations truth value passed very quickly. Most of the participants got used to it, but almost everyone got initially very surprised at the speed of the test despite being informed of the five second time limit. This adds another factor in what OSpan actually tests. Perhaps it is

reasonable to say that people who performed better under stress and pressure, performs better on a test like OSpan, rather than people who easily get stressed under pressure. This is hardly the most important point in the study, but it is an interesting aspect to take into account when similar studies is to be executed.

A suggestion in order to prevent this mathematical bias is to moderate OSpan a little. It would perhaps be a good idea to change the layout of the test. In order to give all participants equal chance to remember the letters, the arthimetics withstanding, instead of presenting the equation and the letter at the same time, to show each for a shorter time period. Perhaps give the mathematical part four seconds and then have the letter only shown for one second. After all, the idea is that the letter should only shortly be observed and then be remembered throughout the calculations.

This method ought to remove the correlation between WMC and mathematical ability since it would give each participant the same amount of time to focus on remembering the letters.

5.2.2 Discussion around the Creativity Tests

For the compound word association test the participants were given not only one, but three chances to grasp the concept of a creative insight and its difference to the other alternative with the more analytical solution strategy. First, it was presented on paper together with the instructions, a paper that was left in front of the participants through the experiment. Secondly, they were presented with definitions on the screen before the test took part. Thirdly, they were asked if they felt like they had grasped the concepts, and were once again informed of how to look at different solutions by the experimenter, before the actual test began.

However, due to the fact that the participants were asked to think aloud if they felt so inclined, it became clear that the participants seemed to have different opinions about when it was to be considered an insight and when it was considered an analytical solution. The experimenter helped to try to define it once again when the participants seemed to be confused as how to answer.

This uncertainty in the strategy was confirmed in the short oral questionnaire that was performed with the participants after each session. They were asked a few questions about the test and whether they had difficulties determining the nature of their solution strategy. Many of the participants said that they had in fact difficulties determining where the line should be drawn. For example they exclaimed that even though their solution strategy had been rather analytical, they experienced an aha!-experience when they thought of a satisfactory solution. Another example is that sometimes they gave clear indications of having insights even though their answers did not solve the problem at hand.

Hence, the results from the compound word association test might not be as reliable as one would desire, even between the participants the definitions seemed both to be somewhat uncertain and also inconsistent within the sample.

Regarding the Torrance creativity test little can be said about the performance since the test in itself was so simply constructed. However, occasionally

the participants did not grasp the concept of unique areas of application despite being given instructions in how it should be interpreted, and almost everyone had at least one or a two application areas that had to be removed.

A lot of the participants had suggestions in which the item, the brick, was not used but rather something was done to it. One example was that some of the participants said that one could "lift it", which was not approved. The participants that instead said that one could use it as a "weight to lift in weightlifting" was approved since it gave a clear application area. It was clear that some of the participants had difficulties to differentiate between these two concepts, and some of the participants seemed to get stuck in one way of thinking, resulting in a lower score on the test. If this test is to be repeated it could perhaps even further be explained how one has to think, still bearing in mind that it may effect the creative performance.

6 Conclusion

This study provides an interesting angle to the debate on the role of working memory in creative insight. It not only gives support to the hypothesis that working memory is not a fundamental part of creative insight, but also provide an interesting view on the nature of insight.

Due to the lack of correlation between WMC and the frequency of creative insights, the hypothesis claiming working memory is not needed for insights, must be supported.

However, the opposing hypothesis claims not only that creative insights needs working memory, but that it needs working memory because it is of a divergent thinking kind. The correlation analysis between the number of brick applications, representing a divergent thinking ability, and WMC showed significant results, clearly stating that divergent thinking is in need for working memory. If this is the case, why is there no correlation between the frequency of insights and WMC? One possibility is that insights is not divergent.

The investigation of the divergent nature of insights contained yet another correlation analysis, namely between the frequency of insights and the number of brick applications. If insights was of a divergent thinking kind, surely the results should return with significance? There was no significance, giving further support for the uprising hypothesis that creative insight is not of a divergent thinking kind.

Consequently, it can be stated that creative insight is not in need of working memory, supporting the first hypothesis. However, due to further analyses it would seem that divergent thinking is in need of working memory making it impossible to completely discard the second opposing hypothesis. The only conclusion that would make sense of the results is that creative insights is not in need of working memory because is is not, exclusively, of a divergent nature. Leaving the first hypothesis supported and the second hypothesis irrelevant for the purpose of this study.

6.1 Future Research

Despite providing support for the hypothesis that creative insight is not in need of working memory the research in the field needs to be properly improved. First and foremost the definitions of this difficult area of study needs to be clarified. It is also important to determine what and how creative insights occur. If this study is to be trusted, creative insights is not form of divergent thinking, which needs to be considered in other studies.

This study is not the only study reporting problems with assessing creative insights. Bowden [3] criticize that the participants themselves assess whether it was an insight or not, and that there is not yet one fully satisfactory definition that easily can be applied. Since this is the case the result is quantified in a qualitative manner. Leaving individual differences a possible problem.

Regarding testing working memory it might be a good idea to test it from several directions and not simply by using OSpan. After all it created an un-

balance between the participants that was good at mathematics and the ones that were not.

Another important note is that the sample used in this study is rather small and perhaps not heterogeneous enough to conduct a study in this difficult area. Researchers interested in determine the components of creative insights, in particular the role of working memory, should make sure to have enough data to get more reliable results.

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