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**THE RELATIONSHIP BETWEEN GENERAL  
INTELLIGENCE FACTOR  $G$ , BROAD  
COGNITIVE ABILITIES AND WORKING  
MEMORY**

**VZTAH MEZI OBECNÝM INTELIGENČNÍM FAKTOREM  $G$ ,  
ŠIROKÝMI KOGNITIVNÍMI SCHOPNOSTMI A PRACOVNÍ  
PAMĚTÍ**

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**I would like to thank my supervisors, Dr. Dipl.-Psych Ludwig Kreuzpointner and PhDr. Simona Horáková Hoskovcová, Ph.D., for their continual support and advice throughout this work. I would also like to thank to all the people for all of the support they have given to me over and made this work possible.**

Prohlašuji, že jsem diplomovou práci vypracovala samostatně a že jsem uvedla všechny použité prameny a literaturu.

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## **Anotace**

Tato diplomová práce pojednává o vztahu mezi obecnou pracovní pamětí, jednotlivými druhy pracovní paměti a obecným inteligenčním faktorem  $g$  a “širokými” kognitivními schopnostmi. Teoretická část se zabývá popisem měřených konstruktů, jejich vývojem, způsoby jejich měření a studii zabývajícími se zjišťováním vztahu mezi nimi. Praktickou částí je výzkum zaměřený na ověření vztahu mezi obecnou pracovní pamětí a obecným inteligenčním faktorem, dále pak na zjištění vztahu mezi jednotlivými druhy pracovní paměti a “širokými” kognitivními schopnostmi. V praktické části je rovněž ověřována otázka týkající se používání strategií účastníky při jejich testování automatickou verzí měření pracovní paměti, které by mohly mít vliv na konečný výsledek.

**Klíčová slova:** Pracovní paměť, obecný inteligenční faktor  $g$ , široké kognitivní schopnosti, pracovní paměť a využití strategií

This thesis deals with the relationship between Working Memory, Working Memory Span tasks and general factor  $g$  and Broad cognitive abilities.

Measured constructs are introduced in the theoretical part, with their evolution, various methods of their measurement and studies investigating the relation between them. The empirical part of the research has been conducted to verify the relationship between Working Memory and general intelligence factor  $g$ . It has been done to reveal the relationship between Working Memory Span tasks and Broad cognitive abilities as well. The question concerning the influence of the use of strategy while performing the automatic version of Working Memory Span tasks has been investigated as well.

**Key words:** working memory, general intelligence factor  $g$ , broad cognitive abilities, working memory and strategy use

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## List of Abbreviations

WM	Working Memory
STM	Short Term Memory
TBR items	To-be-remembered items
LPS	Leistungsprüfsystem
<i>g</i>	General intelligence factor <i>g</i>
OSpan	Operation Span
RSpan	Reading span
SymmSpan	Symmetry span
Gc	Crystallised intelligence
Gf	Fluid intelligence
Gv	Broad visual perception
Gs	Broad Cognitive Speediness



## **1. Introduction**

The scope of this thesis is the investigation of a critical relation, between general intelligence factor  $g$ , broad cognitive abilities, general Working Memory (WM) and WM span tasks. Many studies have already been conducted in this field. Although the researchers differ in opinion even about the basic view of WM, they have achieved similar results – that confirms the significant relation between WM and some of the cognitive abilities.

This topic was primarily chosen to explore the obscure features concerning the relationship between few of the components of general factor  $g$  (broad cognitive abilities) and their relation to WM components (WM Span tasks). As mentioned above many studies have already been conducted to find out more about the relationship between cognitive functions and WM, but not many of them involved complex investigation which would provide multiple tests of a wide range of cognitive ability factors (e.g. reasoning, spatial, verbal, numerical, processing speediness), multiple tests of WM in each of the different content domains (verbal, numerical, visio-spatial). So, the newest testing measurements of WM and cognitive abilities were used in this study to make another closer approach to the problem and see whether the results of the previous studies focusing on the relationship between general WM and general factor  $g$  would be supported by this research and also to find out more about the relation between Broad abilities and WM Span tasks.

It was interesting, using test designed to measure not only the general intelligence factor  $g$  but also broad cognitive abilities of which the results were compared with the results of WM testing in verbal, numerical and the visuo-spatial domain.

Contribution of this thesis I see in the possibility of usage of found results in following research or in the possible improvement of cognitive abilities using WM training.

The assumption is that different types of WM are associated with different broad cognitive abilities. Finding which WM Span task correlate with what broad cognitive abilities could help the possible future development of WM training tasks. It would be possible to train only specific types of WM depending on which cognitive abilities are in deficit.

WM span tasks should be always composed of processing part and to-be-remembered items (TBR) which vary. Depending on the deficit cognitive ability, these features could be modified to contribute to its improvement as much as possible.

Another aim of this thesis was to find out more about differences in strategy used while performing on automated WM-Tasks for the study. The reason for this investigation was the author's personal experience with strategy use while performing WM span tasks. These strategies have been called helping strategies and the author wanted to find more about how they influence the performance on the automated WM Test in case the participants use them. Some researchers have investigated the strategy use in older WM-testing versions and a positive correlation between strategy use and the WM score has been confirmed. Therefore, the author decided to find out whether the results of the newest WM-testing version are also positively influenced by the strategy use. In case of a positive correlation, the results of this investigation could help improving the acceptance of WM Span tasks.

In the first phase of this thesis the term WM will be explained by distinguishing it from another term – Short Term Memory (STM). Studies focused on the investigation of the relationship between STM and higher cognitive functions will be briefly introduced as well as the reasons why STM and its relation to WM is not the scope of this thesis. Later, some of the most influential WM studies would be explained that starts from those which asserts the specific components of the WM (or at least some of its sub-components). The problem of the differences in viewpoints concerning the understanding of the term WM because of the various studies that have already been conducted would also be mentioned. Different

methods of measuring the WM will be described as well with the reasons to choose them.

Next, some of the researchers investigated the degree to which variation in strategy use predicts individual differences in WM span performance will be mentioned.

Then the important studies focused on the relationship between WM and higher cognitive functions will be introduced for better understanding what principles were used in previous studies; what their aim was and what results were achieved.

Finally, this Thesis will present some of the most influential theories of intelligence. The intention being to explain on what basis the intelligence LPS-neu Test was chosen for this study. It appears that Intelligence research because of its subjective nature has a long history with no clear end. This test was compiled using some hypothesises of which I agreed with, enabling access to a large amount of information. It is important to describe what led me to such a choice.

In the second phase I shall introduce my own work conceived on the basis of the results obtained in the previous studies. As mentioned above, my focus was not only the confirmation of the relation between WM and the general intelligence factor (*g*) to support findings of most of the previous works, but also the relation between WM and some of the abilities from the area of so-called broad abilities which are increasingly becoming an interesting area in WM research. I shall discuss next, in more details, the methods chosen for the measurement of both constructs as well as the reasons for this choice and the whole procedure of gaining needed data.

## 2. Working Memory (WM)

### 2.1. *Introduction of the term WM*

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There are many approaches to the study of WM using a range of empirical and theoretical techniques.

In the beginning, I would like to start with Baddeley's way of understanding the nature of human memory in general. He says: „Take an evolutionary perspective and speculate on what memory functions might prove useful to an organism evolving in a complex and varied, but nevertheless structured, world. Let us assume that an organism has been given a number of sensory channels – vision, hearing, touch and smell. Information from these various channels should, in principle, be related; objects such as trees can be seen and touched, and indeed heard as the wind rustles through their leaves. Appreciating this and creating some representation of an object is likely to require memory, at least of a temporary form, a short-term or WM that will allow the organism to pull together information from a number of sources and integrate it into a coherent view of the surrounding World,“ (Baddeley, 2004, p. 14).

He describes how important memory is for our everyday life, and even shows the special role of WM as a necessary mechanism which enables us to understand each situation as a unit in all its various aspects. Exactly this fact (the ability to pull information together to get a corresponding view of world) may attribute WM a special role in explaining the roots of intelligence. But first, it is necessary to explain what is meant by the term WM, and for this purpose some of the accepted theories of WM, especially those which emphasize the conceptual distinction between WM and Short-term Memory, will be used.

Short-Term Memory (STM) is another construct which some researchers were expecting, would correlate with intelligence. (e.g. Engle et al., 1999; Conway et al., 2002) It is typically used to refer to systems specialised for the temporary

storage of information without any explicit concurrent processing requirement (e.g. Colom et al., 2005).

## 2.2. *Distinction between WM and STM*

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STM and WM are both central constructs in modern theories of memory and cognition and many researchers have suggested that these constructs are separate and have different relation to higher cognitive abilities.

A good example of distinction between WM and STM would be the study of Unsworth and Engle (2007), who showed the differences between these two constructs by differing in the methods of their measurement in psychometric batteries of intelligence - „in short-term memory (or simple) span tasks, participants are given a list of TBR items including letters, digits, words, or shapes and are then asked to recall the list in the correct serial order immediately after presentation of the last item. For example, in the letter span task, participants who receive the list “R, S, L, Q, T” must correctly recall the letters in their correct serial order. Any deviation (e.g., recalling “S” as the first letter) is counted as an error. Additionally, list length is typically varied such that participants are required to sometimes recall short lists (e.g., two items) and other times recall longer lists (e.g., seven items). In WM span tasks, such as the simple span ones, participants recall a set of items in their correct serial order. The tasks differ in that complex span requires the participants to engage in some processing activity unrelated to the memory task. The processing component can include reading sentences, solving arithmetic problems, or assessing the symmetry of visual objects. For instance, in the operation span task, participants solve math problems while trying to remember unrelated items,” (Unsworth and Engle, 2007, p.1038).

They give the following as an example of a trial:

$$\text{IS } (8/2) - 1 = 1?R$$

$$\text{IS } (6*1) + 2 = 8?L$$

$$\text{IS } (10*2) - 5 = 15?S$$

$$\text{IS } (12/6) + 4 = 10?Q$$

$$\text{IS } (2*3) - 3 = 3?T$$

It can be concluded that these authors understand STM as a memory capacity measured by short-term memory tasks, tasks requiring storage of some number of items. And WM is described as a capacity measured by tasks requiring a storage of a number of items and focusing the attention on solving arithmetic problems at the same time. The method mentioned above became one of the most important tools for researchers in their quest for investigating WM.

Another example is description in Baddeleys work where he also distinguishes WM from STM. He says that „the term “short-term memory” is typically used to refer to systems specialised for the temporary storage of information within particular informational domains ... term “WM” is used to describe a more complex system responsible for both the processing and storage of information during cognitive tasks,“ (Baddeley, 2000, p. 78).

Conway et al. based on the theories of other researchers views the STM as „a simple storage buffer, the capacity of which is determined by practiced skills and strategies, such as rehearsal and chunking“. WM in contrast „is more complex in that it consists of a storage component as well as an attention component. The function of WM is to maintain memory representations in the face of concurrent processing, distraction, and/or attention shifts,“ (Conway et al., 2002, p.164).

### *2.3. WM, STM and their relation to higher cognitive functions*

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Studies investigated the relationship between STM and g were not convincing. Although some of the researches have supported the idea of possible realtion of STM and intelligence (Mukunda, 1992), many others have not.

Already Daneman and Carpenter in 1980 found out that simple span (task measure STM) was uncorrelated with reading comprehension. In contrast, complex

span (task measure WM) was strongly correlated with reading comprehension. Also many other researchers have supported this contention.

Conway et al. (2002), Engle et al. (1999) found that WM is a slightly better predictor of g than STM. Colom et al. (2005) and Ackerman (2005) asserted that only WM not STM predict individual differences in intelligence.

### **Possible reason**

The traditional measures of short-term memory capacity, such as simple digit span, fail to reveal a strong relationship with measures of comprehension.

Baddeley and Hitch (1974) claimed in their article that the lack of relationship between STM capacity and complex cognition is due to the fact that STM is a passive storage buffer that is not involved in the processing of information.

Another research point out that there can be found differences in the brain activity depending on number of stored informations.

Rypma et al. (1997) examined whether prefrontal areas are activated when only maintenance is required in a delayed-response WM task, without the overt requirement to manipulate the stored information. They found out that small amount of to-be-maintained items ( 3 ) required engagement of frontal areas (areas engaged while performing on STM tasks), increasing the amount of information ( >6 ), without any overt manipulation requirement resulted in recruitment of additional prefrontal areas (areas engaged while working on WM tasks). This results support Unsworth and Engle's theory (2007) of primary (PM) and secondary memory (SM). They suggested that „performance on simple and complex span tasks can be interpreted in terms of dual-component framework that combines an active maintenance component (PM) with a controlled cue-dependent search and retrieval process of information that cannot be maintained (SM)...items are initially maintained in PM but are displaced to SM by other incoming items or by distracting

information. Items that have been displaced must be retrieved via controlled search of SM at recall. Items that have not been displaced from PM are simply unloaded during recall,“ (Unsworth, Engle, 2007, p.1060). If we understand PM as a STM and SM as a WM their conclusion could explain why sometimes STM correlate with WM results. It can be assumed that simple span tasks concerning bigger amount of items measure more likely WM than STM.

Unsworth and Engle (2006) reported that complex span performance was a moderate predictor ( $r = ,45$ ) of fluid intelligence, while simple span performance was not ( $r = ,12$ ). However, at higher memory loads ( $>6$  items), both simple and complex span performance were equally good predictors, with the correlation between simple span and fluid intelligence rising to  $,45$ . These results suggested that simple span tasks measure STM only if they concern about 3 items. More items engaged probably brain areas responsible for WM. This can be the reason, why some of the researchers who were using simple span with higher memory loads to measure STM found significant correlation between STM and  $g$ .

From that reason the aim of this thesis was not to find out more about STM and its relation to intelligence, while only WM seems to be predictor of the higher cognitive functions.

#### *2.4. WM and its development*

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The term „WM“ was first formally introduced more than fifty years ago by Miller, Pribram and Galanter (1960). Miller et al. suggested that behavior is governed by concepts serving the function of goals and plans, on the basis of which the behaviour is judged and modified until a goal is reached. WM was expected to be used to maintain the plans in an effective state and make comparisons between plans and actions (see Cowan, WM capacity, 2005). The term was adopted by Baddeley and Hitch (1974) who were examining a subject's performance on list learning, retrieval, and comprehension tasks under conditions of high and low interference. Their description of WM is probably closest to the current



comprehension of WM as it's found in different studies today, which states: „individual differences in WMC reflect underlying differences in the ability to control attention in order to maintain task or goal relevant information in a highly accessible or active state in situations where there is substantial internal and external distraction and interference,“ (Unsworth, 2009, p.389).

Conway gave a more concrete definition of WM. He interpreted it as „ability to keep important information in mind while comprehending, thinking, or doing something ... this ability changes dramatically over the life span and varies considerably from person to person at a given age,“ (Conway et al., 2007, p.3).

WM became a topic of interest, especially because of its presumed role of a mediator while performing cognitive tasks.

According to Lovett: „almost any cognitive task requires engaging of WM to maintain and retrieve information during processing,“ (Lovett, Reder, Lebiere in Miyake and Shah, 1999, p.135).

„We need WM in language comprehension, to retain earlier parts of a spoken message until they can be integrated with the later parts <sup>1</sup>; in arithmetic , to retain partial results until the rest of the answer can be calculated; in reasoning, to retain the premises while working with them; and in most other types of cognitive tasks. Moreover, we need WM not only to hold new information that has been given to us, but also to integrate it with old information,“ (N.Cowan, 2005, p.36).

Shah and Miyake criticised in their work (1999), that the term WM is understood in quite different senses by different communities of researchers even within the discipline of cognitive psychology itself. In the next ten years a certain coincidence was found and the understanding of WM became uniform – it relies on “the temporary maintenance of any given information while performing some kind

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<sup>1</sup> as an example from my point of view can serve Baddeley's sentence with two endings: He strode across the court and protested vigorously that his opponent was infringing the rules by using (an illegally strung tennis racquet) (inadmissible evidence). It is not possible to tell until the last phrase whether the court is a tennis court or a court of law (Baddeley, 2004).

of concurrent processing,” (Colom et al. 2005, p.1006).

### 2.5. *WM Models and Theories*

---

Great progress has been made in WM research during the past 25 years and a large number of different models of WM were proposed, each emphasising different aspects of the construct. Miyake and Shah focused in their work on a detailed comparison of current WM models and theories by obtaining information from leading WM theorists. The two then investigated which WM models existed and what were their substantial features.

**The WM models and theories are:**

1. The multiple-Component Model (Baddeley, Hitch)
2. An Embedded-Processes Model of WM (Cowan)
3. WM and Controlled Attention Model (Engle, Kane, Tuholski)

Some other models not mentioned by Myiake and Shah shall also be discussed because of their important role in the development of the term WM and their influence on some of the following theories.

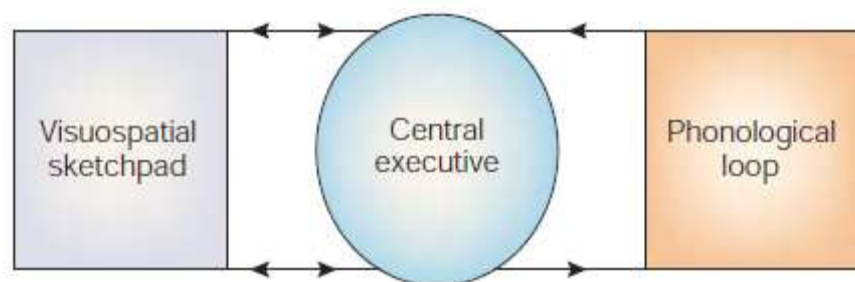
4. Three-Storage-Systeme (Atkinson, Shiffrin)
5. Capacity model (Just and Carpenter)

The biggest part will be devoted to The Multiple-Component Model of Baddeley. This model became very famous especially for its complexity and detailed elaboration.

2.5.1. The multiple-Component Model

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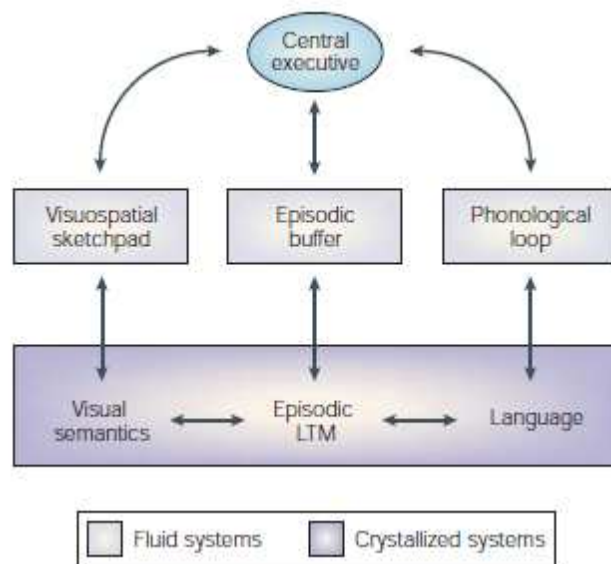
Baddeley and Hitch proposed WM model (1974) consists of three components – phonological loop, visuo-spatial sketchpad, central executive (Fig.1)



**Fig.1 Three component diagram from Baddeley (2003)**

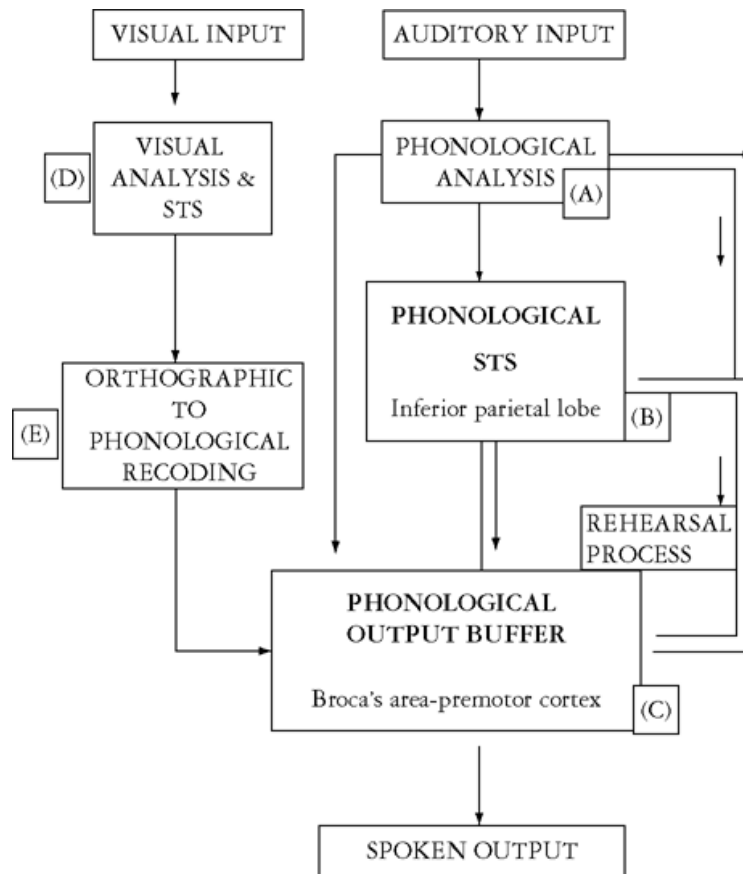
Baddeley and Hitch (2000) later decided to reformulate their theory. The multi-component model of WM has been expanded further with the addition of a

new component - the 'episodic buffer'. The restructured model looks like this (Fig.2) - there are two domain-specific short-term memory systems: the phonological loop, which is responsible for the storage of verbal information, and the visuospatial sketchpad, which is responsible for the maintenance of visuospatial information. These are governed by the central executive, which is likened to a mechanism of attentional control. The fourth component, the episodic buffer, is responsible for integrating information from the subcomponents of WM and long-term memory – i.e. it is capable of storing integrated episodes.



**Fig.2 Component revision diagram from Baddeley (2003)**

Baddeley interprets the structure of phonological loop (Fig.3) as a „phonological store, which can hold memory traces for a few seconds before they fade, and an articulatory rehearsal process that is analogous to subvocal speech. Memory traces can be refreshed by being retrieved and re-articulated. The span of this immediate memory is limited because articulation takes place in a real time – as the number of items rehearsed increases, it reaches a point at which the first item will have faded before it can be rehearsed,“ (Baddeley, 2003, p.830).



**Fig.3 Phonological loop from Baddeley (2003)**

The visuospatial sketchpad was seen by Baddeley as a capacity limited store, limited to about three or four objects. Baddeley concluded that the visual world usually persists over time, and itself provides a continuing memory record, allowing for detailed visual retention.

He describes the central executive as the most important but least understood component of WM which was in the original model treated as a general processing capacity, responsible for elaboration of all the complex issues. Later Baddeley decided to divide control between two processes as a result of adoption of Norman and Shallice model from 1986 of attentional control. Result was distinction between automatic, habitual control and attentional, supervisory control.

As the fourth component was proposed the episodic buffer. Baddeley assumed this to be a limited capacity store that binds together information to

form integrated episodes, i.e. it's a storage system that is capable of integrating information from a variety of sources (Baddeley, 2000; Baddeley, 2003).

The whole model is based on the interaction of domain-specific storage with the domain-general central executive. WM is understood as a non-unitary system, which on the other hand can not function correctly if some of its components are missing (Baddeley, Logie in Myiake, Shah, 1999).

### 2.5.2. An Embedded-Processes Model of WM

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**Cowan's view of WM** considers also diverse relevant mechanism. He understands any processing mechanisms contributing to the desired outcome, which is the temporary availability of information, to participate in the WM system. To this model contribute three components – activation, the focus of attention and awareness, long-term memory. He supports the idea that the central limit in the working system is a capacity limited focus of attention. The focus of attention is the set of highly activated long-term representations that are currently needed for ongoing processing (Cowan in Myiake, Shah, 1999).

### 2.5.3. WM and Controlled Attention Model

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In 1999, Engle, Kane and Tuholski proposed in their famous work, that differences in measurement of WM capacity primarily reflect differences in capability for controlled processing.

„We think of „WM“ as a system consisting of 1) a store in the form of long-term memory traces active above treshold, 2) processes for achieving and maintaining that activation, and 3) controlled attention. However, when we refer to „WM capacity“, we mean the capacity of just one element of the system: Controlled attention. We do not mean the entire WM system, but rather the capabilities of the limited-capacity attention mechanism which Baddeley and Hitch (1974) called the central executive. Thus we assume that „WM capacity“ is

not really about storage or memory per se, but about the capacity for controlled, sustained attention in the face of interference or distraction...it's a domain-general limited attentional capacity which facilitates performing controlled processing by focusing on task-relevant information in the face of interfering or distracting stimuli." (Engle et al. in Miyake and Shah, 1999, p.104) WM performance is according to them influenced not only by the individual ability, but also by the context (Conway et al., 2005).

Unsworth and Engle (2007) proposed later that short-term memory and WM employ the same basic subcomponent processes, but they differ in the extent to which these processes operate. This framework describes primary memory as a place where the incoming items are represented and secondary memory as another place where the items continue after being displaced by other incoming items and from where they must be retrieved by controlled search and retrieval processes. Items are first maintained in primary memory but then displaced to secondary memory by other incoming items or distracting information. So the primary memory is employed only by short-term memory tasks. Secondary memory is not only used by complex span tasks, but also by short-term memory tasks when the list of items is too long and the earlier items are displaced from primary tasks.

#### 2.5.4. Three-Storage-Systeme

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**Atkinson and Shiffrin** (1999) proposed Three-Storage-System for the human memory. This model has come to be known as the „modal model of memory“. The framework organises memory along two dimensions – the structural features of the memory system and the control processes. Structural features include the different memory stores -sensory register, short-term store, and long-term store. Control processes refer to the operations that are used to operate and control memory, such as rehearsal, coding, selection of cues for long-term retrieval, retrieval strategies during memory search, and decision rules (Shiffrin, in Chizuko, 1999).

According to this model the incoming information arrives first in the sensory register, where the sensory information is collected (Baddelay, 2004), and then continues to the short-term storage. Short-term storage has the function of WM and receives information from sensory register and also from the long-term store (Baeriswyl, 1989).

The retrieved information coming from the sensory input is combined with other information retrieved from long-term store. Combination of all this information must be stored during coding (Shiffrin in Chizuko, 1999).

#### 2.5.5. Capacity model

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**Just and Carpenter's** proposed capacity model suggested that the most fundamental reason for the differences in WM can be explained by the capacity of WM. Which means, that individuals with relatively limited WM capacity would perform worse on WM tasks than individuals with a larger capacity. They understand capacity as the ability to retain a certain amount of information with regard to the domain in question. This limited WM capacity is shared between two major functions – storage and processing. Based on the obtained results they concluded that both processing and maintenance functions are important for a prediction of the outcome (Just, Carpenter, 1992).

#### 2.6. *Processing or Storage?*

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"A fundamental characteristic of WM is that it has a limited capacity, which constrains cognitive performance, such that individuals with greater capacity typically perform better than individuals with lesser capacity on a range of cognitive tasks," (Conway et al, 2007, p.12).

The WM constructs distinguish storage and processing operations. The issue concerns how the function of maintaining content in WM relates to the function of



processing that content (deriving new information from it, comparing information, reaching conclusions, and so on).

Engle with his colleagues proposed in their works, that differences in measurement of WM capacity primarily reflect differences in capability for controlled processing. They started to investigate this controlled attention component and established its validity and reliability (Engle et al., 1999).

They also turned their attention to the question „whether people who do well on complex span tasks do well because they maintain more information in active memory or because they are better at constantly moving information from inactive memory back into active memory,“ (Engle, 2010, p.7). They concluded that although the stores are important components of WM, crucial role belongs to controlled attention (Engle, 2010).

However, most theories agree on the importance of both limited attentional capacity, supplemented by storage systems (Miyake, Shah, 1999).

Just and Carpenter concluded that both capacity and processing are important components of WM and deficit in any of the features affects the performance (Just, Carpenter, 1992).

It can be assumed that all the WM theories emphasized the importance of processing and store components of WM. Studies aimed to find out more about the importance of these components - which one of them has the main role while performing WM tasks were not convincing. It seems that the achievement on complex span tasks is not moderated only by one of the components, but they both are necessary.

### **Domain Specificity**

Another important aspect represents the domain specificity. Evidence for domain specificity in WM capacity has come from studies which suggested that

WM span tasks measure domain-specific capacities and have limited value in predicting different domain abilities - verbal span tasks have limited value in predicting spatial ability and spatial span task have limited value in predicting verbal ability (Daneman and Tardif (1987). Morrell and Park (1993) Shah and Miyake (1996) supported these findings and added that domain of the storage items (words vs. arrows), rather than the processing items, most strongly influenced the correlations with verbal and spatial ability measures. Other studies (e.g. Kane et al., 2004; Engle, Kane, Tuholski, 1999) emphasized that shared variance among measures of WM span and complex cognition reflects primarily the contribution of domain-general attention control, rather than domain specific storage or rehearsal.

In this study both verbal and spatial span tasks will be used to control possible account of domain specific storage systems.

## 2.7. The measurement of WM

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Now **the measurement** of WM shall be discussed.

Daneman and Carpenter's (1980) work is of prime importance in measuring WM. They suggested that simple span does not correlate with reading ability because it primarily measures the STM. They showed, that using simple span tasks for measuring WM is inappropriate, because it does not respect the description of WM.

In 1980, Daneman and Carpenter suggested that individual differences in reading comprehension may reflect differences in WM capacity, specifically in the trade-off between its processing and storage functions. They developed a test in which subjects were required to read aloud a series of sentences and then recalled the final word of each sentence. WM span was defined as the maximum number of sentences for which this task could be performed perfectly. They found a high correlation between WM span and reading comprehension. So they developed a reading-span test designed to measure WM capacity by tapping processing and storage functions.

The description of this test was found in an article from 2005. The original version of reading span looked like this: subjects were required to read aloud, at their own pace, sentences presented on index cards, while remembering the last word of each sentence for later recall. After a series of sentences, the subject recalled the TBR words in the order in which they had been presented. There were 15 items, 3 each consisting of two, three, four, five, and six sentences that were 13–16 words in length, and they were presented in ascending order. A subject's reading span was the level at which he or she could correctly recall the information (Conway et al., 2005).

After this test several WM span tasks which follow similar principles (the requirement that the “to be-remembered” items occur at the same time with some form of distracting activity) have been developed.

In addition, all these tasks require serial recall of the items. The variation we can find only in the nature of the distracting task and in the type of the TBR items. Unsworth et al. (2005) mentioned these works in which different distractors were used - reading sentences (reading span; Daneman, Carpenter, 1980), solving math problems (operation span; Turner, Engle, 1989), counting circles in different colors (counting span; Case, Kurland, Goldberg, 1982), and judging whether or not letters are mirror images (spatial span; Shah, Miyake, 1996) - differences in the TBR items include digits, letters, words, shapes, and spatial locations, all of which must be remembered in the correct order (Unsworth et al., 2005).

Unsworth et al (2005) concluded „Thus, although there can be large differences in the types of materials used to assess WM span, performance on these tasks have been shown to share a good deal of common variance and to be reliable indicators of a broader WM construct,” (Unsworth et al., 2005, p.498).

In 1989 Turner and Engle developed the Ospan task which requires participants to solve a series of math operations while trying to remember a set of unrelated words. Their task, the operation span task, requires that subjects solve

mathematical operations while trying to remember words. Later Engle et al. (1992) developed the version of the operation span task currently used in our laboratories. „The primary difference from earlier versions is the manipulation of presentation order, rather than presenting reading span and operation span items in ascending order (items with fewer elements first), which permitted the subjects to anticipate the number of words that they would be asked to remember on any given trial,“ (Engle et al., 1992, p.975).

In 2005, Unsworth et al. presented an automated version of operation span task (OSpan). It was a computer version of the original paper-pen Ospan. This new measuring instrument had a few advantages. First of all it was mouse driven, scored itself, and required little intervention on the part of the experimenter - participants were allowed to complete the task independently of the experimenter compared with the previous version where examiner had to be present to press a key to move on to the next operation. Further improvements consisted of change of TBR items. In this new version letters were used instead of words to suppress possible strategy use (as will be mentioned later some researchers concluded that individual differences in strategy use – interactive imagery or sentence generation – do account for significant variance on span performance). In 2010 another two automated complex-span tasks were validated – Rspan and SymmSpan. (Broadway, Engle, 2010). These three computer versions were used in this study and will be described in detail in the empirical part, chapter *Materials*.

Baddeley (2003), who proposed that WM system with two domain-specific storage structures: a phonological loop that is specialized for maintaining verbal information and a visuospatial sketchpad that is specialized for maintaining visual and spatial information, showed that there is distinction between verbal and visuospatial storage.

By the domain-specific view, span tasks consisting of verbal versus spatial materials may differ for predicting complex verbal versus spatial abilities.

This presumption was also supported by many studies (Daneman, Tardif, 1987; Morrell, Park, 1993, etc.) which reported that whereas span tasks using verbal and

numerical materials correlated significantly with verbal ability measures, a spatial span task did not and only spatial span predicted object assembly performance from diagrammatic, visuospatial instructions.

From that reason not only OSpan and RSpan but also SymmSpan were used in this study.

### **3. WM and higher cognitive functions**

#### *3.1. Conducted studies*

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Many studies have investigated the various possibilities of the relationship between WM and higher cognitive functions.

Andrade concluded that „the WM has an important role as a set of processes which play an essential role in complex cognition. Understanding how we temporarily store and process information is fundamental to understanding almost all aspects of cognition,“ (Andrade, 2001, p.3).

Many studies in this area have investigated the various possibilities of the relationship between WM and higher cognitive functions. During the past decade much attention has been paid to the role of WM in the establishment of intelligence. Some of the most influential studies investigating the relationship between WM and higher cognitive functions from the past years will now be introduced.

As mentioned above in 1980, Daneman and Carpenter suggested that individual differences in reading comprehension may reflect differences in WM capacity, specifically in the trade-off between its processing and storage functions. Kyllonen and Christal (1990) found structural coefficients of ,80 through ,88 between WM and reasoning ability.

Meta-analysis conducted by Ackerman, Beier, and Boyle (2005) indicated average correlation ,36 between measures of *g* and WM tests. They claimed that WM capacity shares less than 25% of its variance with general intelligence (*g*). Oberauer et al. (2005) made reanalysis of this study and showed that *g* and WMC are highly correlated. Also Colom et al. (2005) achieved similar results - WM system largely

drives the relationship between WM and g,  $r = .89$ . Also another researcher supported this finding – e.g. Conway, Kane, Engle (2003)  $r = .59$ , Colom, et al. (2005)  $r = .89$ . Evidence about significant relationship between WM capacity and standard measures of fluid intelligence provided also Fukuda et al. (2010)  $r = .66$

Conway et al. (2002) concluded, that between general fluid intelligence and each of the following constructs exist significant relationships: short-term memory capacity, WM capacity (WMC), and processing speed. They add, that based on the results WMC is a good predictor of general fluid intelligence in young adults. Colom and Martínéz found in 2009 that WM and processing speed are related to intelligence. They measured concurrently WM, processing speed and processing efficiency along with fluid, crystallized and spatial intelligence. Their findings showed that WM and processing efficiency predict fluid, but not crystallized and spatial intelligence.

### *3.2. Possible base for the relation*

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Some of the newest studies are trying to find the possible base for this relation.

Barrouillet et al. (2008) probed, if the influence of WM capacity on high-level cognition is mediated by complexity or resource-dependent elementary processes. Their results suggest that the influence of WM capacity on high-level cognition is mediated by the impact of a basic general-purpose resource that affects each step of cognition. Halford et al. (2007) came out with a new hypothesis, that WM and reasoning share the related capacity limits. They explained that the relationship between these two constructs is a result of them maintaining the common bindings between elements.

Baddeley and Logie (1999) suggested that WM plays a crucial role for complex cognitive activities such as language comprehension, mental arithmetic, and reasoning, because all these cognitive activities require processing of the information, their retention in the storage systems and controlled attention enabled

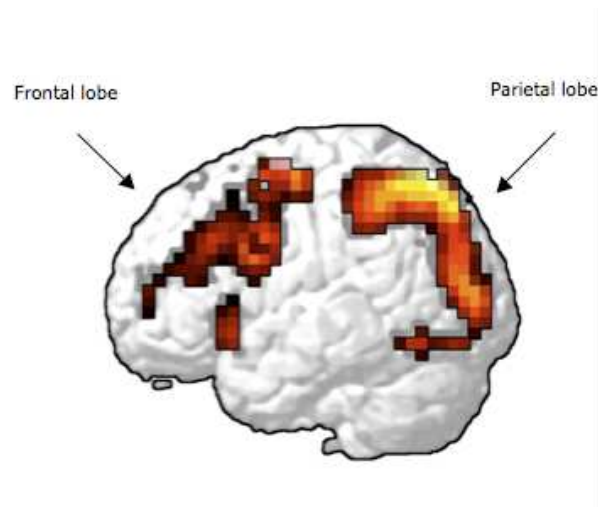
by central executive which includes the coordination of the subsidiary systems, the control of encoding and retrieval strategies, and thus supports the problem solving.

Bailey et al. (2008) suggested, that individual differences which can be found in the performances of a WM and on other cognitive tasks are a result of strategy use. They concluded that relationship between these two constructs can be found, only if the same strategy (like imagery and sentence generation) is afforded by both tasks. Unsworth et al. (2009) examined the relations between WM capacity, attention control (components of WM), and general fluid intelligence. And he suggested that attention control is an important component of the WM and general fluid intelligence relation. Fukuda et al. (2010) suggested that the relationship between WM capacity and standard measures of fluid intelligence is mediated by the number of representations that can be simultaneously maintained in WM.

Theory I agree the most with is Lohman's theory. This author summed up in 2001 that the reason for more often appearing studies which find correlations between WM and reasoning is the interpretation of WM. He concluded, that if WM is interpreted as system of a storage component and a separate executive (or supervisory attentional system) that attends selectively to one stimulus while inhibiting another, coordinates performance in tasks, and switches strategies (Baddeley's theory) it is more likely to find a relationship between this construct and reasoning. Because reasoning requires that one simultaneously remember and transform information.

Lohman's theory seems to be supported by the brain imaging studies.

These studies using brain imaging methods PET and fMRI have suggested a critical role for prefrontal cortex in WM (Salmon et al., 1996; Rypma et al., 1999; Clayton E. Curtis and Mark D'Esposito 2003, Klingberg et al. 2002).



**Fig.4** Colored regions of the brain that are activated by a working memory (Klingberg 2002)

Grey et al. (2003) in their study tested whether general fluid intelligence (Gf) is mediated by brain regions that support attentional (executive) control, including subregions of prefrontal cortex. Their results shown that standard measure of Gf engage these areas of prefrontal cortex. Which means that same brain areas are engaged while performing both WM and intelligence tasks.

#### **4. WM-Tasks and strategy use**

Some of the recent studies investigated the strategy affordance hypothesis - the influence of variation in strategy use on individual differences in span performance as well as on span-cognition relationships (Bailey, Dunlosky, Kane, 2008; Dunlosky, Kane, 2007).

Bailey, Dunlosky, and Kane (2008) used OSpan task where the participants saw a mathematical operation and a TBR word (example in capt. WM measurement) and RSpan where the participants saw either a logical or a nonsensical sentence and an unrelated word. They noted that because the to-be-remembered stimuli for these span tasks were individual words, participants afforded several associative strategies, such as rehearsal, imagery, and sentence generation. After performed span tasks participants indicated which strategy they



had used to remember the words.

This strategy mediation hypotheses was based on the expectation, that „performance is higher when individuals report using normatively effective strategies (e.g., interactive imagery or sentence generation) than when they report using less effective ones (e.g., reading),“ (Bailey, Dunlosky, Kane, 2008, p. 1383).

These studies concluded that individual differences in strategy use do account for significant variance on span performance. That is, span performance was higher when individuals reported using interactive imagery or sentence generation. On the other hand they also concluded, that although strategy use can influence span performance, effective strategy use does not appear to account for span – cognition relationships (Dunlosky, Kane, 2007; Bailey, Dunlosky, Kane, 2008).

In their work, Unsworth and Engle (2005) as mentioned above used letters in their OSpan and RSpan because previous research has suggested that some of the shared variance between span tasks that use words and a measure of higher order cognition, such as reading comprehension, is due to word knowledge.

But it seems that the results when letters are used can also be affected by another well known technique. On the internet, a simple example could be found: „When you took music classes in school do you remember the lines on the music staff, the treble clef, E, G, B, D, and F? If your teacher ever told you to think of the sentence “Every Good Boy Does Fine”, then you might remember them. Your teacher was following that basic memory rule, probably without realising it. He or she was helping you to remember new (and abstract) information, the letters E, G, B, D, and F, by associating them to something you already knew, or at least understood the simple sentence “Every Good Boy Does Fine”. The presented memory rule is: ”You can remember any new piece of information if it is associated to something you already know or remember,” (*Using Association Techniques for Better Memory*, 2006).

## 5. Intelligence

Although this thesis does not aim to describe in detail **the origin of intelligence**, it acts as an introduction for better understanding for what reason the intelligence test LPS-neu was chosen for this study. We can say that this test is a reflection of the recent consensus among different views of intelligence. Many researchers found this consensus reasonable and tests developed on this basis have many advantages because it considers more aspects.

The definitions of intelligence and their relation to the development of the current view of it shall now be presented, after which shall follow an introduction to the development of intelligence theory. The procedure of development of Kreuzpointners´LPS-neu and the introduction of the LPS itself is summed up in the conclusion.

It is possible to find many different definitions of intelligence. Vetta project (2010) collected some of the definitions of intelligence given in encyclopedias that have been either contributed by an individual psychologist or quote an earlier definition given by a psychologist. Some are more focused in conceiving intelligence as a general ability - for example “Intelligence is a general factor that runs through all types of performance.” A. Jensen, “Any system ...that generates adaptive behaviour to meet goals in a range of environments can be said to be intelligent.” (D. Fogel, 1995) “Intelligence is the ability to use optimally limited resources – including time – to achieve goals.” (R. Kurzweil, 2000), or “Intelligence is the ability to process information properly in a complex environment” (H. Nakashima, 1999), “...the essential, domain-independent skills necessary for acquiring a wide range of domain-specific knowledge – the ability to learn anything. Achieving this with ‘artificial general intelligence’ (AGI) requires a highly adaptive, general-purpose system that can autonomously acquire an extremely wide range of specific knowledge and skills and can improve its own

cognitive ability through self-directed learning,” (P. Voss, 2005).

Another definition emphasises the non-uniformity of intelligence – “Intelligence is not a single, unitary ability, but rather a composite of several functions. The term denotes that combination of abilities required for survival and advancement within a particular culture.” A. Anastasi, 1992), “...the term intelligence designates a complexly interrelated assemblage of functions, no one of which is completely or accurately known in man ...” (Yerkes, Yerkes, 1929).

Said definitions are an expression of a long historical development which is marked by a dispute between one set of proponents who believe that all intelligence comes from one general factor, known as ‘g’ and another set who believe there are other types of intelligences.

### *5.1. Throughout the history of intelligence and its testing*

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One of the first persons, who understood intelligence as a general ability, largely inherited, and explainable by the speed of mental processes, was Sir Francis Galton (1869). More influential work was done by Binet. He developed a test which became one of the first scales for the measurement of intelligence in 1905 and was revised in 1908 and 1911 (Eysenck, 1998).

After this, many theories and models of intelligence were developed.

#### **The most influential are:**

- Spearman’s model for general intelligence factor called ‘g’
- Thurston’s Primary abilities
- Horn-Cattell’s Gf-Gc theory
- Carroll’s Three stratum theory

## 5.2. Spearman's model for „g“

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Spearman understands „g“ as a unit represented by a set of separate components in a form of particular abilities. He used a factor analysis and investigated the intercorrelations of various measures of individual differences (Wolman, 1985).

## 5.3. Thurston's Primary abilities

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One of the first persons to test Spearman's theory was Thurston. He used 56 tests of various intellectual abilities and concluded that Spearman's conclusion was wrong. He claimed, that correlations found by Spearman, which he (Spearman) understood as a demonstration of the presence of general cognitive ability, were in fact measurement of different so-called „primary abilities“). Thurston through factor analysis identified primary abilities of verbal comprehension (V), word fluency (W), number facility (N), spatial thinking (S), associative memory (M), perceptual speed (P), general reasoning (R), inductive reasoning (I), and deductive reasoning (D) (Indiana.edu., 2007).

## 5.4. Horn-Cattell's Gf-Gc theory

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It is also possible to find a strong disagreement with Spearman's *g* in all of Horn's contributions (in Wolman, Handbook of intelligence, 1985, in Kyllonen, Roberts, Stankov, Extending intelligence, 2008). He argues that there is more than one general type of intelligence.

Horn represents his knowledge about the abilities of human intelligence in Gf-Gc theory. He found more general organisation, represented by nine major kinds of cognitive capacities: Acculturation knowledge (Gc), Fluency of retrieval from long-term storage (Glm), Fluid reasoning (Gf), Short-term apprehension and retrieval (SAR), Processing speed (Gs), Visual processing (Gv), Auditory processing (Ga), Correct decision speed (CDS), Quantitative knowledge (Cq).

He talks about 60-70 distinct common factors, found by previous researches, operating at primary level and other nine common factors operating at a second-order level. One set of primary level indicators are labelled fluid reasoning and is symbolised Gf. Another set of primary-level indicators is labelled crystallised knowledge and is symbolised Gc.

Horn was inspired in his work by Cattell's theory of fluid and crystallised intelligence from 1941. Cattell summarised in his study, that the cognitive abilities do not represent one unit construct but rather separate intelligences.

Abilities of reasoning that are required to attain understanding of novel relationships and acquire concepts indicate one form of intelligence, which he called *fluid (gf)*.

Abilities of maintaining and accessing concepts, and reasoning with these concepts, indicate a second form of intelligence, labeled by Cattell as *crystallised (gc)* (Horn in Woodcock, 1998).

### 5.5. Carroll's Three stratum theory

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Carroll accepted Spearman's general factor in his work and he emphasised, that Spearman was not interested only in *g* but also in specific factors *s* (these specific factors were called group factors). Based on reanalysis of comprehensive data, he came to his own theory.

Carroll's model of intelligence is called Three stratum theory. This theory became very popular and influenced many following researches as according to McGrew „The major strength of Carroll's meta-factor analysis is that, for the first time ever, an empirically-based taxonomy of human cognitive ability elements was presented in a single organised framework. The raw materials reviewed and analysed by Carroll drew on decades of research by a diverse array of dedicated researchers,“ (McGrew, 2009, p. 2).

Carroll's model is hierarchical and displays cognitive abilities according to

level of generality.

**Stratum I** includes 69 narrow abilities that are subsumed by the **Stratum II** (broad abilities) which includes the abilities of Fluid intelligence, Crystallised Intelligence, General Memory and Learning, Broad Visual Perception, Broad Auditory Perception, Broad Retrieval Ability, Broad Cognitive Speediness, and Reaction Time/Decision Speed. And the **Stratum III** – the broadest level is general intelligence factor *g*.

In his work, Carroll shows the similarities and differences between his model and other intelligence models. Some of these descriptions will be mentioned in this thesis, because they clearly show the main ideas of all of the previously mentioned theories and even approach the particular stratum of Carroll's theory.

As mentioned above, Carroll agree with Spearman about the existence of one general factor and the stratum III is essentially the same as Spearman's factor *g*. Similarly stratum I is essentially equal to Spearman's group factors. Spearman was one of the inspirations for Carroll's famous work from 1993. As other sources usher the Thurston's Primary abilities model. According to Carroll, this model was the basis for his Three-stratum theory. Thurston's model was one-stratum model and Carroll assumed this stratum as similar to the stratum II in his model – represented by broad abilities.

Another inspiration for Carroll's work was also the Horn-Cattell Gf-Gc model. Horn, as mentioned above, has extended the work of Cattell by identifying 9 to 10 broad Gf-Gc abilities.

Carroll concludes this Gf-Gc model as the closest approximation to his three-stratum model of human cognitive abilities that differs abilities as a function of breadth (Carroll, 1993).

The most obvious difference between the two models is the presence of higher order factor *g* in Carroll's model and its absence in Horn's model (McGrew, 2009).

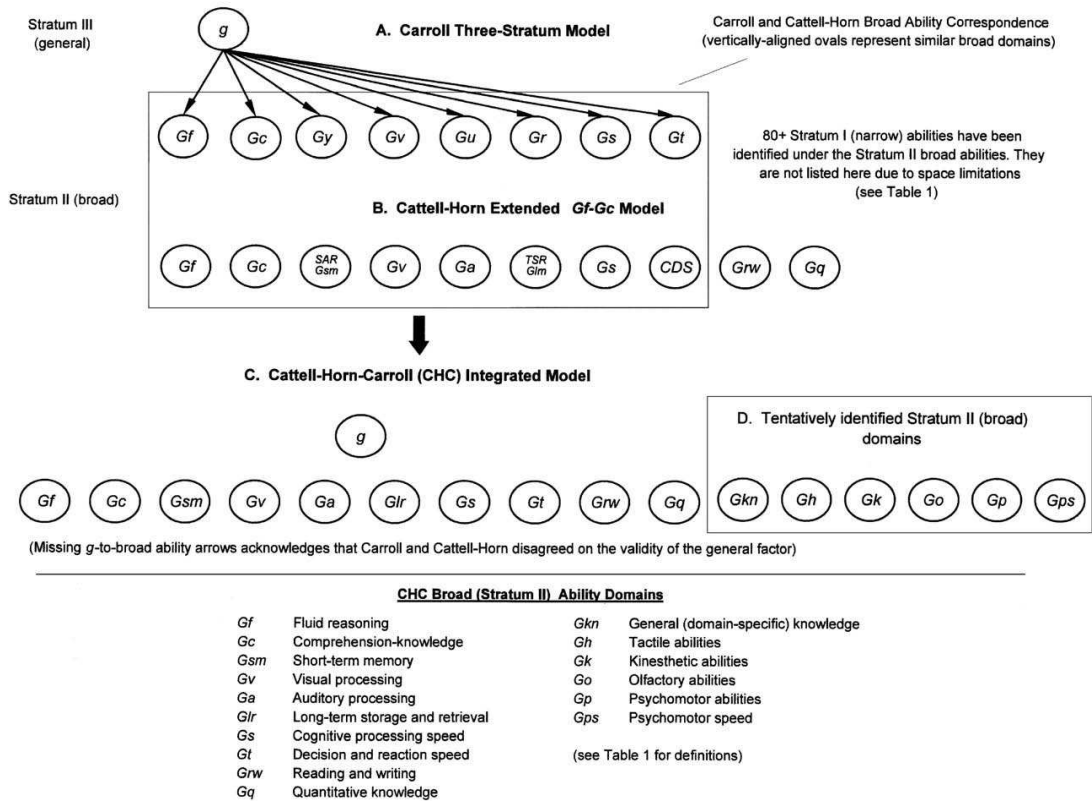
As described earlier, Horn was a sworn enemy of  $g$  and Carroll reacted on his arguments saying: „ It is true, as Horn (1988) points out, that the third stratum factor computed (by the Schmid-Leihman technique) in a given study can be somewhat different from one computed in another study, for its nature depends in part on the types of variables and factors present or emphasised in the battery as a whole. Nevertheless, if a battery contains an adequate diversity of variables the third-stratum factor that is computed can be regarded as an estimator of a true latent-trait  $g$ ; the accuracy of estimation depends in part on whether the battery contains variables selected to represent second-stratum factors known to have high loadings on  $g$ . In principle, it should be possible to derive scores on a third-stratum factor that weigh the scores on the original variables to provide optimal estimation of  $g$ ,“ (Carroll, 1993, p.639).

The existence of a single higher order general factor  $g$  has been the focus of much debate. To conclude, Carroll is one of those who agree that the shared factors among the broad abilities are represented well by the general factor. Horn and others focused on broad abilities and considered  $g$  as a conglomerate of more specific cognitive abilities.

### 5.6. *C-H-C theory*

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The recent results from understanding of intelligence structure were summed up in C-H-C theory. This theory integrates the Cattell-Horn Gf-Gc theory (Horn, Noll 1977) and Carroll’s three stratum theory (Carroll, 1993). „During the past decade the Cattell–Horn Gf–Gc and Carroll Three-Stratum models have emerged as the consensus psychometric-based models for understanding the structure of human intelligence. Although the two models differ in a number of ways, the strong correspondence between the two models has resulted in the increased use of a broad umbrella term for a synthesis of the two models (Cattell–Horn–Carroll theory of cognitive abilities—CHC theory),“ (McGrew, 2009).



**Fig.5 Diagram of synthesis of the two models from McGrew (2009)**

CHC theory describes a hierarchical model of cognitive abilities that vary according to level of generality: narrow abilities (Stratum I), broad abilities (Stratum II), and according to a few, general intelligence ( $g$ ; Stratum III) as well. Narrow abilities include approximately 70 highly specialised abilities. Broad abilities include Fluid Reasoning, Crystallised Intelligence, Short-Term Memory, Visual Processing, Auditory Processing, Long-Term Retrieval, Processing Speed, Reading and Writing Ability, Quantitative Knowledge, and Reaction Time/Decision Speed.

## Summary



Development of intelligence theory has a quite long history evolving in my opinion in accordance with well-known triad - "thesis → antithesis → synthesis".

Thesis is represented in this case by a single common factor explaining the positive correlations among different intelligence tests – general intelligence factor *g*. Antithesis is seen as the negation of the existence of this general intelligence factor and proposal of a several distinct factors. I see the synthesis in the unification of both theories in one theory representing broad cognitive abilities and general factor as a unit. There can be found a huge amount of intelligence tests aimed at identifying either the general intelligence factor or broad abilities. To follow principles of the synthesis, test designed to measure not only the general intelligence factor *g* but also broad abilities was used.

The newest intelligence structure research findings converged on the widely accepted view that intellectual abilities can be structured hierarchically. General factor *g* is postulated on the highest level of aggregation, which is differentiated into more specific mental abilities on at least one level below. Oberauer et al. (2000) suggested that also concept of WM can be understood as one general cognitive resource with differentiated second level. General factor *g* and WM base on these conclusions were understood in this study as a higher order latent variables. Broad cognitive abilities and WM tasks as the second level more specific variables.

### 5.7. *LPS-neu*

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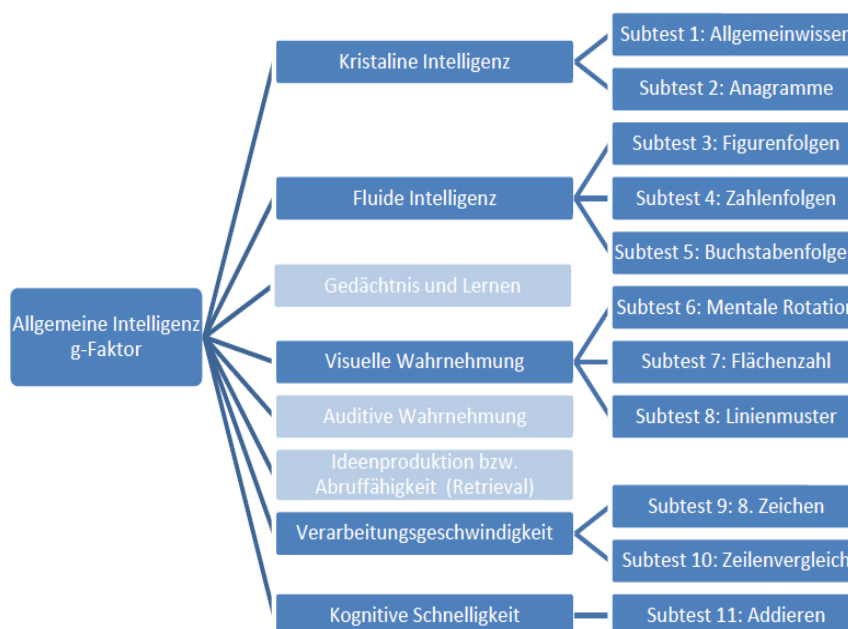
Kreuzpointner (2010) based his research on publications dealing with the revision of the Leistungsprüfsystem (LPS, developed by Horn in 1962; 1983). These results together with results of other studies, which published complete data on LPS, were introduced by him in his work where he explained that the results suggest the possibility of the reduction of the number of subtests of LPS in order to

gain more efficient diagnostic-instrument maybe even with a higher informative value. Kreuzpointner suggested and subsequently established a new efficiency testing system through conducting a new factor analysis of eight studies (from 17 random samples) containing the intercorrelation matrix of the subtests by using the same methods and criteria.

This new compilation follows three principles: preservation of the basic ideas of the LPS, increasing economy and practicality, new orientation of the basis of the structure-theory.

The original LPS contains 15 subtests, whereas the new version has only 11 as a result of analysis of the studies focused on factor analysis of LPS. As an adequate base of the LPS, Kreuzpointner considered the Carroll's three stratum model (Kreuzpointner, 2010).

In his work, Kreuzpointner used the Carroll's three-stratum model as a base for possible comparison of abilities measured by the subtests of LPS and similar looking abilities in Carroll's ordering.



**Fig.6 Intelligence structure diagram from Kreuzpointner, 2010**

Kreuzpointner emphasised that by the development of the paper-pen version,

the principles of Horn's LPS has been given the deserved importance. Especially an elaboration of the items directly in the test and the quadrilateral conception of the test-arch have been maintained which enable printing on DIN A3 (this fact is quite important, because the original version was smaller and was criticised rather for testing visual-skills than cognitive achievement). The items were digitalised and printed on a white paper so that they could be better recognised. The instructions and the item-examples were added on the first side of the test-arch other than on the beginning of the item-column (Kreuzpointner, 2010). Comparing with the new version, both of these facts (enlargement of the items as well as highlighted printing and the order on the sheet) increase the objectivity of the new LPS.

## **6. Empirical Part**

### *6.1. The research problem*

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The main aim of this Thesis is to investigate the relationship between general intelligence factor  $g$  and WM, as well as relationship between some of the abilities from the area of Broad abilities and their relation to WM-Span tasks. Attention was also focused on the methods used to measure WM (automated version of a WM capacity tasks developed by Unsworth et al. 2005) and the various ways it has been elaborated by respondents depending on the usage of different strategies. According to some of the previous studies, the usage of different strategies when answering WM tasks was found to be an important factor contributing to varied results on WM tasks. Usage of these strategies was found to positively influence the results obtained by respondents who used them. The term „strategy“ implies a procedure which helps to better remember the “to-be-remembered” items. The question is whether the strategy use might also influence results gained in the new version of WM measurement, which will be used in this study.

## 6.2. *The research questions*

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### **Hypothesis**

H<sub>A1</sub> – there is a relationship between WM and general intelligence factor *g*.

H<sub>01</sub> – there is no relationship between WM and general intelligence factor *g*.

H<sub>A2</sub> – there may be relationship between Broad abilities and WM span tasks

H<sub>02</sub> – there is no relationship between Broad abilities and WM span tasks

### **Research question**

Is there a difference in participants' scores on automated WM tasks if they use some kind of helping strategy?

### **Controlled variables:**

- Influence of domain specificity on the relationship between WM span tasks and Broad abilities.
- Influence of current well-being on obtained results in WM and LPS Tests
- Influence of attitude towards LPS Test on LPS Test results

## 6.3. *Operationalisation*

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In this study these constructs will be measured– general intelligence factor *g*, so-called Broad abilities, general WM, WM span tasks, the current well-being, the questionnaire acceptance.

Another investigated construct is the strategy that can be helpful in information storage.

G-factor is comprehended as a general cognitive ability.

- The value of **g-factor** is understood as a total score measured by the new version of LPS-Test. (see chapter *Materials*)
- **Broad abilities** are presented by the score on the some of some specific single subtests of the new version of LPS-Test. (see chapter *Materials*)

Crystallized Intelligence, Fluid intelligence, Visualisation, Broad Cognitive Speediness.

- **Crystallized Intelligence** is represented by the score on LPS subtests 1 (Lexical knowledge) and 2 (Anagrams)
- **Fluid Intelligence** is represented by the score on LPS subtests 3 (Form series), 4 (Number series) and 5 (Letter series)
- **Visualisation** is represented by the score on LPS subtests 6 (Mental rotation), 7 (Number of flats) and 8 (Lines pattern)
- **Broad Cognitive Speednes** is represented by the scores on LPS subtests 9 (Signing), 10 ( Lines comparison), 11 (Adding)

WM capacity is represented by the total score on WM span tasks - Ospan, Rspan, SymmSpan (Engle, 2005)

- **Ospan** (operation span task) – score in a task requiring the participants to solve a series of math operations while trying to remember a set of unrelated letters.
- **Rspan** (reading span tasks) – score in a task requiring the participants to read a sentence and determine whether it made sense or not while at the same time trying to remember a set of unrelated letters.
- **SymmSpan** (symmetry span tasks) – score in a tasks requiring the participants to keep track of the positions of filled cells displayed sequentially in a grid and as the next step, trying to judge whether or not displays composed of filled cells in a grid possessed symmetry about the vertical axis
- **“To-be-remembered” (TBR)** items are items used in WM-Tasks. They can

be either letters or various positions of filled cells displayed sequentially in a grid which the respondents are required to remember.

Helping strategy - this term implies the usage of any mental process which enables the participants to better retain the TBR items while performing WM-tasks which are different from simple 'repetition of letters' in the mind. The participants were asked to describe the strategy which helped them to remember letters or keep track of the positions of filled cells. As a strategy by Ospan and RSpan, these letters were used in words and then sentences were made with these words in order to remember the presented letters.

Another strategy by SymmSpan is one where cells are counted from the sites, and then remembering the directions in which the filled cells were presented – any process which made storage easier than pure refreshing.

Current well-being is understood as a total score on the "Fragebogen zum aktuellen Wohlbefinden" (Well-being questionnaire). (see chapter *Materials*)

Attitude towards LPS Test represent the score on Akzeptanzfragebogen (Acceptance questionnaire). (see chapter *Materials*)

Moderator variables

As a possible moderator variable which needed to be controlled, the things considered were current well-being state before performing WM and LPS Tests and attitude towards LPS Test.

#### 6.4. *Participants*

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A total of 54 participants, 19 men and 35 women were German students between 20 and 51 (median 23) years who were made available either through university advertisements or randomly through requests for participation.

Participants gathered through university advertisement were psychology students at the University of Regensburg who had the opportunity to gain experience with a broad range of psychological research and furnishes faculty and graduate students in the psychology department with participants for their research projects. These participants received either course credits or another compensation for their participation. Participation was entirely voluntary.

Participants gathered through random participation requests were students of different subjects at University of Regensburg and Fachhochschule. Participation was also voluntary and recompensed.

Because both WM-Tasks and LPS-new were quite time-demanding, participants had to come twice. This fact was the cause of the sample reduction from the original 54 to 51 participants (16 men, 35 women). 51 participants took part in both tests.

### *6.5. Procedure and Materials*

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The WM tasks (OSpan, Rspan, SymmSpan) were administered to 54 adult students, the LPS-Test was administered to 51 students. Among them, 3 participants refused to continue after performing WM-tasks. These methods were chosen as valid and reliable instruments for the measurement of established constructs. Both the methods were quite time-demanding, WM-tasks required approximately 70 minutes and the LPS-Test 60 minutes, together. All the participants performed first on the WM-tasks and after an interval of a few days, on the LPS-Test. One participant did both of the tests in a one day, performing first on WM-tasks and then on the LPS-Test, without any considerable interval. Both of the tests were administered and interpreted by me.

WM-tasks were presented as a computer version, the participants were asked either to come to the university laboratory or to do the tests at their homes under the control of an examiner (me). Two of the 54 participants did the WM-tasks at their homes in a quiet room without any disturbance. Rest of the participants performed

these tasks in a university laboratory where three computers were provided so that a maximum of three participants could work on the tasks simultaneously. Participants were asked to follow the instructions presented on the computer screen and to inform the examiner as soon as they finish one of the presented sections (OSpan, RSpan) in order to continue with the following one. After finishing the last section (SymmSpan) the total score has been calculated. Between single sections of the WM-tasks, no interval has been taken. The respondents were immediately familiarised with the following section and asked to continue. After finishing all the sections the participants were also asked to fill the Feelings questionnaire.

LPS-Test was presented as pen and paper version and the instructions were read out by an examiner (me). The respondents were also asked to come to the laboratory or do the tests under my control at their homes. Total of 48 participants did the test in the laboratory and 3 at their homes in tranquillity.

LPS-Test was originally a German version, thus, no translation was required. This test contains 11 subtests and on each test is time-limited. First, the participants were familiarised with the general requests of this test, the examples of each subtest on the first page has also been introduced. Then, the instructions together with examples of each subtest were presented. After introducing each of the instructions, participants were asked whether they understood or not and started with the presented subtest. Performance on each subtest was time limited. Participants were asked to stop after the given time and to go back to the instructions page. Again, instructions for the following subtest were presented, and there was no pause between the subtests. In case participants made a mistake they could correct it.

They worked from top to bottom without skipping any of the task. If they didn't know the right answer, they guessed. Tasks became slowly more and more difficult. Each subtest was time-limited and the number of tasks was established so that it was very difficult to get to the end of the subtest. In case participant managed to get to the end, he/she started to control her/his answers from the beginning. After finishing the last subtest respondents were asked to put down their pens.



### 6.5.1. Questionnaires

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- 1) Before performing the WM-tasks, participants were asked to fill up an anonymous personal questionnaire which contained their VP-Code (identification code), gender, age, field of education, year-class, graduation marks. After finishing all the WM-tasks, participants were asked whether they used any kind of helping strategy for better remembrance of the given to-be-remembered items in each section. In case they did, they wrote it down in the questionnaire.
  
- 2) Another questionnaire presented was Well-being questionnaire/□Fragebogen zum aktuellen Wohlbefinden (Stadler, 2010). Participants were asked to assess their current Well-being before performing both on WM and LPS tasks. They marked on bipolar analog scales (without values) how they felt. Eight bipolar scales were presented, each including two polar well-being statements. Participants made a sign on a scale closer to one of the poles depending on how they felt. These scales were: Unbekümmertheit (carelessness), Frische (freshness), Gelassenheit (calmness), Vertrauen (Trust), Behaglichkeit (komfort), Aufmerksamkeit (attention), Entspannung (repose), Interesse (interest). For example when they felt very tired they made the sign closer to the TIRED pole, on the other hand when they felt fresh they made the sign close to FRESH pole etc. They were given this questionnaire before performing the WM-tasks.
  
- 3) After finishing the LPS-Test, participants were given Acceptance questionnaire/Akzeptanzfragebogen (Kersting, 2008). This questionnaire contained 18 questions focused on evaluating just how well the participant had understood the instructions for LPS, and how his/her attitude to the LPS-Test was.

This version of LPS was new, so this questionnaire was used to make sure

that participants understand correctly each subtest and that their attitude towards this new version was good, so the results couldn't be influenced by this fact.

Also three kinds of questionnaires mentioned above were used – Personal questionnaire, Well-being questionnaire, Acceptance questionnaire. All questionnaires were in German, so no need for translation was required.

## 6.6. *WM-Tasks*

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All the participants completed three automated complex-span measures: operation span (OSpan), reading span (RSpan), and symmetry span (SymmSpan) presented by Unsworth et al. (2005).

Three distinct WM measurements were used, to reflex different content domain – Ospan, RSpan (letter content domain) and SymmSpan (visuospatial content domain). Ospan and RSpan differ in the processing part – in Ospan focused on counting in RSpan on reading comprehension.

### **OSpan**

Now the automated version of Ospan will be introduced in more details. The new automated (computerized) version of Ospan could be run independently without intervention of the investigator. Participants read the instructions on the computer screen and needed only to click the mouse button, to run the test and to mark the right solutions.

In the new version made by Unsworth et al. (2005) the tasks were designed to force WM storage in the face of processing, in order to engage executive attention processes. Each processing stimulus was presented until the participant responded or the deadline was reached, memory item (presented for

250 ms in OSPAN and RSPAN and for 650 ms in SSPAN) followed; after each memory item came new processing stimulus or a memory test.

The practise section of this task was broken down into three sections and Unsworth et al. describe it as: „The first practice section was simple letter span. A letter appeared on the screen, and the participants were required to recall the letters in the same order in which they were presented. At recall, the participants was a 4 x 3 matrix of letters (F,H,J,K,L,N,P,Q,R,S,T, and Y). Letters were used because previous research has suggested that some of the shared variance between span tasks that use words and a measure of higher order cognition, such as reading comprehension, is due to word knowledge (e.g., Engle, Nations, & Cantor, 1990). Recall consisted of clicking the box next to the appropriate letters (no verbal response was required) in the correct order. The recall phase was untimed. After recall, the computer provided feedback about the number of letters correctly recalled in the current set. Next, the participants practiced the math section of the task. They first saw a math operation (e.g.,  $(1*2) 1 ?$ ). The participants were instructed to solve the operation as quickly as possible and then click the mouse to advance to the next screen. On the next screen a digit (e.g., 3) has been shown and the participants were required to click either a “true” or “false” box, depending on their answer. After each operation, the participants were given accuracy feedback. The math practice served to familiarise them with the math portion of the task as well as to calculate how long it would take each person to solve the math operations. Thus, the math practice attempted to account for individual differences in the time required to solve math operations. After the math practice, the program calculated each individual’s mean time required to solve the equations. The time required (plus 2.5 *SD*) was then used as a time limit for the math portion of the experimental session for that individual. The participants completed 15 math operations in this practice session. In the final practice session, the participants performed both the letter recall and math portions together, just as they would do in the real block of trials (see Figure 1). As in the Turner and Engle Ospan, the participants first saw the math operation,

and after they clicked the mouse button indicating that they had solved it, they saw the letter to be recalled. If the participants took more time to solve the math operations than their average time plus 2.5 *SD*, the program automatically moved on and counted that trial as an error. This served to prevent the participants from rehearsing the letters when they should be solving the operations. The 2.5-*SD* limit was based on extensive piloting.

Participants completed three practice trials each of set size 2. After the participants completed all the practice sessions, the program progressed to the real trials, which consisted of three sets of each set size, with set sizes ranging from 3 to 7, which took it to a total of 75 letters and math problems each. Note that the order of set sizes was random for each participant. Set sizes ranging from 3 to 7 were used because pilot studies showed that these set sizes produced the best distribution of scores (i.e., neither on ceiling nor on floor). As we wanted to only use those participants who were attempting to solve both the math operations and remember the letters, we imposed an 85% accuracy criterion for all participants. Therefore, they were encouraged to keep their math accuracy at or above 85% at all times.

During recall, a percentage in red was presented in the upper right-hand corner of the screen, indicating the percentage of correctly solved math operations. At the conclusion of the task, the program reported five scores to the experimenter: *Ospan score*, *total number correct*, *math errors*, *speed errors* & *accuracy errors*. The first, *Ospan score*, used our traditional absolute scoring method. This was the sum of all perfectly recalled sets. So, for example, if an individual correctly recalled 3 letters in a set size of 3, 4 letters in a set size of 4, and 3 letters in a set size of 5, his or her *Ospan score* would be 7 (3 4 0). The second score, “total number correct,” was the total number of letters recalled in the correct position. Three types of errors were reported: “Math errors” were the total number of task errors, which was then broken down into “speed errors,” in which the participant ran out of time in attempting to solve a given math operation, and “accuracy errors,” in which the participant solved the math

operation incorrectly. The task took approximately 20–25 min to complete,” (Unsworth, 2005, p.500-501).

### **Rspan.**

In Rspan, the participants were required to read sentences while trying to remember a set of unrelated letters. The whole process was similar to automated OSpan. In this experiment participants tried to memorize letters they saw on the screen while they also read sentences.

First they had practice to get them familiar with how the experiment works. They began by practicing the letter part of the experiment. For this practice set, letters appeared on the screen one at a time. Participants were asked to try to remember each letter in the order presented. After 2-3 letters have been shown, they saw a screen listing 12 possible letters. They were required to select each letter in the order presented. Next, they practiced doing the sentence reading part of the experiment. A sentence appeared on the screen, like this: "I like to run in the park." As soon as they saw the sentence, they should read it and determine, if it made sense or not. An example of a sentence that does not make sense would be: "I like to run in the sky." On the next screen they saw "This sentence makes sense". If the sentence on the previous screen made sense, they clicked on the TRUE box with the mouse. If the sentence did not make sense, they clicked on the FALSE box. After they clicked on one of the boxes, the computer will tell them if they made the right choice.

Next, they practiced doing both parts of the experiment at the same time. 15 sentence problems were presented. Participants were given one sentence to read and once they made their decision about the sentence, a letter appeared on the screen. They were asked to remember the letter. In the previous section where they only read the sentences, the computer computed their average time to read the sentences. If they took longer than their average time, the computer automatically moved them onto the next letter part, thus skipping the True or

False part and counted that problem as a sentence error. After the letter went away, another sentence appeared, and then another letter. At the end of each set of letters and sentences, a recall screen appeared. Participants were not told if their answer regarding the sentence was correct. After the recall screen, they were given feedback about their performance regarding both the number of letters recalled and the percent correct on the sentence problems.

During the feedback, they saw a number in red in the top right of the screen. This indicates their percent correct for the sentence problems for the entire experiment. Only data where the participant was at least 85% accurate on the sentences were used in for other purposes. The real trials looked like the practice trials completed before. First they got a sentence to read, then a letter to remember. When they saw the recall screen, they selected the letters in the order presented. Total of 81 sentences problems were presented in this section (Engle, 2005)

### **SymmSpan**

Last section was SymmSpan. Automated Symmetry span task. Participants were required to keep track of the positions of filled cells displayed sequentially in a grid with and next judging whether or not displays composed of filled cells in a grid possessed symmetry about the vertical axis. In the final practice session, the participants performed both the positions of filled cells and judging whether the figure is symmetry or not together. They began by practicing the "square" part of the experiment. In this practice set, squares appeared on the screen one at a time. Participants were required to remember where each square was, in the order it was presented in. After 2-5 squares had been shown, they saw a grid of the 16 possible places the squares could had been. Participants were asked to select each square in the order presented. They used the mouse to select the appropriate boxes. The squares they select turned red. When they have selected all the squares in the correct order, they hit the EXIT box at the bottom right of the

screen. In case they made a mistake, they could use the CLEAR box to start over. They could also click the BLANK box to mark the spot for the missing square, if they forgot one of the squares.

Next, they practiced doing the symmetry part of the experiment. A picture appeared on the screen, and they had to decide, if it was symmetrical. A picture was symmetrical if it could be folded in half vertically and the picture on the left lined up with the picture on the right. Next, they practiced doing both parts of the experiment at the same time. They were given one of the symmetry problems and once they made their decision about the picture, a square appeared on the screen. Participants were required to remember the position of the square. After the square went away, another symmetry picture appeared, and then another square. Total of 15 symmetry problems were presented. In the previous section where they only decided about the picture symmetry, the computer computed their average time to solve the problems. If it took them longer than their previous average time, the computer automatically moved them onto the square part, thus skipping the YES or NO part and counted that problem as an error. At the end of each set of pictures and squares, a recall screen appeared. They used the mouse to select the squares they have seen. They were not told if their answer to the symmetry picture was correct. After the square recall screen, they were given feedback about their performance regarding both the number of squares recalled and the percent correct on the symmetry problems.

During the feedback, they see a number in red in the top right of the screen. This indicates their percent correct for the symmetry pictures for the entire experiment. They have to keep this at least at 85%. Only data at least 85% accurate on the symmetry pictures are used in the next part of the study. After finishing practice phase they work on the real trials. The real trials look just like the practice trials they just completed and consisted of 48 Symmetry problems (Engle, 2005).

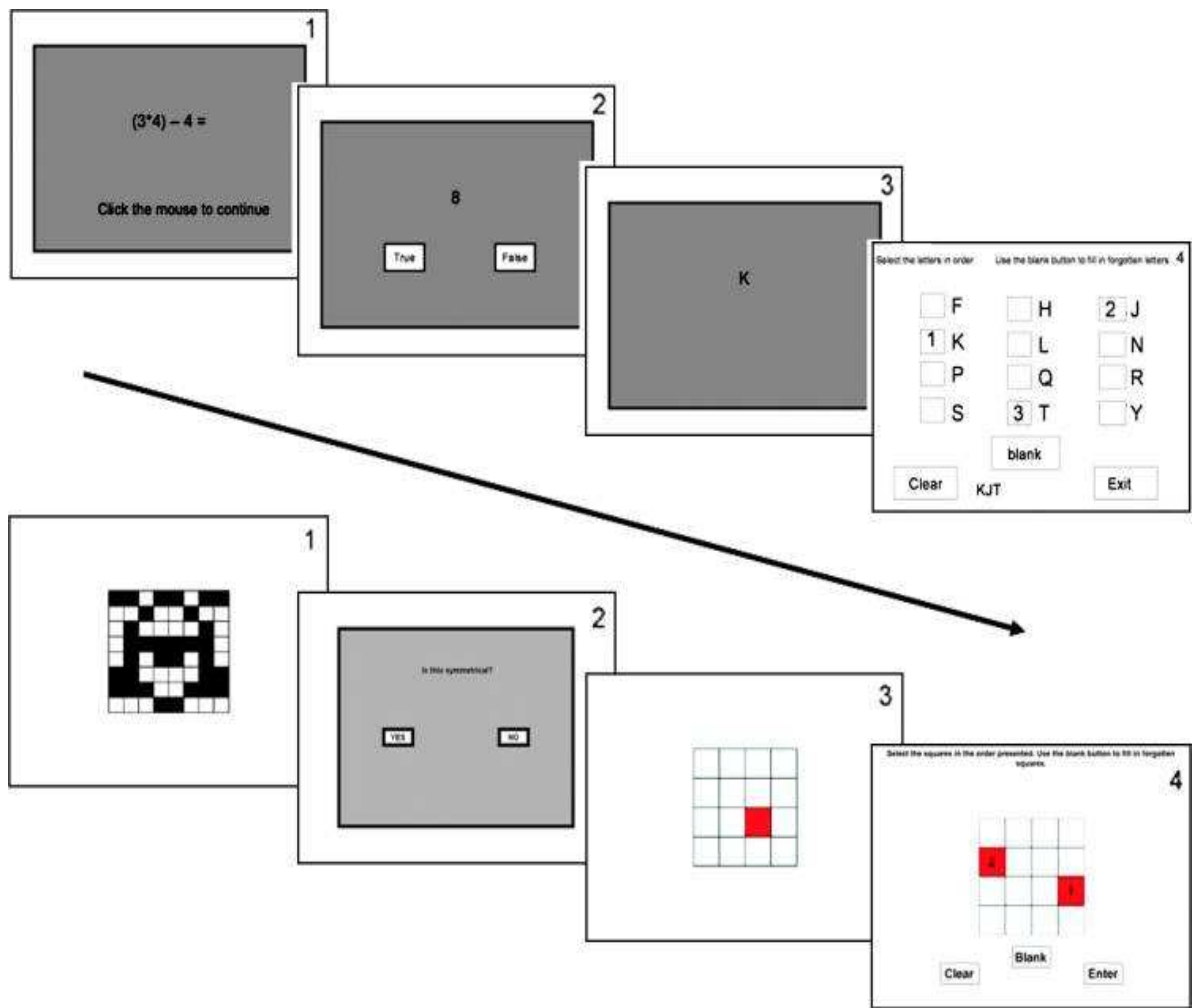


Fig.7 Illustration of OSpan and SymmSpan task (Barch, D.M., et al. 2009)

### 6.6.1. LPS-neu

LPS-neu is a German test revised by Kreuzpointner (Kreuzpointner, 2010). It has been chosen as it is the newest, complex and from my point of view, the most suitable method for the measurement of so-called Broad abilities and general intelligence factor  $g$ . As mentioned above, Kreuzpointner, who reworked Horn's LPS test from 1983, used the Carroll's three-stratum model in his work as base for the comparison of abilities measured by the subtests of LPS-neu and similar looking abilities in Carroll's Stratum II. In Carroll's model, factor  $g$



(General intelligence) which influenced every cognitive achievement is placed on the highest level. The next level, Stratum II includes eight factors (Broad abilities):

As the aim of this study is to discover more about the relationship between WM and general intelligence factor  $g$  and also the relationship between single WM-Span Tasks and Broad cognitive abilities, LPS-neu was the optimal choice because this method measured both of these constructs.

Four of **Carroll's Stratum II Broad abilities** are measured by LPS-neu are:

- Crystallized Intelligence
- Fluid intelligence
- Broad Visual Perception
- Broad Cognitive Speediness

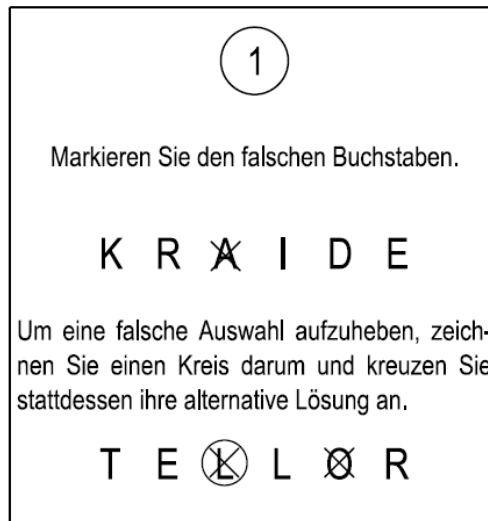
**LPS-Neu** includes 11 subtests, these are:

- 1) Allgemeinwissen (General knowledge)
- 2) Anagramme (Anagrams)
- 3) Figurenfolgen (Form series)
- 4) Zahlenfolgen (Number series)
- 5) Buchstabenfolgen (Letter series)
- 6) Mentale rotation
- 7) Flächenzahl (Number of flats)
- 8) Linienmuster (Line pattern)
- 9) 8. Zeichen (Marking)
- 10) Zeilenvergleich (Lines comparison)
- 11) Addieren (Adding)

The subtests 1 (General knowledge) and 2 (Anagrams) in the LPS are focused on measuring the general education based on the linguistic competence. Based on Carroll's definition of Stratum II, Kreuzpointner included these two subtests in Crystallized Intelligence section. On the grounds of Carroll's other definitions, Subtests 3 (Form series), 4 (Number series) and 5 (Letter series) engaged reasoning and were classified under Fluid Intelligence. Subtests 6 (Mental rotation), 7 (Number of flats) and 8 (Line pattern) were classified under the factor Visualisation. From the remaining three subtests 9 (Signing) and 10 ( Lines comparison) were subsumed under Processing Speed factor and Subtest 11 (Adding) found it is place under the factor Broad Cognitive Speediness.

- 1) Subtest number 1 was designed to measure a general knowledge. The idea of this subtest was that participants with higher general knowledge would be more likely to recognize the presented word and identify the wrong letter in it. Total of sixty words were presented in a column. In the given words there was always one letter changed. Participants were asked to identify this letter and mark it with a cross. For example in the word KRAIDE, A was the wrong letter, because KREIDE (chalk) should be written with an E, so A had to be marked. Participants had three minutes to complete this task.

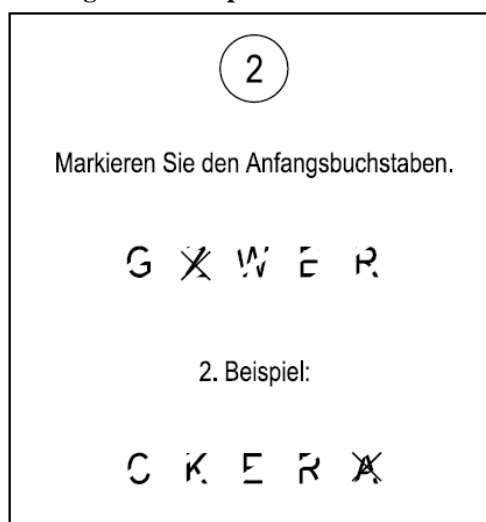
**Fig.8 Example of LPS subtest 1**



Also subtest 2 was based on the presumption that participants with higher general knowledge are more likely to identify well-known words, this time presented with intermittent structure and mixed letters.

The task in this subtest was to find the first letter of the word and mark it with a cross. For example from letters G-Z-W-E-R-K the word ZWERG (dwarf) could be generated, therefore Z had to be marked with a cross. Participants had three minutes for forty tasks.

**Fig.9 Example of LPS subtest 2**

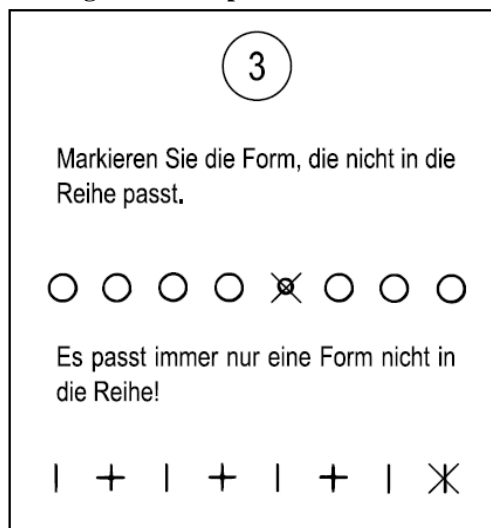


Subtest 3 and also subtest 4 and 5 were designed to measure reasoning in terms of the Thurston's primary mental abilities. All of the subtests required participants to find a rule which underlay the systematic.

In subtest 3 thirty series of 8 symbols were presented whose order and form underlay some rules. Participants had to find this rule and cross the symbol which misfitted. For example in series |+|+|+| is the rule |+|+, from that reason the last | misfits and must be marked with a cross.

Participants could work for three minutes.

**Fig.10 Example of LPS subtest 3**



In subtest 4 there were forty series made of nine numbers whose order also underlay a rule .

For example 4 5 5 4 5 4 5 4 5, the rule is 4 5 4 5, so the second 2 must be marked with a cross.

**Fig.11 Example of LPS subtest 4**

4

Markieren Sie die Zahl, die nicht in die Reihe passt.

2 2 2 2 2 ~~2~~ 2 2 2

Es passt immer nur eine Zahl nicht in die Reihe!

4 ~~5~~ 5 4 4 5 4 4 5

Similar in subtest 5 it was presented letters or a couple of letters and participants had to mark with a cross not fitting items. They were given both in subtest 4 and subtest 5 five minutes.

**Fig.12 Example of LPS subtest 5**

5

Markieren Sie den Buchstaben bzw. das Buchstabenpaar, das nicht in die Reihe passt.

a b a b a b a ~~a~~ a

Es passt immer nur ein Buchstabe bzw. ein Buchstabenpaar nicht in die Reihe!

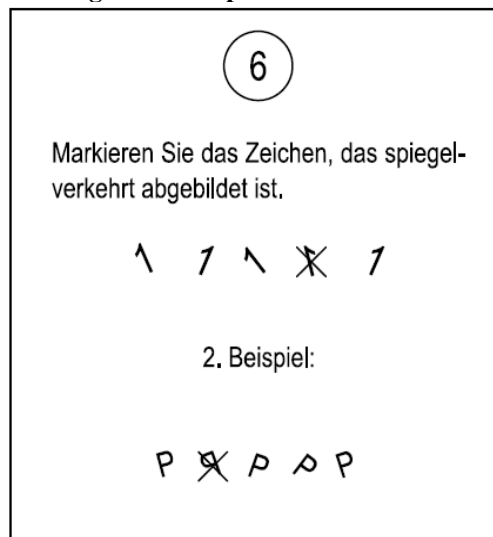
aa ~~bb~~ b aa aa b aa aa b

Subtests 6, 7 and 8 were based on the Thurston's Space factor.

In subtest 6 it was shown 40 series, each series consisted of five repetitions of the *same symbol* (numbers or letters). Each symbol was rotated around the center. One of the symbols was always mirror-inverted. Participants were tasked to recognize this mirror-inverted symbol and mark it with a cross. To find this mirror-inverted symbol mental rotation and comparison was needed.

For this test participants were given two minutes.

**Fig.13 Example of LPS subtest 6**

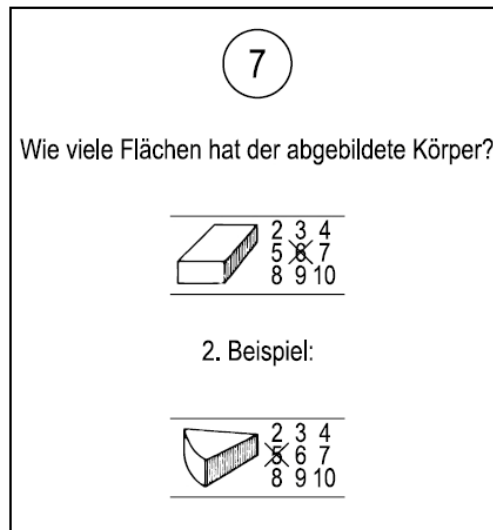


In subtest 7 the task was to calculate the number of surfaces of presented geometric solids and cross the right answer next to the solid. Also not visible surfaces had to be counted in.

Participants had to use visualization and rotation to be able to count all of the surfaces.

For example, the rectangular solid / rectangle has six surfaces, so number six had to be marked. Solids were organized in two columns. Participants were asked to start with one column and after they finished continue to the next one. This task lasted three minutes and participants counted surfaces of twenty geometric solids.

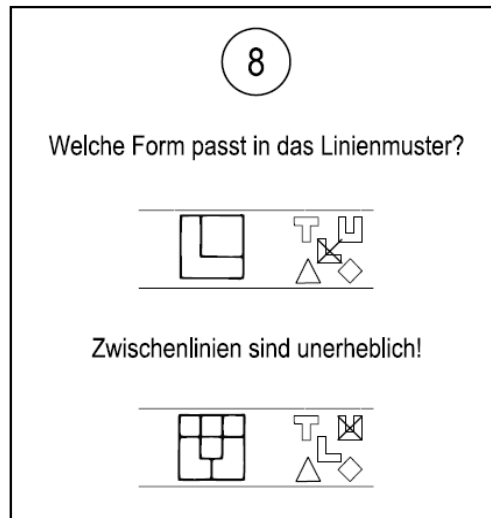
Fig.14 Example of LPS subtest 7



Subtest 8 contained forty line patterns and lasted two minutes. Participants were required to decide which one of presented five shapes fitted in the line pattern. Shape but also position had to fit. Stroke in some of the fitting patterns was irrelevant. Only one of the shapes fitted correctly. Shapes couldn't be rotated. This task didn't require any mental rotation.

Also there were here shapes organized in two columns and participants followed the same rule as in previous subtests.

**Fig.15 Example of LPS subtest 8**



Subtests 9, 10 and 11 were focused on Cognitive Speed.

In subtest 9 the task was to mark every eighth 0. They had to go through the row step by step, count nulls and mark every eighth one. When all eight nulls were marked then participants were to go back to the beginning and start to count 1 – every eighth 1 had to be marked, and then again with 2, 3, 4, 5, 6, 7, 8, and 9.

If participants started to work first in column 9 and marked numbers, it would be very difficult for them to compare column 9 with column 10 in the following subtest.



**Fig.16 Example of LPS subtest 9**

9

Markieren Sie jede achte 0.  
ACHTUNG: nur in Spalte 9

A00B00  
00L0M0  
0S000R  
00F00T

Wenn Sie am Ende der Spalte angelangt sind,  
beginnen Sie, jede achte 1 zu zählen, dann  
jede achte 2, jeder achte 3 usw.

In subtest 10 participants had to first peruse row in subtest 9 then in subtest 10 and mark the wrong symbol/s, after that they could work on the following row. More than one symbol could be marked but some of the rows could be without.

**Fig.17 Example of LPS subtest 10**

10

Markieren Sie die Zeichen in Spalte 10,  
die nicht mit den Zeichen in Spalte 9  
übereinstimmen.

A 0 0 B 0 0 | A 0 ~~X~~ B 0 0

Es gibt auch Zeilen, die vollständig  
identisch sind, und Zeilen, die sich in  
mehr als einem Zeichen unterscheiden!

0 0 L 0 M 0 | 0 0 L 0 ~~X~~ 0

Subtest 11 assesses the ability to concentrate. In this subtest were presented eighty rows each of ten numbers. The task was to count numbers of each row. The result was a two-digit number and participants were asked to mark a single-digit number of the result. For example  $2+4+2+6+2+4+2+6+2+5 = 35$ , so 5 had to be marked.

Fig.18 Example of LPS subtest 11

11

Addieren Sie die zehn Zahlen und markieren Sie die Einerziffer der Lösung.

2 4 2 6 2 4 2 6 2 ~~8~~

Die Einerziffer der Summe ist unter den zehn Zahlen immer nur einmal aufgeführt!

8 2 6 ~~8~~ 4 2 6 4 2 6

Because the research took place in Germany the English version of WM tasks had to be translated to German. The translation has been done by me and native German speakers and controlled by the supervisor of this thesis.

#### 6.6.2. Strategy use

One of the research questions was whether the participants used any kind of helping strategy except for refreshing of the "to-be-remembered" items (repeating them over in mind). This question was formulated after analysis of the pilot study. It was discovered in this study that although the researchers wanted to avoid intervening variables in the form of word knowledge, which they suggested to be the reason for the shared variance between span tasks that use words and a measure of higher order cognition, such as reading comprehension (e.g. Engle, Nations, Cantor, 1990), and used letters instead, the participants were not only refreshing these letters while performing on the WM tasks but were also integrating these letters in words which helped them in recalling them. This strategy is called

Association technique which was also used by some participants while performing on Rspan tasks. Different kinds of strategies were found while performing on SymmSpan tasks, wherein some participants were not just refreshing the track of the positions of filled cells.

Based on this finding the participants were asked about the ways which helped them to remember the "to-be remembered" items after they performed all the WM tasks. Total of 26 participants mentioned using some kind of helping strategy. These strategies were often mentioned by Ospan and Rspan: making words (especially names or often used subjects) from the presented letters, or even making sentences with these words. Helping strategies were not used often by SymmSpan. Participants who did use strategy mentioned counting of cells from the sites, additional remembering of direction – in which was the presented filled cell

## 6.7. Results

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To reject or accept null hypothesis several statistical tests were performed. 51 participants took part both in LPS and WM tests. The WM tasks ( OSpan, Rspan, SymmSpan) were administered to 54 adult students. Only data where the participant was at least 85% accurate on the processing part of the WM span tasks were used for other purposes. 52 participants were successful in OSpan, 49 in SymmSpan and 47 in RSpan.

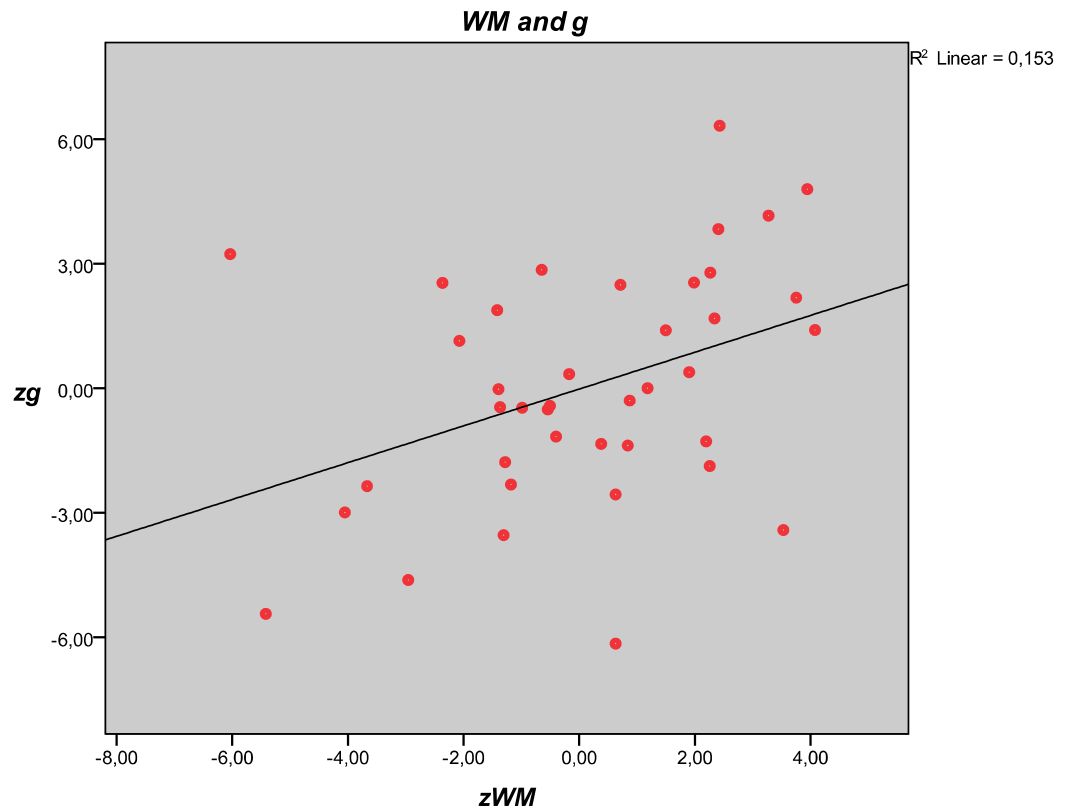
Descriptive statistics can be found in Table 1.

**Table 1: Descriptive statistics**

	<b>N</b>	<b>Missing</b>	<b>Mean</b>	<b>Std.Dev.</b>
<b>G</b>	51	0	285,12	37,12
<b>Gf</b>	51	0	64,18	7,73
<b>Gc</b>	51	0	64,84	17,35
<b>Gv</b>	51	0	87,59	14,57
<b>Gs</b>	51	0	68,51	11,37
<b>WM</b>	43	11	102,65	38,48
<b>OSpan</b>	52	2	43,81	18,209
<b>RSpan</b>	47	7	36,47	9,023
<b>SymmSpan</b>	49	5	20,96	18,593

Before proceeding with the statistical analyses, all the measures were converted to z-scores to compute composites for the constructs of interest. Firstly, the correlation between g and WM was computed. The results suggested that the relation between WM and g is significant ( $r = .391$ ) ( $p < .05$ ). Regression analysis can be seen in Graph 1.

**Graph 1: Regression analysis of the relationship between WM and g**



Based on the results, H0 is rejected and accepted H1 – there is a relation between WM and general Intelligence.

Next, correlation analyses was conducted to test the hypothesis about the association between WM Span tasks and Broad abilities.

This analyses suggested that all correlations between Broad abilities and WM Span tasks were positive. Rspan and Ospan were both significantly related to Gc ( $p < ,05$ ). SymmSpan and Ospan were both related to Gf ( $p < ,05$ ), SymmSpan was related to Gs ( $p < ,05$ ). No significant correlation was found between Gv and WM span tasks. All the correlations can be found in Table 2.

Given these results, I am inclined to reject the null hypothesis and accept H2 – there is a relationship between Broad abilities and WM Span tasks

To see the relation more generally the correlation between general WM and broad abilities was also conducted. Significant correlation was found between WM and two of the Broad abilities Gc ( $p < ,05$ ), Gf ( $p < ,05$ ).

**Table 2: Correlation between general WM and general factor g, and correlations between 4 Broad abilities and 3 WM Span tasks**

	<i>z g</i>	<i>z Gc</i>	<i>z Gf</i>	<i>z Gv</i>	<i>z Gs</i>
<b>z WM</b>	,391*	,365*	,328*	,213	,225
<b>z Ospan</b>	,338*	,318*	,314*	,163	,185
<b>z Rspan</b>	,221	300*	,180	,063	,088
<b>z SymmSpan</b>	,366*	,177	,320*	,249	,322*

\*. Correlation is significant at the .05 level (2-tailed).

Based on the results I rejected H0 and accept H1 – there is a relation between WM and general intelligence.

The research question was, whether participants' scores on a WM test would differ if the helping strategy is used?

The results show, that use of a helping strategy influences performance on WM Span tasks. Participants who didn't use any form of helping strategy scored significantly higher on both OSpan and RSpan, but not on SymmSpan (Table 6). No significant correlation was found between strategy use and SymmSpan performance

The descriptive statistics can be found in Table 3, 4 and 5.

**Table 3: Descriptive statistics of strategy use in Ospan task**

Ospan	N	Mean	Std.Dev.
<b>No_Strategie</b>	34	50,18	15,103
<b>Strategie</b>	17	30,35	17,281

**Table 4: Descriptive statistics of strategy use in RSpan task**

<b>RSpan</b>	<b>N</b>	<b>Mean</b>	<b>Std.Dev.</b>
<b>No_Strategie</b>	26	41,85	17,456
<b>Strategie</b>	20	30,55	18,312

**Table 5: Descriptive statistics of strategy use in SymmSpan task**

<b>SymmSpan</b>	<b>N</b>	<b>Mean</b>	<b>Std.Dev.</b>
<b>No_Strategie</b>	43	20,98	9,127
<b>Strategie</b>	5	22,40	9,154

**Table 6: Results of the conducted T-Test**

<b>Strategy vs. No_Strategy use</b>			
<b>WM span task</b>	<b>T</b>	<b>Df</b>	<b>P</b>
<b>OSpan</b>	4,211	49	<,0001**
<b>RSpan</b>	2,130	44	<,039*
<b>SymmSpan</b>	-,330	46	<,743

\*. Correlation is significant at the 0.05 level (2-tailed).

\*\*. Correlation is significant at the 0.01 level (2-tailed).

One of the controlled variables was the current mental state.

The question was whether current mental state may have an effect on the WM and LPS test results.

As can be seen in Table 7 the results suggest that the performance on WM Span tasks was not influenced by the current mental state.

**Table 7: Correlation between WM span tasks and current mental state**

	Tension	Interest	Carelessness	Freshness	Calmness	Trust	Comfort	Attention
<b>OSpan</b>	,014	,189	-,159	,207	,092	,073	,007	,214
<b>RSpan</b>	-,075	,187	-,044	,099	,023	-,030	,036	,225
<b>SymmSpan</b>	,139	-,110	-,138	-,043	-,050	,143	-,240	,085

Performance on LPS Test seems to be uninfluenced by current mental state. Performance on GC and Gs weakly correlated with Tension. Gc score also correlated weakly with Trust. The results can be found in Table 8.



**Table 8: Correlations between Broad cognitive abilities and current mental state**

	Tension	Interest	Carelessness	Freshness	Calmness	Trust	Comfort	Attention
<b>Gf</b>	-,152	-,090	,108	-,037	-,233	,036	-,143	,059
<b>Gc</b>	<b>-,294*</b>	,170	,159	,179	-,231	<b>-,281*</b>	,155	,144
<b>Gv</b>	-,188	,180	,248	,126	-,151	-,095	,071	,038
<b>Gs</b>	,070	,003	-,155	,063	,169	,133	-,275	-,061

\*. Correlation is significant at the 0.05 level (2-tailed).

These results suggest that both test results were virtually unburdened by the current mental state of participants.

An acceptance questionnaire was used to find out more about the level of interest of the participants. This questionnaire was focused, among other things, on participants' attitudes towards the LPS-Test.

Results shown in Table 9 suggest that the performance was not influenced by the participants' attitudes towards LPS-Test. The positive responses significantly outnumbered the negative ones. The descriptive statistics can be found in Table 9 and the results of the T-Test can be seen in Table 10.

**Table 9: Descriptive statistics of obtained responses in acceptance questionnaire**

<b>SymmSpan</b>	<b>N</b>	<b>Mean</b>	<b>Std.Dev.</b>
<b>Positive Responses</b>	50	23,509	4,504
<b>Negative Responses</b>	50	32,254	4,840

**Table 10: Results of the conducted T-Test**

<b>Positive vs. Negative_Responses</b>			
	<b>T</b>	<b>Df</b>	<b>P</b>
<b>Acceptance questionnaire</b>	37,26	50	< ,0001**

\*. Correlation is significant at the 0.05 level (2-tailed).

\*\*. Correlation is significant at the 0.01 level (2-tailed).

## 6.8. Discussion

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### 6.8.1. Sample:

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This study involved a randomly selected group of 54 german university students with a median of age 23. The results are therefore generalizable to that population.

Common criterion for inclusion in this study was completion of neither LPS-neu nor an automated version of WM span tasks. They also did not come into contact with each other before performing WM tasks, so the possibility of the use of this strategy in WMSpan tasks would not be known.

Based on the selection, participants could be divided into two groups. One group was composed of students whose participation was voluntary and our main aim was to find out more about their test results. Another group was composed of psychology students at the University of Regensburg gathered through university advertisements, their primary goal was to gain course credits. Differences between these two groups were not controlled, but it is possible that obtained results may have been influenced by the motivation of the participants in each groups.

Although both WM-Tasks and LPS-new were quite time consuming, the reduction of the sample for personal reasons was only 3 participants which should not have had greater influence. Additional reduction of the obtained data depended on the requirements of the WM tasks and there was nothing to prevent them. These losses were caused by WM processing sections in which the participants were required to keep at least 85% accuracy criterion. Data of participants who did not manage to keep this level were eliminated. It was not possible to know in advance how much data would be lost, because success in processing could not be controlled

#### 6.8.2. Procedure:

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Testing was conducted in a quiet environment and the same conditions of administration were followed throughout. As possibly intervening variables, current mental state and attitude toward LPS neu were controlled. Tension and Trust, two of the variables reflecting current state of mind, seemed to have a weak negative influence on performing Gc in LPS. Although influence of tension on LPS performance was only weak, it was possible to avoid it by arranging another appointment. But since I evaluated this questionnaire only after participants performed the LPS test i did not receive this information on time.

LPS-neu was a new version of the performance test and for that reason, attitude toward this test was assessed. In more detailed investigation it did not show that attitude (trust included) could be affected by LPS performance.

### 6.8.3. Methods:

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Because the research took place in Germany all the tests had to be in German. For that reason, translations of WM span tasks written in English were required.

The answer to the research question whether there is a difference in participants' scores on automated WM tasks if they use some form of helping strategy was surprising. Although previous research suggested that there is a positive correlation between strategy use and WM results in earlier versions, statistical analysis of data gained in this work showed the opposite. This means that participants who didn't use any kind of helping strategy scored significantly higher on both OSpan and RSpan.

Strategy use had no influence on SymmSpan performance. But this could be due to a small number of strategy use in performing SymmSpan (only six participants used strategy when they were performing SymmSpan). However, this finding indicates that participants who tried to aid their memory and used a form of the helping strategy (normatively effective strategies) (e.g., interactive imagery or sentence generation) had worse outcomes than participants who didn't. A possible explanation may lie in the difference in the use of to-be-remembered items. In earlier versions, words were used as to-be-remembered items and it was found that performance on these tasks was moderated by strategy use and the shared variance between span tasks that use words and a measure of higher order cognition was due to word knowledge (Bailey et al. 2008). In contrast, in the new version in order to avoid the possible influence of mentioned strategies, letters were used instead. Participants who wanted to aid their memory and decided (of their own volition) to use strategy in the form of sentence generation had first to make words from presented letters and only subsequently generate the sentence. This procedure required much more time which could result in participants not using the strategy optimally (WM-tasks were timed) and consequently got worse results. Another possible explanation may lie in the characteristics of the sample. Studying

at university requires frequent involvement of working memory. Thus take advantage of this capacity may lead to better results than, if helping strategy is use. It would be interesting to see, how the results would be affected by population that does not use working memory much.

Another thing which could possibly have influenced obtained results was the fact that a few randomly asked respondents said, that they have used a stragy in LPS subtest 11 focused on cognitive speediness measurement. The task was to count numbers in each row. The result was a two-digit number and participants were asked to mark a single-digit number. For example, if the task is  $6+5+8+5+4 = 24$ , 4 has to be marked. Some of the participants would work only with single-digit numbers (they would be counting  $6+5=11$ ,  $11+8+5=24$ ) which is less demanding than counting with two-digit numbers ( $6+5=11$ ,  $11+8+5=24$ ). This strategy helped participants to work faster. This could cause individuals whose mental processing is slower, to get a higher score than participants with quicker mental processing who did not use a helping strategy. The use of this strategy could have influenced Gs.

#### 6.8.4. Findings:

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##### **Found correlations:**

Significant correlation was found between WM and  $g$  ( $r = .39$ ,  $p < .05$ ).

Although this correlation was significant it was much less than was found in previous studies where  $g$  and WM were viewed as (almost) isomorphic constructs (e.g. Oberauer, 2005, Conway Y, A.R.A., Kane, M.J., Engle, R.W., 2003; Colom, R., Shih, P., 2004; Colom, R. et al., 2005) or a strong relationship between both constructs was revealed (Buehner, M., Krumm, S., Ziegler, M., Pluecken, T., 2006). More detailed focus showed that there is a significant correlation between WM and Fluid Intelligence and WM and Crystallized intelligence. Correlation between WM and Fluid intelligence corresponds with findings of previous studies Unsworth et al.(2005), Colom et al(2005), Conway et al. (2002), FRY, A.F., Hale, S.(1996), Kane, M.J. et al. (2004), but here the correlation was lower. Mildly significant

correlation found between WM and Crystallized Intelligence does not correspond with findings of Colom and Martínéz, (2009) who suggested that WM and processing efficiency predict fluid, but not Crystallized intelligence. No evidence about the relationship between WM and Broad visual perception was found which does not correspond with the results obtained in another study conducted by Bühner M., Kröner S., Ziegler M. (2008) who suggested that Gv and working memory were highly related. Also no relation was found between WM and Processing speed, whereas Conway et al. 2002 suggested these two variables were correlated.

Another reason may be the fact, that although there has been recent consensus among the researchers in the view of the term WM, various tests are used for its measurement. Complex span requires that participants engage in some processing activity unrelated to the memory task – this is quite a big demand which enables usage of large amount of methods.

Also methods used in mentioned studies were based on different principles. Some WM span tasks concerned work with TBR items in processing part. (ABCD and Alphabet and Mental Counters tasks task used in Colom et al, 2005).

In another mentioned study, storage was assessed in the context of processing component of the WM model by dual tasks when first several TBR were presented followed by several processing tasks (Bühner et al. 2006)

Different TBR-items, different processing tasks and different ways of combining them were used in the previous studies.

I have not found any irregularity in the measurement of a g or its subcomponents in this or other mentioned studies, but variations in the naming of these variables may also lead to distinct conclusions. As mentioned by Yuan: „ Different terms for fluid intelligence were used interchangeably, such as “nonverbal intelligence”, “reasoning ability”, “g”, “general fluid intelligence”, and “intelligence.” (Yuan, K. et al., 2006)

Upon closer examination of the relationships between WM Span tasks and Broad cognitive abilities it seems that explanation of found correlation relate only to the processing portion of WM tasks which are (unlike TBR) different in RSpan

(determination of sense of sentences) and OSpan (solving of math operations).

Significant correlation found between OSpan and Gc, Gf would support the idea that, math problem solving probably reflects a mix of Gf and Gc“ (Snow, R.E., Yalow, E. in Sternberg, R.J., Handbook of intelligence, 1982, st. 535) and similarly correlation found between RSpan and Gc corresponds with the expectation that reading comprehension requires crystallized intelligence.

A possible explanation could be that participants with greater Gf and Gc would have less problems while performing processing portions and can better focus their attention on remembering of TBR.

Similarly participants with greater Gc would have less problems while performing processing sections with sentences and could better focus their attention on remembering of TBR.

Also correlation found between SymmSpan and Gf, Gs could have the same base. In SymmSpan processing portions, participants were required to judge whether or not displays composed of filled cells in a grid possessed symmetry about the vertical axis. It was necessary to be fast (Gs) to compare all details of both halves, or find some another way to compare in an easier way (Gf).

This would mean that the shared variance between WM Span tasks and Broad cognitive abilities might be only due to same requirements in Wm processing portion and broad cognitive constructs.

#### 6.8.5. Conclusion:

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Resolution of the question of how and how much general WM, WM Span tasks and general intelligence factor  $g$  and broad cognitive abilities relate seems to be complicated.

Although both correlate significantly, the relation is only mild. It seems that application (uplatnìní, póínos) of WM in Speed testing of cognitive abilities in more detailed view is relatively limited and the relation between these two constructs can be explained by the ability to process a specific type of information.

For further investigation of the relationship between WM and cognitive

functions, it would also be interesting to find out more about the possible application of WM in power testing of more complicated problem solving tasks. To solve these tasks WM capacity could be necessary and its improvement could most influence the performance on these tasks.

The response to the research question regarding strategy use was surprising. It turned out, that strategy use does not have a positive contribution to WM span task performance. Given, that participants who used these strategies achieved worse results than those who did not further research focused solely on this issue would certainly be beneficial.

Zdá se, že uplatnění WM ve Speed testing of broad cognitive abilities je poměrně omezené a vztah mezi těmito konstrukty může být v tomto případě dán spíše schopností zpracovávat určitý typ dat. Pro další zkoumání vztahu mezi WM a cognitive functions by bylo zajímavé zjišťovat uplatnění WM v Power testování složitějších problem solving úkolů pro jejichž řešení může být její kapacita nezbytná a kde by se mohl právě trénink WM projevit nejvíce.

Na otázku týkající se používání strategií při testování jednotlivých typů WM byla překvapivá odpověď. Ukázalo se, že používání těchto strategií nemá pro účastníky pozitivní přínos. Účastníci používající tyto strategií dosahovaly signifikantně horších výsledků, než ti, co je nepoužívali. Další výzkum soustředěný pouze na tuto problematiku by byl určitě přínosný.



## **7. Appendix:**

LPS- neu

Fragebogen zum Aktuellen Wohlbefinden (Well-being questionnaire)

Akzeptanzfragebogen (Acceptance questionnaire)

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