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KATEDRA PSYCHOLOGIE

RIGORÓZNÍ PRÁCE

THE RELATIONSHIP BETWEEN INTELLIGENCE AND WORKING MEMORY, AND BETWEEN WORKING MEMORY AND TRANSITIVE INFERENCE

VZTAH MEZI INTELIGENCÍ A PRACOVNÍ PAMĚTÍ, VZTAH MEZI PRACOVNÍ PAMĚTÍ A TRANZITIVNÍ INFERENCÍ

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

V Praze dne 19.8.2011

Anotace

Tato rigorózní práce pojednává o vztahu mezi obecnou pracovní pamětí, jednotlivými druhy pracovní paměti a obecným inteligenčním faktorem *g* a “širokými” kognitivními schopnostmi, dále se zabývá otázkou vztahu pracovní paměti a tranzitivní inference. Teoretická část se zabývá popisem měřených konstruktů, jejich vývojem, způsoby jejich měření a studiemi zabývajícími se zjišťováním vztahu mezi nimi. Praktickou částí je výzkum zaměřený na ověření vztahu mezi obecnou pracovní pamětí a obecným inteligenčním faktorem, na zjištění vztahu mezi jednotlivými druhy pracovní paměti a “širokými” kognitivními schopnostmi, a dále pak na zjištění vztahu mezi vizuo-prostorovou pracovní pamětí (SymmSpan) a tranzitivní inferencí. 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, používání strategií, SymmSpan, tranzitivní inference

This thesis deals with the relationship between Working Memory, Working Memory Span tasks and general factor *g* and Broad cognitive abilities. In addition the relationship between Working Memory and Transitive Inference is investigated.

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 relationship between visuo-spatial Working Memory and Transitive Inference has also been researched. 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, strategy use, SymmSpan, Transitive Inference

Contents

Graps, diagrams and tables

List of Abbreviations

• WM	Working Memory
• STM	Short Term Memory
• TBR items	To-be-remembered items
• LPS	Leistungsprüfsystem
• g	General intelligence factor g
• 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.

Another aim of this thesis was to find out more about the relationship between automated WM Span tasks and Transitive Inference tasks. In some of the previous studies Transitive Inference tasks, based on their construction, were concluded to be the same as WM measurement. Thus the intention was to test the relationship between Transitive Inference tasks and automated WM tasks in order to find out more about how strong the relationship between these two different construct is.

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 part 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. The term “Transitive Inference” as well as some examples of its measuring will be introduced later, in more detail. The basic features of Transitive Inference will be described and mentioned, along with some important studies concerning the relationship between Transitive Inference tasks and WM.

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 part 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 found also interesting to get to known? more about the relationship between WM and relational reasoning. The results from the conducted analysis will be also presented in the second part. I shall discuss next, in more details, the methods chosen for the measurement of all of the 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

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 Word,” (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

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," (Unswoth and Engle, 2007, p.1038).

They give the following as an example of a trial:

IS (8/ 2) -1 = 1?R

IS (6*1) + 2 = 8?L

IS (10*2) - 5 = 15?S

IS (12/6) + 4 = 10?Q

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).

Engle et al. (1999) pointed out that WM and STM are separate but highly related constructs (r = .62). A similar conclusion was also reached by Conway et al. (2002). They found high correlation between these two constructs (r = .82)

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

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) exmined 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 recruitmaent 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 then 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

The term „WM“ was first formally introduced more than fifty years ago by Miller, Pribram and Galanter (1960). Miller et al. sugessted 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 addopted 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 [1]; 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.

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[1] as en 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).

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 whyle performing some kind 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

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

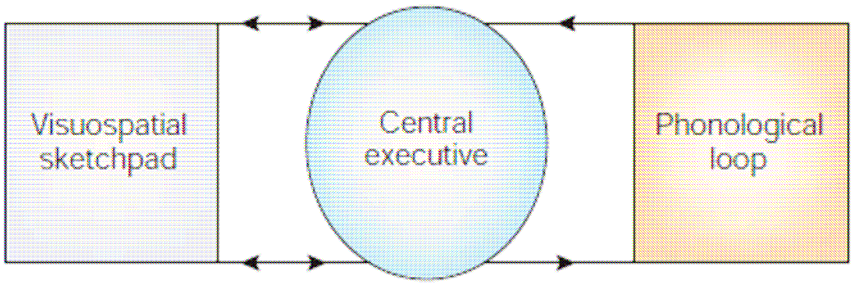


Fig.1 Three component diagram from Baddeley (2003)

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.

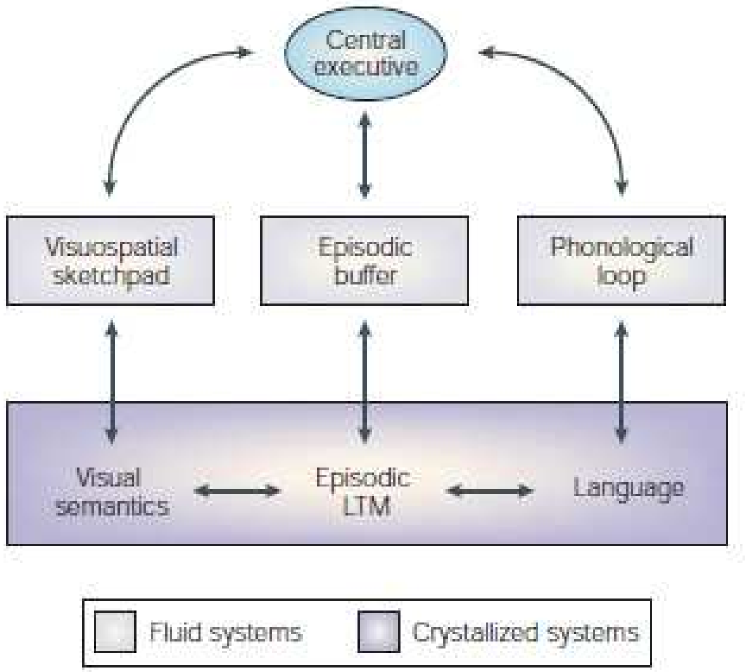


Fig.2 Component revision diagram from Baddeley (2003)

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).

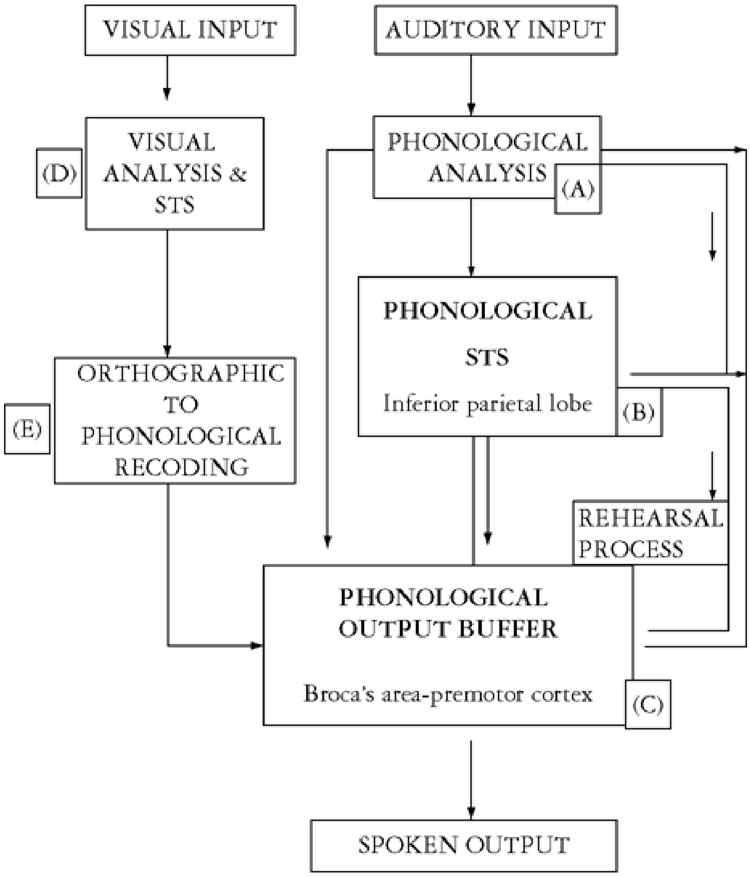


Fig.3 Phonological loop from Baddeley (2003)

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 devide 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

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 understands long-term memory and STM to be different states of the same representations. Long-term memory is activated either through perceptual input or through the spread of activation from other representations, while the focus of attention holds the representation that is the object of the next cognitive operation. He supports the idea that capacity limited focus of attention is the central limit in the working system. 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

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 set, but about the capacity for controlled, sustained attention in the face of interference or distraction...it´s a domain-general limited attentional capacity which faciliates 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 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 an 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

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).

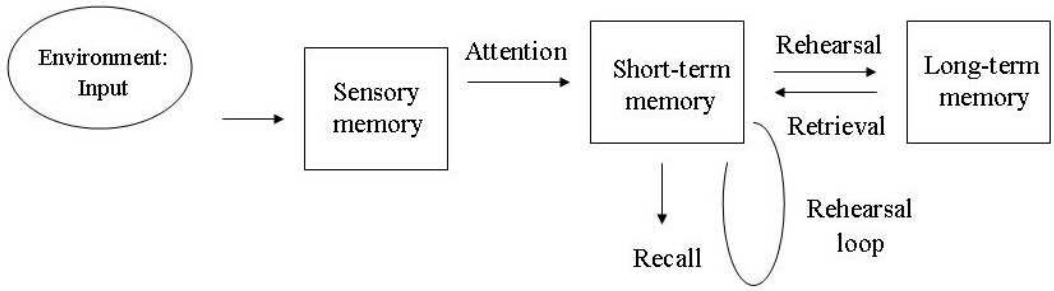


Fig.4 Multi Store Model of Memory - Atkinson a Shiffrin, 1968 (in McLeod, 2007)

2.5.5. Capacity model

Just and Carpenter‘s proposed capacity model suggested that the most fundamental reason for the differences in WM among people 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?

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

The WM constructs distinguishe 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.

2.7. Domain Specifity

Another important aspect represents the domain specifity. Baddeley (2003) proposed WM system with two domain-specific storage structures: a phonological loop that is specialized for maintaining verbal informations and a visuospatial sketchpad that is specialized for maintaining visual and spatial informations. He showed that there is distinction between verbal and visuospatial storage.

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.

Myiake et al. (2001) focused their study on the the relationship between simple storage-oriented span measures and complex processing plus storage span measures. The aim of their study was to detect the extent to which conclusions from the verbal domain can be generalized to the visuo-spatial domain. They concluded that if visuo-spatial domain is used, both STM and WM tasks are similarly correlated with executive functioning. This is contrary to sudies where verbal domain was used and only WM was correlated to execituve functioning.

Some evidence of domain general processes came from a work of Hill et al. (2010). Theys suggested that “resource distribution encountered during search in one domain can alter subsequent search in another domain because of cognitive parameters in the shared search architecture that have been tuned to perform appropriate switching between exploration and exploitation in the first environment. Once they have adapted to a particular environmental structure (e.g., clustered or diffuse resources), these parameters tend to exhibit some inertia, such that their values will take time to adapt to the circumstances of any new search environment. If a second task is given relatively soon after the first task, the first task’s search parameter values will thus automatically affect the second task,” (Hill et al., 2010).

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

2.8. The Central Executive

Central executive is understood in Baddeley´s model (2003) as the most important component of WM based on two processes - automatic habitual control, and attentional supervisory control.

He understands it as a capacity to coordinate performance on two separate tasks, the capacity to switch retrieval strategies as in random generation, the capacity to attend selectively to one stimulus and inhibit the disrupting effect of others comprises the third line of research, and the fourth involves the capacity to hold and manipulate information in long- term memory, as in measures of working memory span. (Baddeley, 1996)

As mentioned by Hofmann et al. (2004) “Even though there is no generally agreed upon definition of the central executive to date, most researchers regard it as a broad system (or collection of subsystems) that has evolved in order to allow the flexible, controlled processing of information in the service of one’s goals.“

More involved was the central executive as investigated by Myiake et al. (2000). Their aim was to develop an empirical basis for a theory how executive functions are organized and what roles they play in complex cognition. They focused on three executive functions: shifting of mental sets, monitoring and updating of working memory representations and inhibitions of propotent responses. They focused on these three executive functions and examined the extent of unity or diversity of these three executive functions. Their results indicated that the three executive functions contribute differentially to performance on the more complex executive tests. Shifting seemed to contribute to WCST (Wisconsin Card Sorting Test) performance, Inhibition to TOH (Tower Of Hanoi) performance, Inhibition and Updating to RNG (Random Number Generation) performance, and Updating to operation span performance.

Another author who claims central executive doesn´t exist is Parkin (1998). He criticizes studies where central executive is considered as a unitary system and, based on a neuropsychological examination, he concluded central executive to be associated with different neural substrates and therefore represented by a higher number of different functions.

In 2010 Hill et al. claimed there is a unitary, domain general, central executive. Their results supported the idea about the generality of underlying control processes and their relation to search processes . “This can be modelled as search over goal hierarchies brings together the evidence for a shared neural ancestry involving spatial foraging and our current understanding of a central executive process that handles goal-maintenance in tasks involving self-regulation," (Hill et al., 2010)

Marklund et al. (2007) investigated in their study the extent to which executive functions might be shared across the separate domains of working memory. They concluded that both unity and diversity are present among executive control processes.

Also Collette et al. (2005) suggested that central executive shows signs of unity as well as diversity. In their study they concluded the right intraparietal sulcus to play a role in selective attention to relevant stimuli and in suppression of irrelevant information. They also concluded the left superior parietal region to be involved in modal switching/integration processes. They also found that the lateral prefrontal cortex plays an important role in the monitoring and temporal organization of cognitive processes, which are necessary to carry out ongoing tasks.

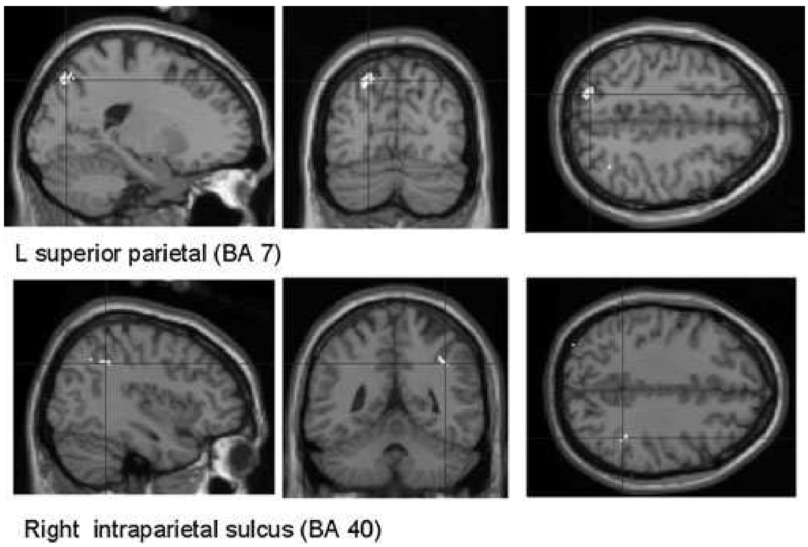


Fig.5 Brain activation observed in the conjunction analysis between eight executive tasks (Collette, F., et al. 2005)

Similar conclusions were also reached by Stuss and Alexander in their study (2000). According to them distinct processes are related to different regions of the frontal lobes. "When functions of the frontal lobes are tested with complex tasks, this brain region appears functionally homogenous. Increasing the complexity of a task may demand multiple processes in different frontal lobe regions," (Stuss and Alexander, 2000)

2.9. The measurement of WM

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 vision where examiner had to be present to preses a key to move on to the next operation. Further improvements consisted of chase of TBR items. In this new version letters were used instead of words to suppress possible strategy use (as will be mentioned latter some researchers concluded that individual differences in strategy use – interactive imagery or sentence generation – do account for signifficant variance on span performance). In 2010 another two automated complex-span tasks were validated – Rspan and SymmSpan. (Braodway, 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 informatic and a visuospatial sketchpad that is specialized for maintaining visual and spatial informatic, 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

Many studies have investigated the various possibilitties 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 possibilitties 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.

Bühner et al. (2006) suggested that WM remained a significant predictor of reasoning after controlling for crystallized intelligence. WM and sustained attention together accounted in this study for about 83% of reasoning variance.

The goal of the Shamosh et al. (2011) research was to identify candidate neural mechanisms that account for the relation between intelligence and delay discounting, focusing especially on mechanisms involved in WM. They showed that delay discounting is negatively related to intelligence, and also found that it is negatively related to WM. In their study they also detected WM to be strongly related to *g* (r = .60).

In the investigation by O’Connor et al. (2003) with regard to children, they found a strong relationship between working memory and cognitive functioning (β = .83).

Research on children´s working memory capacity and its relationship to fluid intelligence was also conducted by DeJong et al. and Das-Smaal (1995). These researchers concluded WM capacity to be strongly correlated with fluid intelligence performance (r = .66) Both WM capacity and fluid intelligence were also found to be significantly correlated with school achievement (r = .72) (r = .82).

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 Martinéz 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.

Mogle et al. (2008) investigated the relationship among Working Memory, Secondary Memory, and Fluid Intelligence. They understand PM and SM in the terms of Unswort and Engle (2008) as described above.

The main aim of their study was to compare the SM and WM capacity to account for variability in fluid intelligence. Their presumptation was “If WMC predicts unique variance in fluid intelligence after we account for SM, this would suggest that maintenance of information in the face of distraction underlies the relationship among these constructs. If, instead, SM predicts fluid intelligence after we account for WMC, then encoding and retrieval processes may be likely to drive the relationship,” Mogle et al. (2008).

Their results showed, that SM was a significant predictor of fluid intelligence after controlling for WM capacity, but WMC was no longer significantly associated with fluid intelligence after controling for SM. They concluded, that SM processes like search and retrieval rather than maintenance of information in the face of distraction, are the base for the relationship to fluid intelligence.

Results obtained in this study were not surprising given the fact that Raven´s progressive Matrices test was used as a fluid intelligence measure. This test requires the participant to remember as many details of the matrix and also of each of the presented segments as possible so that he can compare them and find out which one fits best. To solve such problems SM is essentials required.

Also Shelton et al (2010) concluded “when trying to decide which pattern segment will best complete a matrix design (e.g., Raven’s Progressive Matrices; Raven, Raven, & Court, 1998) it is necessary to maintain separate reces of the design to determine how they fit together. As the designs increase with complexity, it becomes more difficult to hold these items in the limited space of primary memory, leading to some of the items being displaced into secondary memory. Ultimately, pertinent items must be retrieved from secondary memory to determine which option will best solve these complex problems.” (Shelton et al., 2010)

Shelton et al.(2010) replicated and extended the findings of Mogle et al. in their study. To test fluid intelligence they used not only Raven’s Progressive Matrices but also Block Design subtest and Matrix Reasoning (Wechsler, 1997). They demonstrated that working memory has its special role in the prediction of fluid intelligence, above and beyond secondary memory.

3.2. Possible base for the relation

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 maintaing 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.

The causes underlying the correlation between working memory and fluid intelligence was also investigated by Colom et al. (2006). They focused in their research on the role of the executive component of working memory. They reported

that the shared variance between executive functioning and working memory do not account for the relationship between intelligence
and working memory.

In contrast, De Jong and Das-Smaal (1995) suggested the important role of the central executive that especially contributes to the relationship with intelligence.

Schweizer et al. concluded that both working memory and attention are both important predictors that showed to be neither uncorrelated nor appropriate for replacing each other.

Later Colom et al. (2008) investigated why working memory and the general intelligence factor g are highly related constructs. They suggested that short term memory is the single predictor of working memory (the executive factor was not a significant predictor of working memory once its storage component was removed, also mental speed did not predict working memory variance) and the simple short term storage largely accounts for the relationship between working memory and intelligence.

Garlick and Sejnowski (2006) argued that "the notions that working memory capacity and executive function are explanations of fluid intelligence are plausible. After all, the solution of fluid intelligence tasks undoubtedly involves the use of working memory. Similarly, executive functions are the result of an evolutionary recent brain area, so equating the operation of this brain area with fluid intelligence, again a capacity that is most evident in humans, would again seem plausible. It is also logical to identify fluid function with the prefrontal cortex, an area that is notable for playing a control function and not having direct connections with sensory input." In some studies, low correlation was found between intelligence and WM tasks. Garlick and Sejnowski (2006) reasoned that this low correlation is due to dissimilarities in the construction of WM and intelligence tasks. This suggests that some researchers, when arguing for a working memory capacity explanation of intelligence, could strengthen the relationship simply by making working memory tasks involve the manipulation and transformation of information, elements that are commonly involved in fluid intelligence tasks.

As mentioned above, Kyllonen and Christal (1990) found structural coefficients of .80 through .88 between WM and reasoning ability. Their reasoning tests used arithmetic reasoning, mathematics knowledge, AB grammatical reasoning, verbal analogies etc. WM tasks were, for example, ABCD grammatical reasoning, ABC numerical assignment, and digit span. They explained that these tests of working-memory capacity were chosen because subjects simultaneously engaged in component processing operations (solving arithmetic problems and solving grammatical reasoning problems, respectively) and storing outcomes of those processes. But similar requirements are also essentials for solving fluid intelligence tasks.

Also Lohman in his theory 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 (Baddeleys 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 imagine 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).

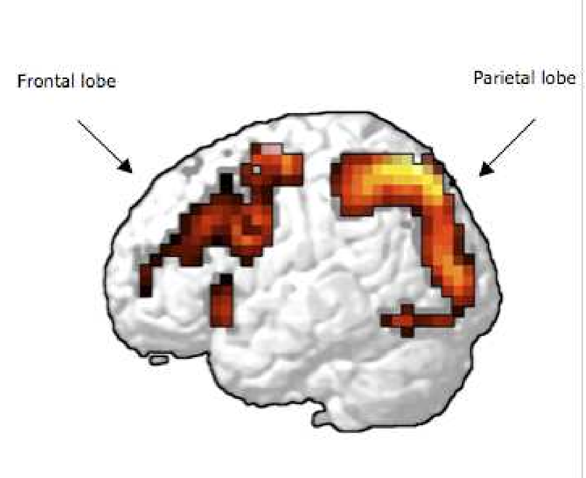


Fig.6 Colored regions of the brain that are activated by a working memory (Klingberg 2002)

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. Transitive Inference

Transitive Inference is a form of relational reasoning. Relational reasoning represents tasks where the right answer depends not only on the correct reasoning, but also on the ability to maintain information while processing such tasks.

These tasks involve the number of relations and the number of objects, or events, being manipulated in order to find the right solution. A relation is understood as a mental representation of the relationship between objects or events.

“The term relational reasoning usually refers to the processing of information about the the relation between objects, with the aim of generating new information that is not explicitly available. It´s required when solving spatial problems such as:

- the fork is to the left of the plate;
- the glass is to the left of the fork;
- which relation holds between the glass and the plate?,”

(Ruff, C.C. et al., 2003).

This example is called the transitive inference problem, requiring the reasoner to generate a new proposition based on the information presented. Transitive Inference is one of the forms of relational reasoning. An alternative type of task called the propositional reasoning problem, requires only the information presented in order to answer the problem. For example: There is either a circle or a triangle. Therefore, there is no triangle. (Morrison, 2001)

According to some of the researchers, Transitive Inference tasks can even be understood as a measurement of WM.

For example Fales, C.L. et al., 2003, used in their study both traditional WM tasks (n-back) and Transitive Inference tasks to find out more about the nature of the deficits in WM with people having Klinefelter syndrome. The authors concluded that there are no differences in the performance, whichever task is used to test the working memory. Deterioration was observed in traditional WM tasks and also in verbal Transitive Inference tasks. The authors believe that the lower performance on the Transitive Inference task relates to a verbal working memory deficit.

The Transitive Inference test was conducted as follows – participants were given index cards that were each printed with the name of a person. They were asked to order the people named on the card according to the instructions specifying their relation. In two-relation problems the information was presented in the form of binary relations (e.g., “Jim is taller than Bob” and “Bob is taller than Tom”), always one proposition less than the number of cards given. In three-relation problems, participants get two relations in a row in which no common names are used: “Jim is taller than Bob,” “Tom is taller than Mike,” and “Bob is taller than Tom.” The ordering of the propositions could present a group of names, as a one-, two-, or three-relation problem. (Fales et al., 2003)

Kyllonen and Christal (1990) used WM measurement tasks based on a similar principle - ABCD Grammatical Reasoning. In this task subjects are required to process three successively presented sentences that constrained the order of the four letters A, B, C, and D. “A typical item was (screen 1) "A precedes B"; (screen

2) "D is not preceded by C"; (screen 3) "Set 1 is preceded by Set 2"; (screen 4) "Which order is correct? 1-ABCD; 2-ABDC; 3-BACD; 4-BADC; 5-CDAB; 6-CDBA; 7-DCAB; 8-DCBA." In these items, Set 1 always referred to the letters A and B; Set 2 always referred to the letters C and D; A and B were always contiguous; C and D were always contiguous (e.g., BCAD would not be possible). The test allowed unlimited per-screen study time, but subjects could not move backwards to review screens."

The relationship between WM and relational reasoning is supported in the findings of Krawczyk et al. (2008), who proved significant differences in the reasoning performance of patients with frontal-variant frontotemporal lobar degeneration, and patients with temporal-variant and healthy controls. „..frontal-variant FTLD patients performed less accurately than temporal-variant FTLD patients, who in turn performed worse than healthy controls, when semantic and perceptual distractors were present among the answer choices. When the distractor answer choices were eliminated, frontal-variant patients showed relatively greater improvement in performance…. Frontal-variant patients showed performance deficits on all tasks relative to the other subject groups, especially when distracted." (Krawczyk et al. (2008).

In the study of Waltz et al. (1999), patients with prefrontal damages exhibited deficit in the intergration of relations in both deductive and inductive reasoning tasks.

They concluded that the neurological base integration of relations is similar to the WM functions located in the prefrontal areas of the brain.

The question is twofold - why do transitive inference tasks seem to be strongly correlated to WM and why, in some of the studies, are they used as WM measurement?

WM is understood as construct consisting of storage and attention components.

To engage both of the components WM span tasks should always be composed of TBR items, which occur at the same time with some form of distracting activity.

Tasks constructed to satisfy such demands differ especially in the way in which TBR items are used. TBR items can either be part of the processing activity or indepedent of this part.

Examples:

- TBR items are separated from the processing activity

As an example can serve Automated WM Span tasks. Automated WM Span tasks are based on the idea that the processing part is clearly separated from the memory part. Unsworth and Engle (2007) claimed 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.

- TBR items are part of the processing activity

Visuo-spatial N-back tasks are also considered as a traditional WM measurement. These tasks require the participant to view letters presented on a computer screen, one at a time, and to compare the current letter to the immediately preceding letter. If the two letters are the same, the participant marks them as “yes” , when different, he marks them as “no”.

At the second level the participant compares the current letter with the second letter back, and so must store two letters at time. At the third level, the participant is required to compare the current letter with the letter three positions back.

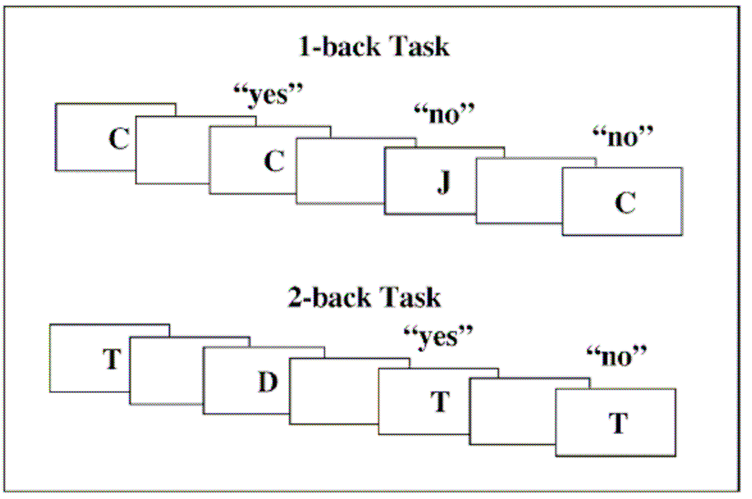


Fig.7 Illustration of N-back task (Fales 2003)

Similarly, Transitive Inference tasks are such tasks where both the number of relations and the number of items are manipulated. A relation is understood as the mental representation of the relationships between objects or events.

In contrast to Automated WM Span tasks, Transitive Inference requires manipulation of the TBR items (relations and objects or events) also in the processing part. (e.g. False et al., 2003; Colom et al, 2005)

In Transitive Inference tasks, the right answer depends not only on the correct reasoning, but also on the ability to maintain information while processing such tasks. Especially transitive inference tasks. which require the ability to integrate two relations that share an element. (Waltz, et al.1999)

The cognitive capacity for Transitive Inference refers to the ability to make relational links between individual memory traces that share common elements (Libben and Titone, 2008).

Lohman (2011) distinguishes between four components of reasoning – WM, assembly processes, control processes and learning. He says, that WM is required, because reasoning is based on simultaneously remembering and transforming information. Also necessary is a plan of attack, which is understand as a systematic plan for solving problems. Control processes involve the ability to monitor the effects of one´s cognitions and actions. Learning means that one can learn rules on easy items that will later be needed on harder items.

Also this description shows that Transitive Inference tasks require the storage of information as well as its processing. The processing part depends on the ability to form and manipulate mental representations of relations between objects and events. The storage component is represented by the ability to keep objects and relations in memory unchanged. Due to this fact, one might consider Transitive Inference tasks to be a measurement of WM.

In Transitive Inference tasks, TBR items are used as a part of the processing activity. The same rule is followed in another WM measurement, as mentioned above- N-back. Although *N*-back has become a standard WM measurement in cognitive neuroscience, studies examining its construct validity have highlighted the shortcomings of this test.

Kane et al. reported that *N*-back and WM span (OSpan) correlated weakly, suggesting they do not reflect primarily a single construct; moreover, both accounted for independent variance in Gf. (Kane et al. 2007)

It would be interesting to find out more about the relationship between Transitive Inference tasks and WM span. From this reason the correlation between automated Span task and Transitive Inference tasks was also conducted.

Ruff et al. reported in their study that relations reasoning is based on visuo-spatial mental models, which means that people don´t solve reasoning problems by language-based representations (formal rules) due to a the visual representations of the situation. Their conclusion was supported by the results of functional magentic resonance paging which showed the relational reasoning tasks engaged occipital cortex. (Ruff, C.C. et al., 2003).

„Our visual systems are adept at computing spatial relations—such as *above*(), *larger-than*()—and many of these relations are transitive: If object A is above object B and B is above C, then A will be above C. Importantly, the visual machinery that computes these relations from the information in a visual image must have this knowledge built into it implicitly. The reason is that images are quintessentially analog: If, in some image, A is above B and B is above C, then A will necessarily be above C, so the same machinery that computes A above B and B above C (from their locations in the image) also has the information necessary to compute A above C. To the machinery that computes spatial relations from visual images, the "inference" that A is above C is not an inference at all, but rather a simple observation.“ (Hummel, 2001)

5. WM-Tasks and strategy use

Some of the recent studies investigated the strategy affordance hypothesis - the influnce 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 conluded, 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).

6. 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 leasing,” (P. Voss, 2005).

Another definitions 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.

6.1. Throughout the history of intelligence and its testing

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*“
- Thurstons Primary abilities
- Horn-Cattel´s Gf-Gc theory
- Carrol´s Three stratum theory

6.2. Spearman´s model for „g“

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).

6.3. Thurston´s Primary abilities

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 abilitities“). 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), indusctive reasoning (I), and deductive reasoning (D) (Indiana.edu., 2007).

6.4. Horn-Cattel´s Gf-Gc theory

It is also possible to find a strong disagreement wih 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 Cattel´s theory of fluid and crystallised intelligence from 1941. Cattel summerised 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 Cattel as *crystallised* (*gc*) (Horn in Woodcock, 1998).

6.5. Carroll´s Three stratum theory

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-Cattel Gf-Gc model. Horn, as mentioned above, has extended the work of Cattel 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 breath (Carroll, 1993).

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

As described earlier, Horn was a sworn enemy of *g* and Carrol 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 ragarded 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 drive 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.

6.6. C-H-C theory

The recent results from understanding of intelligence structure were summed up in C-H-C theory. This theory integrates the Cattel-Horn Gf-Gc theory (Horn, Noll 1977) and Carroll´s three stratum theory (Carrol, 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).

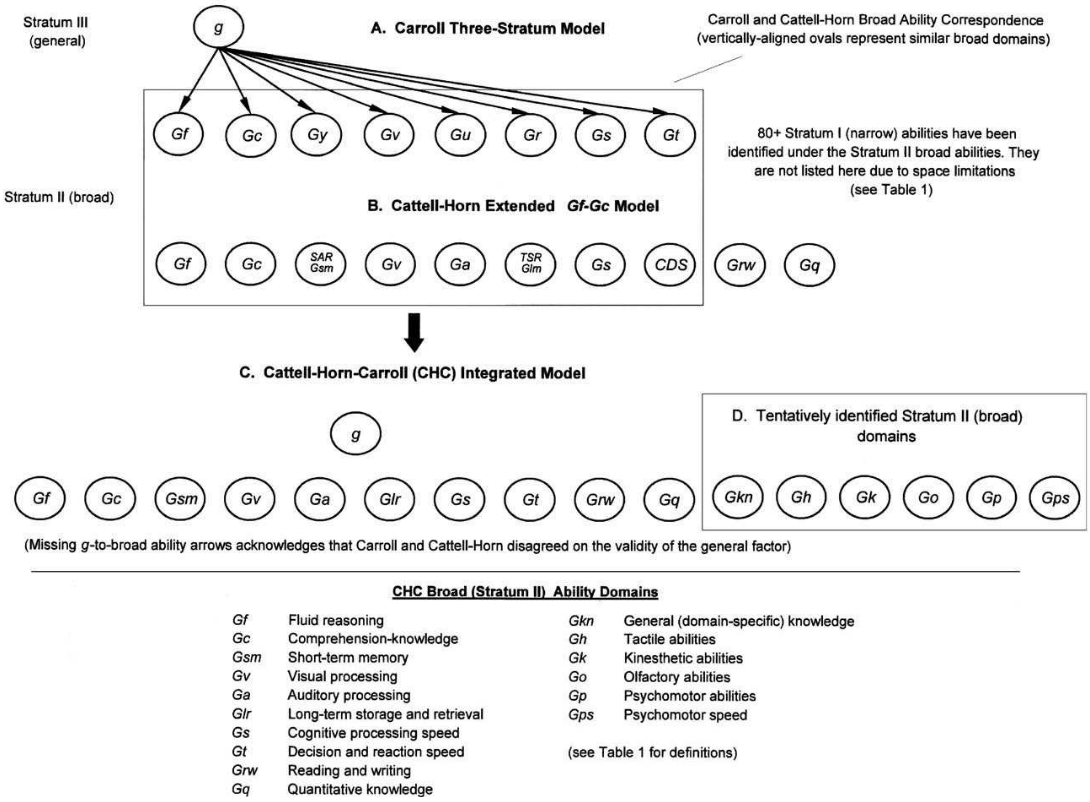


Fig.8 Diagram of synthesis of the two models from McGrew (2009)

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. Generall factor g is postulated on the highest level of aggregation, which is differentiated into more specifc 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 ressource with differentied 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.

6.7. LPS-neu

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 Carrol´s ordering.

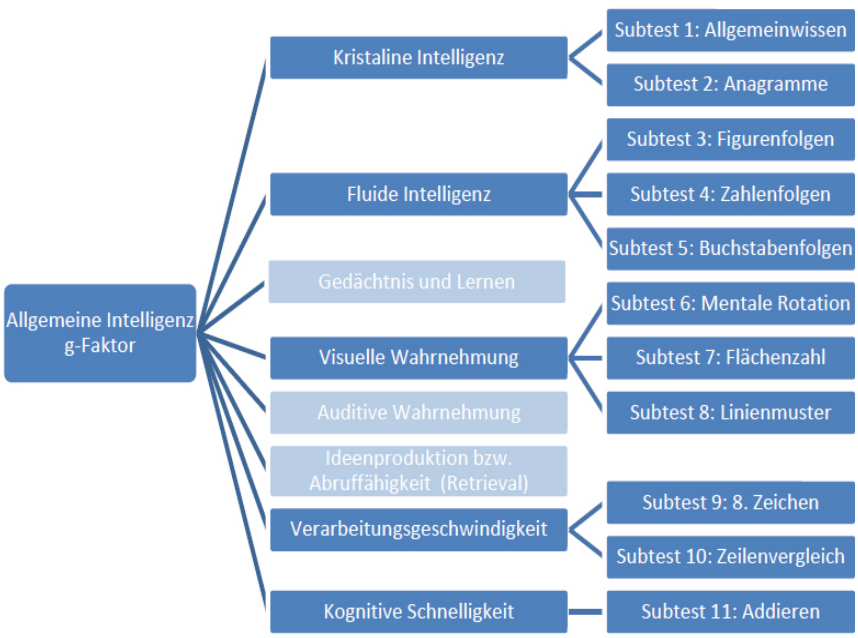


Fig.9 Intelligence structure diagram from Kreuzpointner, 2010

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 testarch 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.

7. Empirical Part

7.1. The research problem

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 possitively 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. Another aim of this work was to find out how does the performance on WM tasks differs depending on in which way the TBR are used. The intention was also to test the relationship between Transitive Inference tasks and automated WM tasks in order to find out more about how strong the relationship between these two different construct is.

7.2. The research questions

Hypothesis

H_{A1} – there is a relationship between WM and general intelligence factor *g*.

H_{01} – there is no relationship between WM and general intelligence factor *g*.

H_{A2} – there may be relationship between Broad abilities and WM span tasks

H_{02} – there is no relationship between Broad abilities and WM span tasks

H_{A3} – there is a relationship between Transitive Inference tasks and automated WM span (SymmSpan)

H_{02} – there is no relationship between Transitive Inference tasks and automated WM span (SymmSpan)

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 current well-being on obtained results in WM and LPS Tests
- Influence of attitude towards LPS Test on LPS Test results
- Influence of education on obtained results in Transitive Inference tasks and SymmSpan

7.3. Operationalisation

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 either be letters or various positions of filled cells displayed sequentially in a grid which the respondents are required to remember. Or they can also be names of a people or objects used in the Transitive Inference tasks tasks.
- **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 stratergy 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.
- **Transitive Inference** is understand as a total time (in seconds) needed to answer correctly five Transitive Inference tasks.
- **Current well-being** is understood as a total score on the "Fragebogen zum aktuellen Wohlbefinden” (Well-being questionnaire). (see chapter *Materials*)
- **Attitute towards LPS Test** represent the score on Akzeptanzfragebogen (Acceptance questionnaire). (see chapter *Materials*)

Moderator variables

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

7.4. Participants

7.4.1. Sample 1)

A total of 54 participants, 19 men and 35 women were german students between 20 and 51 (median 23) years who were made availiable 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.

7.4.2. Sample 2)

A total of 60 participants between 21 and 60 (median 30) were made available randomly via a request for participants. They were either Czech graduates, or Czech High School graduates, 31 men and 29 women. For their participation they were reimbursed with a small amount of money. They performed both tests on the same day.

7.5. Procedure and Materials

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 administred 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.

7.5.1. Questionnairs

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 thay 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 (repase), 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.

7.5.2. WM-Tasks

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 contant domain – Ospan, RSpan (letter contant domain) and SymmSpan (visuospatial contant 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 wass 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 wass 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 to keep this at least at 85%. Only date 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).

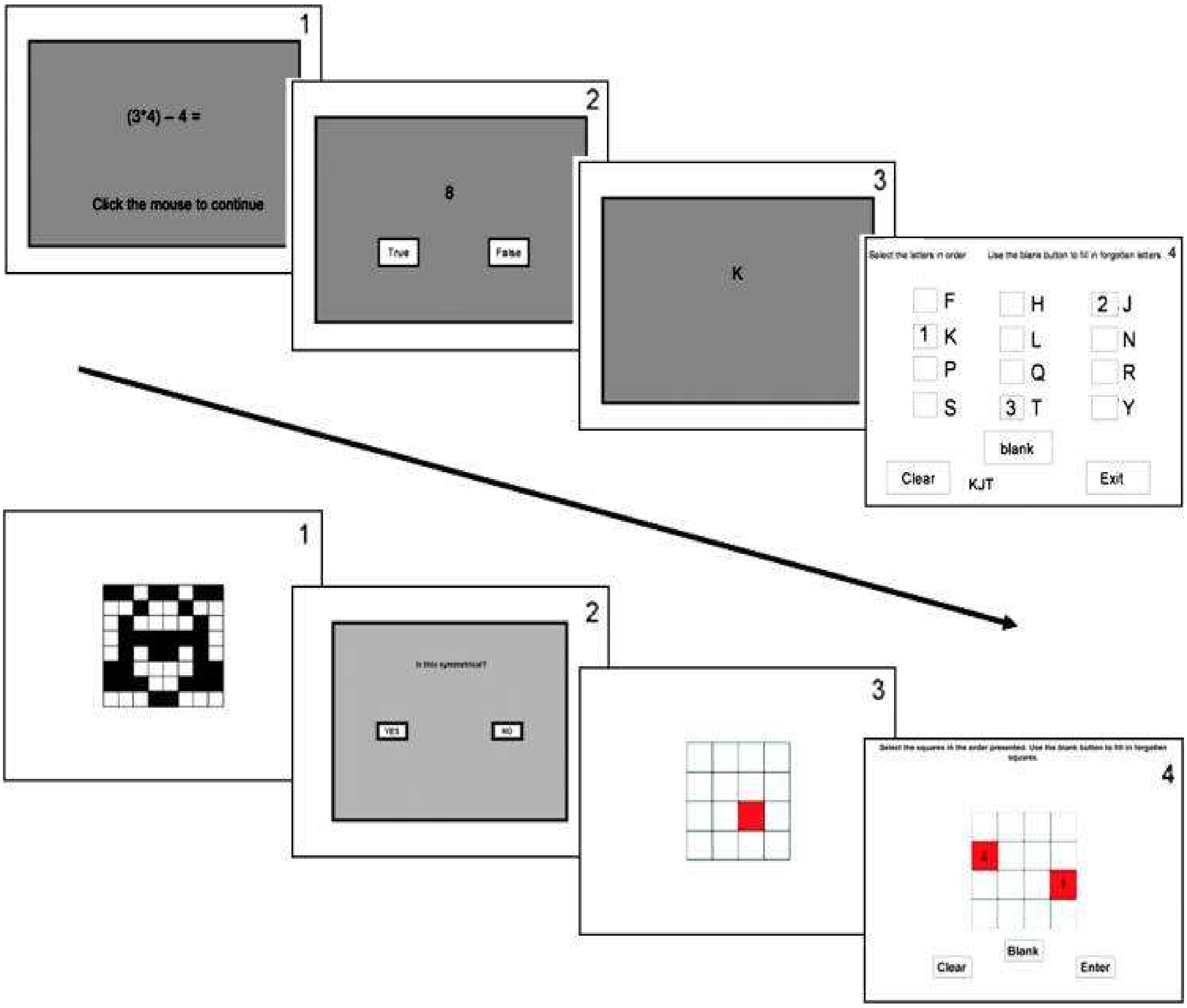


Fig.10 Illustration of OSpan and SymmSpan task (Barch, D.M., et al. 2009)

7.5.3. 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 Carrol´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 Carrol´s definition of Stratum II, Kreuzpointner included these two subtests in Crystallized Intelligence section. On the grounds of Carrol´s other definitions, Subtests 3 (Form series), 4 (Number series) and 5 (Letter series) ebgaged 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.

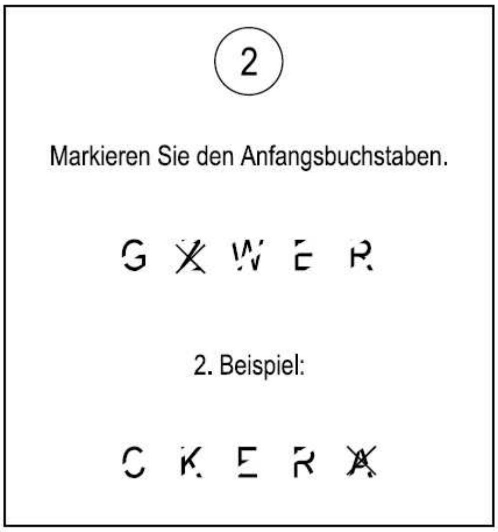
1) Subtest number 1 was designed to measure a general knowledge. The idea of this subtest was that participants with higher general knowledge would be more likely to recognize the presented word and identify the wrong letter in it. Total of sixty words were presented in a column. In the given words there 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.11 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.12 Example of LPS subtest 2

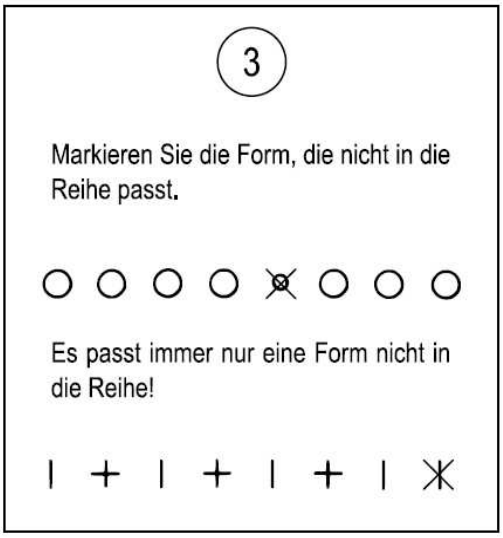


Subtest 3 and also subtest 4 and 5 were designed to measure reasoning in terms of the Thurston´s primary mental abilities. All of the subtests required participants to find a rule which underlay the systematic.

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.13 Example of LPS subtest 3



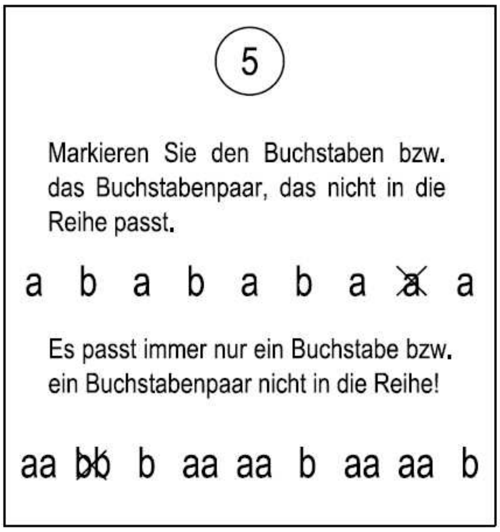
In subtest 4 there were forty series made of nine numbers whose order also underlay a rule .

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.14 Example of LPS subtest 4

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.

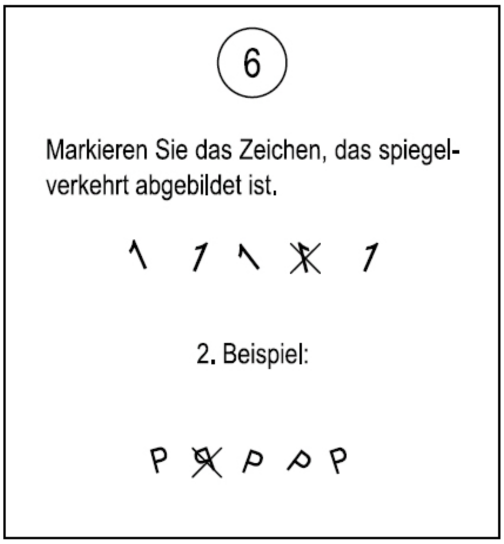
Fig.15 Example of LPS subtest 5



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.16 Example of LPS subtest 6

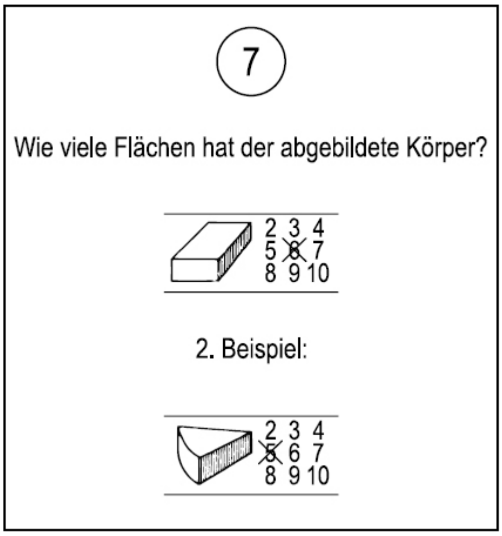


In subtest 7 the task was to calculate the number of surfaces of presented geometric solids and cross the right answer next to the solid. Also not visible surfaces had to be counted in.

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.

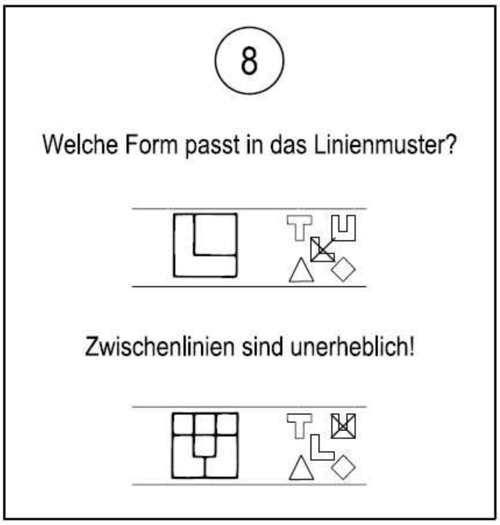
Fig.17 Example of LPS subtest 7



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.18 Example of LPS subtest 8

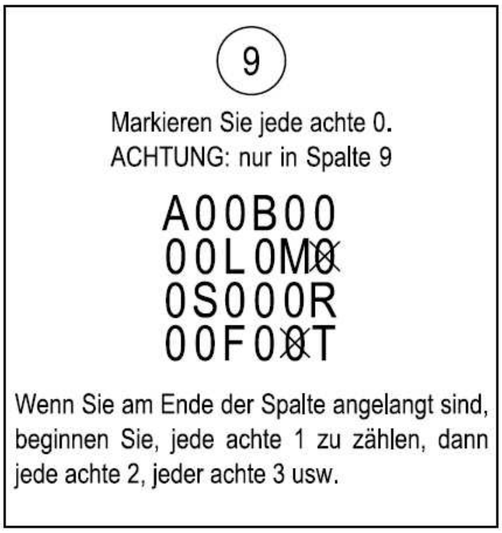


Subtests 9, 10 and 11 were focused on Cognitive Speed.

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.

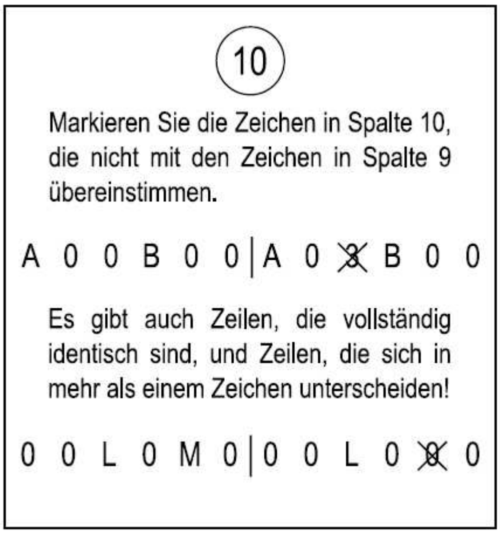
If participants started to work first in column 9 and marked numbers, it would be very difficult for them to compare column 9 with column 10 in the following subtest.

Fig.19 Example of LPS subtest 9



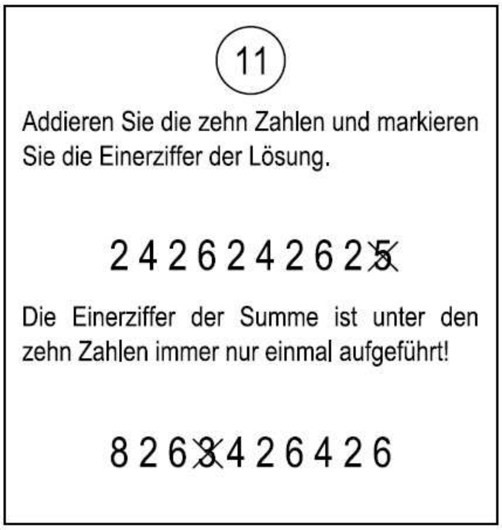
In subtest 10 participants had to first peruse row in subtest 9 then in subtest 10 and mark the wrong symbol/s, after that they could work on the following row. More than one symbol could be marked but some of the rows could be without.

Fig.20 Example of LPS subtest 10



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.21 Example of LPS subtest 11



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.

7.5.4. 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

7.5.5. Automated WM Span task and Transitive Inference tasks

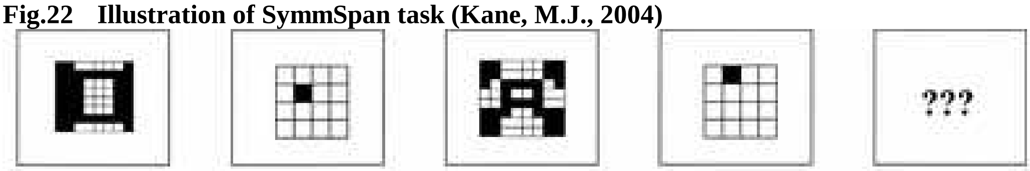
The intention was to find out, whether there is a relationship between WM and Transitive Inference tasks. To find out more about the correlation between these two constructs, standardized automated WM Span task was used.

To find out whether the performance in these two differently constructed types of tasks would differ, or not, depending on the way the TBR items are used (separate from the processing part in automated WM Span tasks or involved in processing part in Transitive Inference), participants will be tested both by an automated WM span task and by Transitive Inference tasks.

As a representation of relational reasoning tasks, transitive inference tasks were used (as mentioned above - type of deductive reasoning, in which the truth of the premise ensures the truth of the conclusion) as in Fales et al.(2003) study as a WM measurement.

Based on the presumption that people solve reasoning problems by visual representations of the situation, the same domain should be also kept in automated WM tasks. For that reason only Automated visuo-spatial WM Span task SymmSpan (Fig. 22) was used.

Fig.22 Illustration of SymmSpan task (Kane, M.J., 2004)



For the needs of the following research SymmSpan and five Transitive Inference problems were used. These Transitive Inference tasks were similar to those used in Fales et al. (2003) study.

The SymmSpan and Transitive Inference tasks were administred to 60 adult university or High School graduates.

All the participants performed first on the SymmSpan and continued immediately afterwards on the Transitive Inference tests. Both of the tests were administred and interpreted by me.

The participants were asked either to come to the library or to do the tests in their homes under the control of an examiner (me). Five of the participants did the tests in the library. The remainder of the participants performed these tasks in their homes in a quiet room without any disturbance.

Before performing the SymmSpan, participants were asked to fill up an anonymous personal questionnaire which contained their VP-Code (identification code), gender, age and education.

Participants were asked to follow the SymmSpan instructions presented on the computer screen and to inform the examiner as soon as they finished, in order to continue with the Transitive Inference tasks. The performance on Transitive Inference tasks was timed. The presumption was that the slowest participant would take the most amount of time needed to solve all of the problems.

The presumption was that participants who were slowest in remembering TBR items and not accurate in processing them, would also take more time. It was also presumed that time gained in the transitive inference tasks would negatively correlate with the score obtained in SymmSpan.

SymmSpan

SymmSpan has been already described in the previous WM task description. No changes were made in the test performance. Because the research took place in the Czech Republic, the English version of the SymmSpan had to be translated into Czech. The translation was undertaken by me. SymmSpan performance required approximately 20 minutes.

Transitive Inference

Five Transitive Inference problems were created by me according to the basic requirements for their design. It was deemed appropriate to create Transitive Inference tasks for this study as there is no standard Transitive Inference task available. These tasks contained either objects or the names of people and the relations between them. Participants were asked to sort the items based on their relationships. As they read the information the experimenter (me) started a timer. Tasks were sorted from the easier to the more difficult. The first three tasks required serial processing . The last two problems were based on higher-order interactions (i.e., those with more than two independent variables) to create higher processing loads. (Halford, 2007) The assumptation was that it would be easier for participants with greater WM to remember.

Participants were asked to solve the problem mentally and to write the answer as soon as they had discovered it. Their answers were checked immediately, and if wrong, the participants were asked to solve it again. They were allowed to a make maximum of two mistakes per task.

In the first task, objects and their relations were used as TBR items. Well-known objects were used as they are easy to imagine and therefore easy to remember.

In the second, third, fourth and fifth tasks, names of people were used. To avoid facilitating remembering by connecting commonly used Czech names with friends faces (thereby make it easier to imagine and remember), unusual Czech names or foreign names were used.

The first three tasks were presented in the form of two-relation problems and were made up of three items.

The fourth and fifth tasks were three-relation problems, including four items, and therefore the most demanding. Tasks were constructed of a maximum of four TBR items and four relations. Four is the number of relations most people are able to remember and process without any major difficulties.

1) Skříň je napravo od postele a lampa je napravo od skříně
   ("Cupboard is to the right of the bed" and "lamp is to the right of the cupboard")

2) Marvin je větší než Zina a Darek je větší než Marvin
   ("Marvin is taller than Zina" and "Darek is taller than Marvin")

3) Amar sedí vedle Alexe a Alex nesedí vedle Tiny
   ("Amar sits next to Alex" and "Alex doesn´t sit next to Tina")

4) Judita sedí směrem vlevo od Felixe, Artur sedí směrem vpravo od Judity, Judita sedí směrem vpravo od René, Artur nesedí na kraji.
   ("Judita sits to the right of Felix", "Artur sits to the right of Judita", "Judita sits to the right of René", "Artur doesn´t sit at the edge")

5) Mlada bydlí směrem nahoru od Selmy, Karen bydlí dvě patra od Selmy, Dona bydlí pod Karen.
   ("Mlada lives on a floor above that of Selma´s", "Karen lives two floors from Selma", "Dona lives on a floor beneath that of Karen´s")

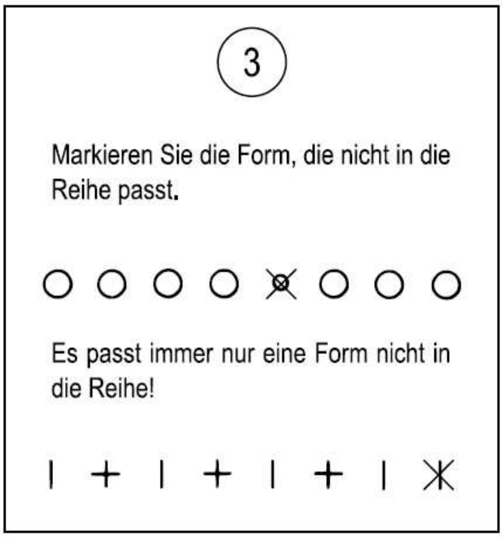
Based on the results of the pilot study, in which tasks with a different number of items were used, it showed that the maximum amount of items and relations that most people can solve, is four. Most respondents of the pilot study found that tasks having five or more items could not be solved without making notes. Five Transitive Inference tasks were chosen because of the fact that, after the fifth task, there was already a difference of twelve minutes in the performing time between participants, and also most of the people began to feel tired, something which could negatively influence the performance.

Also of interest, the correlation between WM and spatial fluid intelligence (reasoning) subtest 3 (LPS) from the previous research was compared to the correlation between WM and transitive inference from the research that followed. Transitive Inference tasks as well as spatial fluid intelligence subtest 3 are both reasoning tests. The difference lies in the rules for solving them.

Subtest 3 requires participants to find a rule which underlies the systematic and put a cross against the symbol which misfits. To mark the misfitting symbol with a cross, the participant must first find the right symbol. To find such symbol, he needs only the information presented - only accurate processing is required to solve such a problem - there is no need for manipulation of TBR. Alternatively, in the presented Transitive Inference tasks not only the processing of items, but also the remembering of them, is required. To find out whether processing is the main component which drives the relation between WM and Gf, correlations between these two components will be compared with those between WM and Transitive Inference tasks. The presumption is that if only processing is the important component influencing the results obtained in WM tasks, both tests should have similar relation to WM Span tasks.

Subtest focused on visouspatial reasoning in LPS was subtest 3

Fig.23 Example of LPS subtest 3



7.6. Results

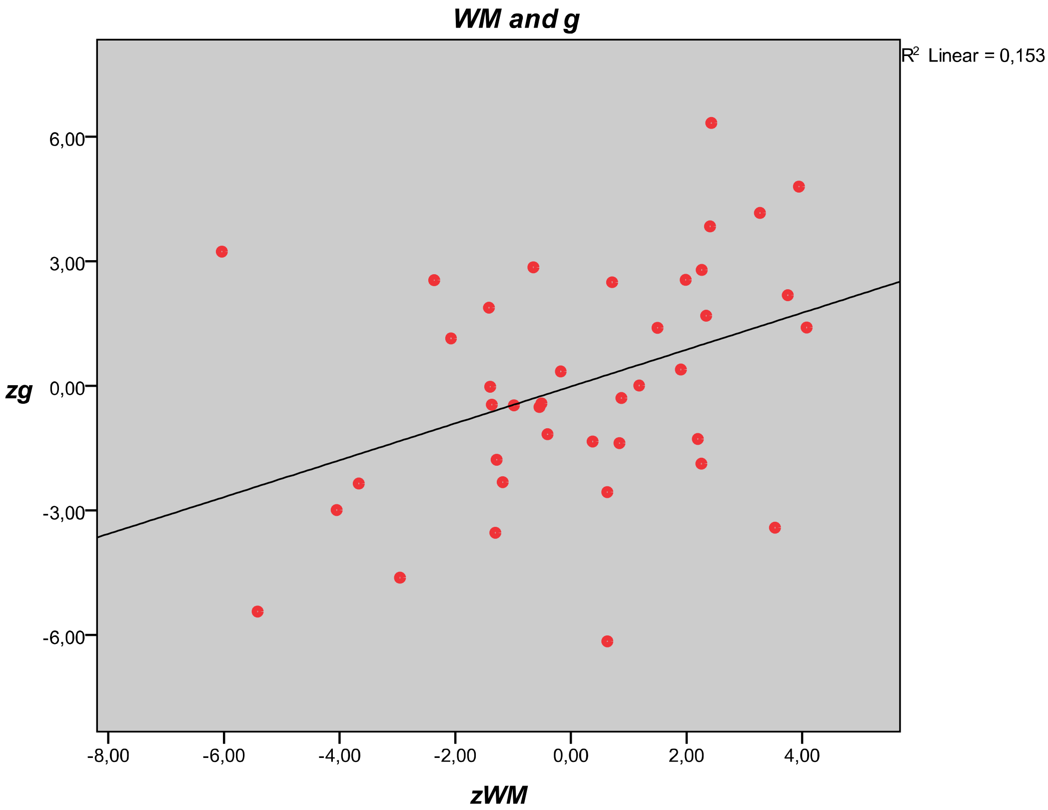
To reject or accept null hypothesis several statistical tests were performed. 51 participants took part both in LPS and WM tests. The WM tasks (OSpan, Rspan, SymmSpan) were administered to 54 adult students. Only data where the participant was at least 85% accurate on the processing part of the WM span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

	N	Missing	Mean	Std.Dev.
G	51	0	285,12	37,12
Gf	51	0	64,18	7,73
Gc	51	0	64,84	17,35
Gv	51	0	87,59	14,57
Gs	51	0	68,51	11,37
WM	43	11	102,65	38,48
OSpan	52	2	43,81	18,209
RSpan	47	7	36,47	9,023
SymmSpan	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 possitive. 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 btween general WM and general factor g, and correlations between 4 Broad abilities and 3 WM Span tasks

	z *g*	z Gc	z Gf	z Gv	z Gs
z WM	.391*	.365*	.328*	.213	.225
z Ospan	.338*	.318*	.314*	.163	.185
z Rspan	.221	.300*	.180	.063	.088
z SymmSpan	.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.
No_Strategie	34	50,18	15,103
Strategie	17	30,35	17,281

Table 4: Descriptive statistics of strategy use in RSpan task

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

Table 5: Descriptive statistics of strategy use in SymmSpan task

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

Table 6: Results of the conducted T-Test

	Strategy vs. No_Strategy use		
WM span task	T	Df	P
OSpan	4,211	49	<.0001**
RSpan	2,130	44	<.039*
SymmSpan	-,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
OSpan	.014	.189	-.159	.207	.092	.073	.007	.214
RSpan	-.075	.187	-.044	.099	.023	-.030	.036	.225
SymmSpan	.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
Gf	-.152	-.090	.108	-.037	-.233	.036	-.143	.059
Gc	-.294*	.170	.159	.179	-.231	-.281*	.155	.144
Gv	-.188	.180	.248	.126	-.151	-.095	.071	.038
Gs	.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

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

Table 10: Results of the conducted T-Test

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

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

SymmSpan and five Transitive Inference tasks were administered to 65 adult University or High School gradautes. Only data where the participants were at least 85% accurate on the processing part of the SymmSpan were used for other purposes. From the initial number of 65 respondents five participants failed to keep 85% and these data were discarded.

Descriptive statistics can be found in Table 11.

Table 11: Descriptive statistics (Reasoning and SymmSpan)

	N	Minimum	Maximum	Mean	Std.Dev.
Reasoning	65	99	853	462,75	187,891
SymmSpan	60	96	127	113,35	8,640

Before proceeding with the statistical analyses, both measures were converted to z-scores.

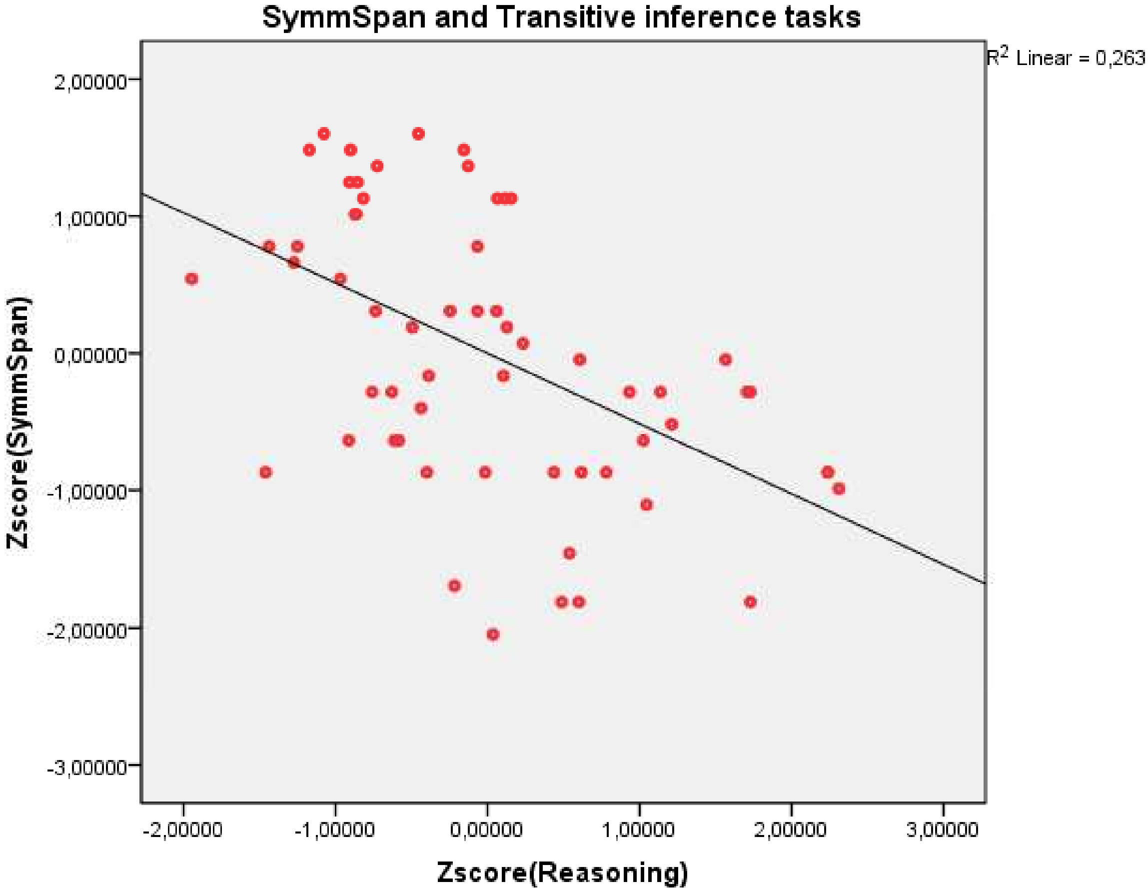
To test the relation between transitive inference tasks and SymmSpan, the correlation analysis was computed (Table 12). The results suggested that these two tests are significantly related. The performations on Transitive Inference tasks and SymmSpan were moderately correlated (r = -.513) ($p < .01$) with SymmSpan providing some evidence of convergent validity. Negative correlation was due to the transitive inference score obtained in seconds. The more time participants needed for the tasks, the worse the performance and the worse the score expected in SymmSpan.

Table 12: Correlation between SymmSpan and Transitive Inference

	Trans.Inference
SymmSpan	-.513**

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

Graph 2: Regression analysis of the relationship between SymmSpan and Transtive Inference



The scater plot shows that 26 percents of SymmSpan could be explained by Transitive inference.

The correlation did not approach unity, but was higher than the intercorrelations between SymmSpan and Broad cognitive abilities conducted in the previous reasearch (Table 13)

Table 13: SymmSpan, Transitive Inference and Broad cognitive abilities

	z *g*	z Gc	z Gf	z Gv	z Gs	Trans.Inference
z SymmSpan	.366*	.177	.320*	.249	.322*	.513**

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

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

Based on the results, I rejected H0 and accepted H1 there is a relationship between Transitive Inference tasks and automated WM span (SymmSpan) providing some evidence of convergent validity.

Next, the t-test for independent samples was conducted. The descriptive statistics can be seen in Table 14 The results of the conducted T-test shows there is a significant difference between participants based on their education. Participants with High School education (1) scored significantly higher in Transitive Inference tasks than those with University education (2), purely because they took much more time.

As can be seen in Table 15 High School graduates scored also significantly lower on SymmSpan tasks.

Table 14: Descriptive statistics (Transitive Inference)

	Education	N	Mean	Std.Dev.
Reasoning	1	28	506,11	187,891
	2	30	378,87	152,161

Table 15: Descriptive statistics (SymmSpan)

	Education	N	Mean	Std.Dev.
SymmSpan	1	28	110,79	8,085
	2	30	116,83	7,115

Table 16: Results of the conducted T-Test (SymmSpan)

	SymmSpan_1 vs. SymmSpan_2		
SymmSpan	T	Df	P
	-3,029	56	<,004**

Table 17: Results of the conducted T-Test (Transitive Inference)

	Transitive inference_1 vs. Transitive inference_2		
Transitive inference	T	Df	P
	2,869	56	<,006**

.

The correlation between WM and spatial fluid intelligence subtest 3 from LPS from the previous research was compared with the correlation between WM and Transitive Inference from the research that followed.

The correlations were both moderately strong (Table 18), but the relationship between SymmSpan and transitive tasks was stronger.

Table 18: Correlation between SymmSpan, LPS – S3 and Transitive Inference tasks

	SymmSpan
Transitive inference tasks	,513**
LPS – S3	,339*

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

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

7.7. Discussion

7.7.1. Sample:

Sample 1) 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.

Sample 2) In the following research - there were two different groups of respondents – University graduates and High School graduates. A total of 60 participants with median age 30, took part in this research. The results are therefore generalized within this demographic. None of the participants had previous experience with SymmSpan. Because transitive inference tasks are often used in fun tests or games, the participants might have had some experience with them. In this research, however, they were not allowed to use notes.

All the participants took part voluntarily and under the same conditions so the results would not have been influenced by any untoward motivation.

Since both tests were performed one after the other, on the same day, there was no sample reduction.

Only date reduction was caused by SymmSpan processing section, in which five of the participants didn´t manage to keep the 85% accuracy criterion and therefore had to be eliminated. As in the previous research, this sample reduction was not able to be controlled.

7.7.2. Procedure:

Procedure 1) 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. Althoug 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.

Procedure 2) SymmSpan and Transitive Infernce testing also followed the same conditions throughout. Both of the tests were also conducted in a quiet environment and followed the same conditions throughout.

Because none of the tests demanded too much time (SymmSpan about 15 min, Transitive Inference tasks, 2 – 15 min. depending on the participant´s speediness) all the participants performed the tests on the same day. For that reason it was not necessary to control intervening variables such as the participants´ current mental states, because the same mental conditions were assumed to be present when performing both tests.

Transitive Inference tasks were presented as a written version, in Times New Roman, font size 13. To be certain that all the participants would be able to read it, they were asked to read a sample sentence in the same font size. None present complained about the presented font size.

7.7.3. Methods**:**

Methods 1) Because the research took place in Germany, all the tests had to be in German. For that reason, the original WM span tasks, written in English, had to be translated. The research continued in the Czech Republic and therefore the SymmSpan once again had to be translated.

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 possitive 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 perticipants 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 resulted 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=1, 1+8+5=4) 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.

Methods 2) In the following research, because there was some evidence for domain specificity in WM capacity (WM span tasks measure domain-specific capacities and have limited value in predicting different domain abilities (Daneman and Tardif, 1987) and previous research showed that solving transitive inference tasks required visuo-spatial abilities to keep the same domain conditions, only SymmSpan was used as a visuo-spatial WM measure.

This research continued in the Czech Republic. For that reason translation of SymmSpan in Czech was also required. Because there is no clear evidence from previous research that there is a correlation between strategy use and SymmSpan results, participants were not prohibited from using it.

Transitive inference tasks were created by me in Czech. All five tasks were presented as statements about the relationships between elements with gradually increasing difficulty, according to Fales et al. (2002). A maximum of four relations was presented. Because participants could not take notes and had to find the solution mentally, the pilot study showed that it was possible to remember a maximum of four items. Although only five problems were presented, participants differed widely in the speed of their solutions, and their scores varied from 2 to 16 minutes.

Five problems was the maximum number reached before most participants started to feel tired, while a higher number of problems would certainly influence detrimentally, their performance.

7.7.4. Findings (found correlations):

Findings 1) 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 signifficant correlation found between WM and Crystallized Intelligence does not correspond with findings of Colom and Martinéz, (2009) who sugessted 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 priciples. 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 iregularity 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.

In all of the automated WM span tasks the computer began by computing the average time taken by the participants when processing the first part. If they took longer than this average in the next part, the computer automatically moved them to the next letter/block part, thus skipping the True or False part, counting the problem as a sentence error.

However, switching between processing and remembering might be more demanding, thus participants who were not so good in processing could therefore have even bigger problems when having to decide which is the right solution, while at the same time trying to remember the TBR.

. A possible explanation could be that participants with greater Gf and Gc would have less problems while performing processing portions with math problem solving 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.

Findings 2) In the following research, correlation analysis was conducted in order to find out more about the relation between WM Span task and Transitive Inference tasks. Significant correlation was found between these two tasks, but the correlation was not high enough to conclude that these two measurements actually measure the same construct.

Results obtained in the correlation analysis did not suggest unity of SymmSpan and Transitive Inference tasks. Nevertheless, these two tasks were moderately correlated and appear to have a lot in common. It seems that transitive inference probably requires more than a fluid processing component based on a lower relation between SymmSpan and Gf in previous research. Remembering also seems to play an important role in the relationship between WM and Transitive Inference tasks. But there is still a difference between WM and transitive Inference tasks – this would support the idea that the main reason for the discovered difference between these two tasks lies in the fact that participants work with TBR items at the same time as processing them in Transitive Inference tasks, whereas in SymmSpan these two processes are divided.

The reason why different strong correlations between fluid intelligence test / Transitive Inference tasks and WM Span tasks were found, could be due to the differences in the number of participants (49 in the previous research and 60 in the research that followed), and the fact that two different samples were used might also have influenced the results.

1.1. Conclusion:

A resolution for 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 seemed that application of WM in Speed testing of cognitive abilities in more detailed view was relatively limited, and the relation between these two constructs could be explained by the ability to process a specific type of information.

But the results obtained in the research that followed showed that remembering also plays an important role while performing WM tasks. It transpired that transitive inference requires probably more than a processing component based on the lower relation between SymmSpan and Gf as found in previous research. The difference between WM and Transitive Inference tasks supports the idea that the main reason for the discovered difference between these two tasks lies in the fact that participants work with TBR items at the same time as processing them in Transitive Inference tasks, whereas in SymmSpan these two processes are divided.

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.

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 would be most beneficial for their performance.

8. Appendix:

LPS- neu

Fragebogen zum Aktuellen Wohlbefinden (Well-being questionnaire)

Akzeptanzfragebogen (Acceptance questionnaire)

Transitive Inference tasks

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