**TITLE**

**Working Memory**

Working memory has been a critical component to human cognition studies in the literature. Baddeley (1986) describes working memory (WM) as the temporary storage of stimuli being encoded. Working memory plays its biggest role as part of your short-term memory (STM). STM, defined by Baddeley (1986), is when you can hold a short amount of information for a limited time. STM works in an interacting system that serves higher level mental processes. These higher level mental processes include reasoning, problem-solving, and learning.

Baddeley and Hitch (1994) first proposed a working memory model in 1974. Their model included the idea of a phonological loop, visuospatial sketchpad, and central executive. The phonological loop (previously the articulatory loop) has two parts: phonological storage and subvocal rehearsal. Phonological storage is when a person holds a sound memory trace until this trace is then rehearsed by the subvocal rehearsal of the model by repeating the trace internally. Baddeley and Hitch’s memory model additionally includes a visuospatial sketchpad, which is primarily responsible for visual and spatial encoding. Visual encoding would be when you receive an incoming image or stimuli and your brain is recognizing it so you can respond appropriately. Baddeley and Hitch (1994) explain that the visuospatial sketchpad is a type of work space for incoming information. The final piece of their model is the central executive. The central executive is responsible for controlling when the phonological loop and visuospatial sketchpad are used, and how they interact with one another (Baddeley, 2002).

**Fluid Intelligence**

There are copious amounts of brain mechanisms that work into how much you can hold in your working. One factor is intelligence, specifically fluid intelligence (*Gf*). Horn (1968) describes intelligence as behavior that can be observed and measured. Horn is describing that, for researchers in the behavioral sciences, intelligence needs to be measured in some aspect for it to be considered observable.. Jaeggi et al. (2008) classify *gF* as a human ability that allows participants to adapt their thinking to the problem at hand regardless of acquired knowledge. In addition, Gray, Chabris, and Braver (2003) highlight that *gF* is related to attentional control, or a person’s ability to disregard any interference that could affect performance. Gray et al. also says that attentional control is necessary for the abstract thinking needed for *gF.* Horn (1968) reports that Cattell presented the idea of *gF* in 1941 at an APA convention. Since then it has grown popular in the behavioral sciences as a way to measure intelligence that is always expanding. One of the primary ways to measure *gF* is to use the Raven’s Advanced Progressive Matrices (APM).

**Measuring of Working Memory and Fluid Intelligence**

Working memory has been tested in the field of psychology since Miller introduced the “magic number” in 1956. Yuan et al. (2006) suggest that there are two types of measurement: simple memory span and dual-tasks. Simple memory span tasks are when a participant is presented with a stimuli (words, numbers, or positions) and then asked to recall them in either the same or reversed order they were presented. Simple span tasks are generally used to measure short term memory (Mathy, Chekaf, & Cowan, 2018). Dual-trials tasks are when both processing and storage are both being encoded at the same time. Conway et al. (2005) identified most working memory measurements are considered dual-task because of their complexity. More modern working memory measurements are considered complex span tasks (Schmiedek, Hildebrandt, Lovden, Wilhelm, & Lindenberger, 2009). This distinction occurs because of the two components required for the task: the processing component and the storage component.

One of the most used tests to measure WM is the Operation Span (OSPAN) created by Turner and Engle (1989). In the OSPAN the participant is given a math problem which they have to identify the solution as correct or incorrect (processing component) with a word or letter being presented after they answer. The participant is then supposed to recall (storage component) those words after a few trials. The original OSPAN and the automated OSPAN (Unsworth, Heitz, Schrock, & Engle, 2005) still hold the same task, but the automated OSPAN is available completely online. This online presentation allows for less confounding variables between the researcher and the participant. The automated OSPAN also has a practice period where the participant is presented with a math problems. After the math practice, they are given a sample trial of math problem where they are told to remember a letter after answering whether the math problem was true or false. After both practice portions are completed the participant then begins the real study. The participants must maintain 85% accuracy for the math operations in order for their data to be considered useful (Unsworth et al., 2005). After the task is completed, the researcher is given the participants scores (Millisecond Software, 2016). The first is a raw score of the correctly recalled letters or words for each set. The researcher is also given a report on the participants math errors to account for accuracy.

Daneman and Carpenter’s (1980) Reading Span Task (RSPAN) is another example of a complex working memory measurement. The authors originally had two ways of testing reading span. In the first part of the RSPAN, participants read sentences out loud to the experimenter. After the participant finished a few sentences, they had to recall the last word in each sentence in order. For the second part, Daneman and Carpenter (1980) had the participant read sentences that were from general knowledge, politics, and other subjects; while still trying to remember the last word. After reading the sentence, the participant had to identify if the statement was true or false. The experimenters were interested in if the participant had recalled the words in order or not for reading span; however, the true/false verification increased the difficulty of the task, much like the math problems in the OSPAN task. The participants are scored on the number of correct words they recalled in the correct order. For example, the participant is supposed to recall the words: tent, shoe, and bottle. If the participant recalled shoe and bottle, they would receive 2/3. It is important to note for this task that the order is crucial for scoring. For instance, if the participant recalled the same words as above in this order: shoe, tent, bottle, they would still only get a 2/3.

The N-Back task was created in the late 1950’s (Kirchner, 1958). The idea behind this task was to measure short-term memory retention. It consists of different visual stages presented to the participant (Gajewski et al., 2018). After a stimuli is presented, the participant is asked if it matches a stimuli that was presented *n* trails before it. For example, if the stimuli was presented with letters, and this pattern was shown: A, B, D, A. The participant would have to identify if the ‘A’ was presented three trials back. This would be considered a 3-back task because of the number of stimuli in-between the two matching pieces. The stimuli would keep being produced, and the participant would need to keep identifying if the same stimuli was presented before. This process can be repeated with different difficulties, starting with 1-back, the researcher would just increase the number of stimuli between the two stimuli you would want the participant to match. The *n-*back is scored by the reaction times and percentage correct correlated to those in the same age group as the participant. This task challenges the participant because it requires encoding and updating of incoming stimuli while irrelevant stimuli are being introduced (Gajewski et al., 2018).

The Raven Progressive Matrices (RPM) is a measure of gF. Raven (1936) initially wanted to develop a test that would allow the researchers to interpret it without any social barriers, as compared to the criticisms of other standardized intelligence tests. In 1988, it was updated and became the Raven’s Advanced Progressive Matrices (APM) (Bors, & Stokes, 1998). The participant is presented with several images that represent a complex pattern, and they must pick one of six or eight options that would complete the sequence. The images in the matrix may be rotated, flipped, or change in size. The APM consists of two sets. Set one has 12 items and is generally used as practice for the participant. Set two has 36 items that is more difficult than set one. The participant is scored by how many of their answers were correct. These raw scores are then compared to percentiles based on the participants age. Researchers can choose to use a time restriction, five minutes for Set one or forty minutes for Set two (Bors, & Stokes, 1998). The time restricts could be used as an assessment of intellectual efficiency, without the time restrictions it can be used to evaluate clear thinking.

Conway et al. (2002) presented a latent variable analysis between WM. gF, STM and processing speed. In their study they had participants complete multiple simple and complex tasks including the OSPAN, RSPAN, and APM. They found that WM and gF were strongly linked, WM and STM were strongly linked, but gF was not linked to STM. The authors suggest that since WM is correlated with STM and gF is not, that WM and gF are different constructs that need different ways of being tested.

**Expertise**

The last construct that may affect your working memory or fluid intelligence is expertise. Chi, Glaser, and Rees (1982) describe expertise as having an abundance of knowledge and having skill to apply that knowledge. The authors argue that having this knowledge and skill plays a large part in intelligence as a whole. Because participants are able to recall their skill better and faster, they are perceived as more intelligent. This effect has been demonstrated primarily with the skillsets of chess (Chase & Simon, 1973) and physics (Chi, Feltovich & Glaser, 1981).

In Chase and Simon’s (1973) study on chess and memory, they had three classes of participants who played chess. From highest to lowest they were: master, Class A player, and beginner. The way the authors decided to study working memory was to isolate “chunks” that would then be encoded by the participant. These chunks were created by having a chess position set up having one of 28 variations. Chunks refer to Miller (1956) and his “magical number” 7, which proposes that most humans can contain 7 individual pieces of information plus or minus 2. During the memory task the players were asked to recall different chess positions from memory (Chase & Simon, 1973). These positions were recreated two ways. The first position was played games that were in the middle of a match and the second was from randomly placing the pieces on the board. The experimental design included two chess boards that were placed in front of the participant. One with the chess position already displayed with the chunk they were to recall, and the second with all the chess pieces at their starting places. The participant was told to examine the preset board for five seconds and recall the as much as they could remember on the full set board in front of them. The participant was able to repeat memorizing and recalling the board layout until they recalled the original set perfectly. It took those in the master class less trials than the Class A players and beginners to recreate the middle of the match positions. Those in the “master” class could encode the preset chess boards and recreate their model in less trials than the other two groups of participants, because they had more expertise playing chess.

This suggests that the expertise influenced the results based off the position being a playable game or not.

Chi et al. (1981) looked at the same idea of expertise, but with those in the field of physics. For their categories of participants, they used PhD students in the physics department (experts) and undergraduates who had only completed one semester of a physics course (novices). They were given 24 problems to group together by the how the solution to the problem was to be found. All participants were interviewed after they separated the problems to their respective categories to see how they reasoned why that problem fits with the category they chose. They determined that the experts sorted by the laws of physics, and the novices sorted by surface structures. Theses surface structures refer to objects, terms, or configurations of the problem presented.

In the second part of the study, the experts and novices were presented a new set of 20 physic problems. This part of the study also included an intermediate participant who was a fourth-year physics major. These problems were created to include both physic laws and surface features combined to see how the participants would categorize them. The results were replicated from the previous study by the expert and the novice participants. Yet, the intermediate participant reasoned both by using the laws of physics and surface structures, showing that they had applied the laws, but not yet left the surface structure. These studies by Chase and Simon and Chi et al., demonstrate that expertise is perceptually learned through practice and understanding. They both demonstrate ideas of chunking (working memory) and previous knowledge (intelligence) that can lead to expertise.

**Interplay between these systems**

With these three constructs combined, WM, *gF,* and expertise, they could help shape how we understand stimuli storage in our short term or long-term memory. They each play an important part in how we view the world around us and evaluate everyday situations. Shelton et al. (2010) found in their study that WM was a predictor for *gF*. The authors did so by looking at multiple WM and *gF* tests and seeing how they correlated with processing speed, primary and secondary memory, WM and *gF*. They used the digit symbol and symbol search subtests from the WAIS-III for processing speed. The primary memory N-back for primary memory. The Story Recall, Verbal Paired Associates I, Family Pictures I from the WMS-III for secondary memory. The automated OSPAN, listening span, and working memory N-back for working memory. Finally, the AMP, and the block design and matrix reasoning from the WAIS-III, for *gF*. After running a SEM model from the scores of all these tests, they found that processing speed, primary and secondary memory, and working memory all correlated with *gF*. They looked further into their SEM model to look at how much variance those constructs were explained by *gF*. After creating four smaller SEM models the authors found that WM had a unique variance when it came to predicting *gF* that none of the other constructs had. This supports that WM is prime component of *gF*.

Grabner, Neubauer, and Stern (2006) looked at the impact of intelligence and expertise on performance and neural efficiency. The authors recruited chess players for their study. The participants had to complete psychometric tests which included; the NEO-Five-Factor-Inventory, state anxiety test, and an unpublished questionnaire on the participants mood. The also had to complete an intelligence test (Intelligenz-Struktur-Test 2000 R) to identify the participants cognitive ability. These were used as a control for the EEG data collected. The participant also had to complete a speed, memory, and reasoning task using different types of chess boards and pieces. The authors found that the more intelligent participants had better performance than less intelligent participants in chess. There was an exception that those who were an expert at the task (chess in this study), could make up for their lack of intelligence.

Template Theory (Gobet & Simon, 1996) uses the idea of templates, or patterns, which you (as a person or participant) can fill in different information at hand to complete problems (such as chess). These templates can also be chunks. LT-WMT (Ericsson & Kintsch, 1995) is described as the association of information that has been encoded and the retrieval cues in LTM. For chess this would be remembering a certain cluster of pieces and being able to retrieve them and use them in a match. While in everyday life this could easily be after studying for long periods of time and seeing a definition to term question on an exam. Therefore, one could use TT with LT-WMT and as an expert, the LT is used as WM which would make that individuals memory storage and processing have higher processing (Guida et al., 2012).

Expertise works alongside WM and *gF* because it is needed to be able to recall and think about new problems at hand that the expert is evaluating.

**Methods**

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