REVIEW OF LITERATURE

In order to have probe in earlier researches in the field of working memory, long term memory activation and intelligence comprehensive review of related researches was carried out. The resume of researches has been compiled under four separate sections.

1. WORKING MEMORY PROCESSES:

The ability to mentally maintain information in active and readily accessible state, while concurrently and selectively processing new information, is one of the greatest accomplishments of the human mind. This kind of processing makes possible planning, reasoning, problem solving, reading, and abstraction. Of course, some minds accomplish these goals with more success than do others. Working memory (WM) is the term that cognitive psychologists use to describe the ability to simultaneously maintain and process goal relevant information. As the name implies, the WM concept reflects fundamentally a form of memory, but it is more than memory, for it is memory at work, in the service of complex cognition. As well, WM is a system with multiple components, or a collection of interrelated processes, that carries out several important cognitive functions.

Baddeley and Hitch, (1974) pioneer workers in the field of working memory, described WM as a system or mechanism underlying the maintenance of task-relevant information during the performance of a cognitive task. They conceptualized it as a cognitive operation in which some bits of information are held in a storage characterized by rapid decay in memory while other bits of information are retrieved from long-term storage. Baddeley (2002) further opined it to be a system responsible for maintaining and manipulating temporary information while other cognitive tasks are being performed.
Despite the familiarity of the term, however, it is not easy to figure out what working memory really is. To begin with, the term working memory is used in quite different senses by different communities of researchers. Baddeley and Hitch (1974) are duly credited with launching the empirical investigation of WM that continues today.

Baddeley and Hitch acknowledged that a considerable amount of important research had been conducted to address fundamental questions about STM itself, such as how information is coded in STM, what the capacity of STM is, how information is retrieved from STM, and whether forgetting from STM is due to decay or interference. However, they also lamented the fact that very little research had addressed the role of STM in more complex cognitive behavior. This was indeed a strange state of affairs, especially considering the primary role granted to STM in the most influential information-processing models of the time (e.g., Atkinson & Shiffrin, 1968; Broadbent, 1958). Baddeley and Hitch proposed a multicomponent WM model that consisted of domain specific storage buffers (later referred to as the “slave systems”; Baddeley, 1986) as well as a central executive. They provided empirical evidence from dual-task studies showing that the mental juggling required by complex cognitive behaviors, such as reasoning, can be achieved by coordinated storage and processing between the slave systems and the central executive. A certain amount of information can be held at bay in the slave systems while the executive works on new information.

While dealing with the structure, functions, and development of working memory. Charles (1995) also held that working memory systems is responsible for the temporary storage and manipulation of information during the performance of cognitive tasks. There is evidence that verbal-short term memory functions as a working memory system.
The common association between impairments of cognitive development is considered, as well as the relationship between short-term memory development and cognitive development. It is composed of a central coordinating executive system and one or more subsidiary systems as proposed by Baddeley (1983). The central executive is assumed to exert control functions, and the subsidiary systems are assumed to store specific information about items being processed, although there is some debate about the exact nature of the subsidiary systems. An important feature of working memory is that it has a limited capacity, so that if more demands are being made on the executive, there will be less processing space and cognitive energy available for the subsidiary systems.

The working memory literature is filled with seemingly contradictory claims. For example, some articles emphasize the unitary nature of working memory (e.g., Engle, Cantor, & Carullo, 1992), whereas others focus on its non-unitary nature and argue for a more domain specific view of working memory (e.g., Daneman & Tardif, 1987). Some articles put forth a theory in which individual differences in working memory capacity are conceptualized in terms of variation in the total amount of mental resources available (e.g., Just & Carpenter, 1992), whereas others claim that long-term knowledge and skills provide a better account of individual differences in working memory (e.g., Ericsson & Kintsch, 1995). Just and Carpenter (1992) assume a unitary, domain-general notion of working memory. Their approach included only one “resource pool,” but it only reflected the fact that the model was restricted to the domain of language comprehension. Just and Carpenter themselves had a more domain-specific view of working memory, assuming at least a distinction between language and visuospatial working memory. Another common misinterpretation
concerns the processing capabilities of the visuospatial sketchpad system in Baddeley’s model. Although Baddeley himself has consistently argued that it can actively manipulate mental images, some researchers have portrayed Baddeley’s sketchpad system as a pure storage buffer without any processing capability.

Shah and Miyake (1999) believe that The limited capacity character of working memory has the implications that if more demands are being made on the central executive component, there will be less processing resources available for the subsystems. The accepted assumption is that usually the capacity of working memory is 7 plus or minus 2 chunks of information. Although the capacity is limited, there is a claim that there is a significant growth of the working memory as a function of age (Siegel & Ryan, 1989). Geary et al. (2004) found that the capacity of working memory increases from preschool through the elementary school years. They suggest that the mechanisms underlying these developmental changes appear to include an ability to use strategies, such as rehearsal, in order to keep the information active in the working memory.

Cowan (2008) focuses primarily on recent evidence on a limit in how many chunks can be held in working memory, how this kind of limit can be measured, and how it can be distinguished from other types of limits. The theoretical and practical importance of different working memory limits in research that is homothetic (referring to general laws) and ideographic (referring to individual and group differences) explored. The appropriate measure of working memory depends on one's holistic or analytic scientific interest.

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The structure of working memory and its development across the childhood years were investigated by Gathercole et al’s (2004) in which children 4-15 years of age. The children were given multiple assessments of each component of the A.D. Baddeley and G. Hitch (1974) working memory model. Broadly similar linear functions characterized performance on all measures as a function of age. From 6 years onward, a model consisting of 3 distinct but correlated factors corresponding to the working memory model provided a good fit to the data. Gathercole et al. (2004) result indicates that the basic modular structure of working memory is present from 6 years of age and possibly earlier, with each component undergoing sizable expansion in functional capacity throughout the early and middle school years to adolescence.

Dickamp et al. (2002) studied working memory as the ability to temporarily store and manipulate currently relevant information which is required for most cognitive faculties. In humans and other mammals, the prefrontal cortex (PFC) provides the underlying neural networking for these processes. Within the PFC, WM neurons display sustained elevated activity while holding active an internal representation of the relevant stimulus during its physical absence or retaining a motor plan for the forthcoming response. WM is not a hallmark of higher vertebrates endowed with a neocortex. Birds also master complex congestive problems invoking WM, but they lack a laminated neocortex. Behavioral studies in pigeons show that the neostriatum caudolaterale (NCL) plays a central role in executive functions, such as WM and
response control. For neurons in the NCL of pigeons, they saw activity changes during the delay of a WM task, which were similar to those, observed in PFC neurons and were related to the subsequent behaviour.

These issues were also taken up by Dagenbarch et al. (2001) who examined the effects noticed in PFC neurons and were related to the subsequent behaviour. They further examined the effect of thalamus damage on verbal working memory. Six individuals (aged 49-83) with isolated thalamic stroke completed screening tests concerning working memory performance. Results show evidence of impairment on a number of working memory span tasks, but not on a forward digit span measure. Finding suggests a role for the thalamus in working memory.

Effects of synaptic complexity on the on-line measures: There was some evidence that older participants were more affected than younger participants by synaptic complexity on the off-line measures. The results support the hypothesis that on-line processes involved in recognizing linguistic forms and determining the literal, preferred, discourse coherent meaning of sentences constitute a domain of language processing that relies on its own processing resource or working memory system.

The experimental manipulation of working memory tasks has shed considerable light on the probable structure of the human working memory system, and, to a lesser extent, the specific processes captured by working memory paradigms (Jarrold, 2006). However, individual differences research has also had a crucial role to play in the development of theories of working memory. Correlational approaches have been particularly informative in three areas of working memory research. These are, first, the importance of working memory measures as correlates of high-level cognitive skills such as reading, mathematics, reasoning, and fluid intelligence; second, the extent to which human
working memory relies on domain-general or domain-specific component subsystems, and third, the precise reasons why working memory measures do relate to other important indices of human cognitive functioning. The findings from each of these areas suggest that working memory depends on a combination of domain-specific representational systems and domain-general processing and control systems, and that working memory measures capture individuals' ability to combine maintenance and processing demands in a manner that limits information loss from forgetting or distraction.

Study looked at how comprehension and memory processing at the situation model level is related to traditional measures of working memory capacity, including the word span, reading, span, operation span, and spatial span tests. Issues of particular interest were the ability to remember event descriptions, the detection and memory of functional relationships, the detection of inconsistencies, sensitivity to causal connectivity, and memory for surface form, text base, and situation specific content. There was little evidence that traditional measures of working memory span were directly related to processing at the situation model level. However, Radvansky and Copeland (2004) conclude the study that working memory span was related to their few text-level tests.

Oberauer (2003) conducted three experiments with an arithmetic working memory, which was interpreted as evidence for a focus of attention within working memory. Experiments 1a and 1b showed object switch costs with a task that requires selective access to items in working memory, but did not involve counting, and did not require updating of working memory contents, thus ruling out two alternative explanations of Garavan’s results. Experiment 2 showed object switch costs with a task that required no selective access to working memory
contents, but involved updating, thus providing evidence for a second component to the overall object switch costs. Further analysis revealed that the object switch cost increased with memory set size; that there were (smaller) switch costs when the switch was to an item of the same type; that repeating an arithmetic operation does not have the same effect as repeating the object it is applied to; and that object switching is not mediated by backward inhibition of the previously focused object.

Jameson (2005) explored the finding in greater detail with an individual differences approach. To accomplish this goal, two experiments were conducted in which participants performed several working memory tasks as well as a decision-making task known as the gambling task. In the first experiment, results replicated prior research showing that a working memory load does yield poorer performance on the gambling task. However, no relationship was found between the working memory tasks and the gambling task. The second experiment differed from the first only in that a physiological measure of performance, the skin conductance response, was recorded during the gambling task in addition to the behavioral performance. Results of the second experiment did not replicate the findings that a working memory load affects performance, nor was there any relationship found that between the working memory tasks and the gambling task.

Working Memory (WM) span tasks involving a complex activity performed concurrently with item retention have proven to be good predictors of high-level cognitive performance. Lepine et al. (2005) presented a study that demonstrates that replacing these complex self-paced activities with simpler but computer-paced processes, such as reading successive letters, yield more predictive WM span measures. This finding suggests that WM span tasks evaluate a fundamental capacity that underpins complex as well as elementary cognitive
processes. Moreover, the higher predictive power of computer-paced WM span tasks suggests that strategic factors don’t contribute to the relationship between WM spans & high-level cognition.

Barrouillet and Lepine (2005) tested the hypothesis that children with high working memory capacities solve single – digit additions by direct retrieval of the answers from long-term memory more often than do children with low working memory capacities. Counting and reading letter span tasks were administered to groups of third grade (mean age = 107 months) and fourth-grade (mean age = 118 months) children who were also asked to solve 40 single-digit additions. High working memory capacity was associated with more frequent use of retrieval and faster responses in solving additions. The effects of span on the use of retrieval increased with the size of the minimum addend. The relation between working memory measures and use and speed of retrieval did not depend on the numerical or verbal nature of the working memory task. Implications for developmental theories of cognitive arithmetic and theories of working memory are discussed.

Unsworth and Engle (2005) conducted a study in which high and low Working Memory (WM) capacity individuals performed the serial reaction time task under both incidental and intentional learning conditions to determine the role of WM capacity in the learning of sequential information. WM capacity differences emerged in conditions of intentional but not incidental learning, indicating that individual differences in WM capacity occur in tasks requiring some form of control, with little difference appearing on tasks that required relatively automatic processing. Furthermore, an index of learning was significantly related to a measure of general fluid under intentional conditions only. Thus, the degree of learning was significantly related to higher order cognition, but only when intentional processing was emphasized.
Camos (2008) aimed to evaluate the impact of individual differences in working memory capacity on number transcoding. A recently proposed model, ADAPT (a developmental asemantic procedural transcoding model), accounts for the development of number transcoding from verbal form to Arabic form by two mechanisms: the learning of new production rules that enlarge the range of numbers a child can transcode and the increase of the mental lexicon. The working memory capacity of 7 year-olds was evaluated along with their ability to transcode one to four digit numbers. As ADAPT predicts, the rate of transcoding errors increased when more production rules were required and when children had low working memory capacity, with these two factors interacting. Moreover, qualitative analysis of the errors produced by high and low span children showed that the latter have a developmental delay in the acquisition of the production rules.

Stephan (2011) noted that working memory is crucial for many higher-level cognitive functions, ranging from mental arithmetic to reasoning and problem solving. Likewise, the ability to learn and categorize novel concepts forms an indispensable part of human cognition.

2. Working Memory and Long Term Memory Activation

The field of working memory has made significant progress during the past three decades, which is reflected in the large range of researchers and models of WM, each with different scopes and emphases (Logie & D’Esposito, 2007; Miyake & Shah, 1999; Osaka, Logie & D’Esposito, 2007). One important aspect on which some models have radically different views is the flow of information in the memory system, and related to this, the interaction between WM and Long-Term Memory (LTM). Current interest focuses strongly on this link between...
WM and LTM, as researchers are more and more realising that there is a stronger interaction between WM and LTM than often assumed. Working memory is often defined as that part of permanent long term memory that is temporary active above some critical threshold and that can be recognized and manipulated by ongoing cognitive processes. It has become clear that models of WM alone are incapable of capturing some of our complex cognitive abilities, and researchers from different areas have now stressed the importance of understanding the relationship of WM with LTM (e.g., Baddeley, 2000, 2002; Burgess & Hitch, 2005; Jones, Ranganath & Blumenfeld, 2005; Woodman & Chun, 2006).

Anderson (1983) noted that the inclusion of a WM in system architecture was central, but that typical capacity limits imposed on WM needed to be unconventional. Anderson (1983, 1993) consider WM simply as the contents of long-term declarative memory that are currently active, with activation varying on a gradient rather than all-or-nothing availability. There was no capacity limit, except that activation had to be distributed among all elements receiving activation from a given source. Anderson et al. (1996) added an explicit assumption that the amount of source activation had a fixed limit which reflected the amount of attention that could be devoted to source objects. Thus, the capacity for activation was coupled with that of attention, despite the fact that a great deal more information could be activated to some level of availability than would be predicted from Baddeley's limited capacity storage subsystems.

Engle and his colleagues (Engle et al., 1992; Turner & Engle, 1989) hold the idea that working memory capacity is a general, domain-free system that is independent of any one processing task. This General Capacity (GC) Theory of working memory proposes that the working
memory system consists of storage processes, including long-term memory traces activated above the threshold and the processes required for achieving and maintaining that activation, as well as an executive attention component. This assertion has received support from a variety of experiments (Cantor, Engle, & Hamilton, 1991; Engle et al., 1992; La Pointe & Engle, 1990).

In reviewing the models of WM Kintsch et al. (1999) concluded that most models explicitly acknowledge a close relationship between WM and LTM, regardless of whether they emphasise the distinction or the continuity between the two constructs. However, some aspects of Baddeley’s working memory model have recently been questioned, especially the relationships between working memory and long-term memory (Van der Linden, 1998). Baddeley (1996) opined that working memory is a gateway between sensory input and long-term memory. In particular, working memory is considered to be closely involved in the learning of novel information. In this perspective, a vast amount of data has suggested that the long-term acquisition of phonological forms of new words requires the integrity of the phonological store.

It is also assumed that the contents of working memory is information in long term memory that has been stimulated or activated above some critical threshold. As with Anderson’s (1983) ACT model, activation is a resource that automatically spreads or otherwise divides among related concepts and is limited. The activation associated with a single concept can build or sum, and is not all or none. As the activation level of a concept increases, so does its accessibility.

Logie (1996) proposed a rather different interpretation of the long-term memory contribution to working memory performance. He suggests that working memory operates not as a gateway between
sensory input and long term memory but as a workspace. In this view, the storage components of working memory are not input buffers but rather they serve as temporary buffers for the information that has yet to be processed or is about to be rehearsed overtly. Thus, information that has been recently presented to the senses will activate the whole corresponding traces in long-term memory (visual, phonological, semantic, etc.), which then become available for temporary activation in the different components of working memory. This model furnished an explanation of the intervention of long-term memory in span tasks by suggesting that the performance depending on the phonological loop will be increased if semantic and visual information are simultaneously available for the other components of working memory.

Indeed, it could be suggested, as Gathercole and Martin (1996) did, that the incoming to-be-acquired new words activate phonological elements in a phonological network and these activated phonological elements are available for temporary retention in the phonological loop. Moreover, the more discriminating and durable is the temporary trace in the phonological loop, the more readily a stablelong-term phonological representation can be constructed in the lexical memory system. From this point of view, working memory still plays a role in long-term memory by processing the information it receives and returning it to long-term memory. Cantor and Engle (1993) assumed that working memory span scores and reading comprehension is that individuals differ in level of activation available for long term memory units Cantor and Engle, 1993. Two experiments used the fan manipulation to test this idea. In Experiment 1, high and low working memory Subjects learned a set of unrelated sentences varying in the number of shared concepts (fan) and then performed speeded recognition for those sentences. Low working memory Subjects showed a larger increase in recognition time
as fan increased. When the slope of the fan effect was partialed out of the relationship between working memory span and verbal abilities, the relationship was reduced to non-significance. In Experiment 2, Subjects learned thematically related sentences that varied in fan. Low span Subjects showed the positive fan effect typically found with thematically unrelated sentences, whereas high span Ss showed a negative fan effect.

There have been few attempts to directly measure the available but unattended LTM construct of WM and estimate its relationship with complex cognitive performance. In one such attempt, Cantor and Engle (1993) investigated the relationships between a style span task, a fan measure of LTM activation, and general reading ability. The data suggested that the fan measure of activation accounted for the majority of variance in reading that could be explained by the WM measure. However, following a series of experiments using a variation of the memory scanning task, Conway and Engle (1994) argued that an attention resource explanation of individual difference in complex WM memory measures was more appropriate than that of an activation explanation. Bunting, Conway, and Heitz (2004) also demonstrated that a controlled-attention interpretation accounted for individual differences in the fan effect.

Many researchers have tried to incorporate it within previously conceived memory systems simply by combining terms—that is, short-term working memory (Neath, Brown, Poirier, & Fortin, 2005) and long-term working memory (Ericsson & Kintsch, 1995) although whether such compound terms refer to procedures, constructs, or functions is often unclear. Despite being originally developed out of the concept of a system for STM, the concept of WM, as instantiated in several recent models, is intimately related to LTM (Cowan, 1999; Oberauer, 2002; Unsworth & Engle, 2007). They suggest that WM provides an interface
between STM and LTM, and has modified his original model by adding a new component, the episodic buffer, to accommodate the way in which WM and LTM interact.

Cowan (1999) have conceptualized the relation between WM and LTM as one in which WM is actually a subset (i.e., the currently activated portion) of LTM. According to Cowan’s (1999) embedded-process model of WM, the capacity of the focus of attention is limited to four chunks of information, and all other items in WM reside within, and must be retrieved from, the activated portion of LTM. On similar pertain Oberauer (2002) has proposed a concentric model of WM. In Oberauer’s model, information in memory may exist in different states of accessibility. A limited number of chunks may be within a state of direct access and other, recently activated information remains in a passive state of readiness within LTM. Importantly, because LTM is not constrained by the same capacity limits as the focus of attention or the region of direct access, reliance upon LTM may appear to expand the capacity limitations of WM.

According to Unsworth and Engle (2007) dual-component model, secondary tasks require that participants temporarily switch attention away from maintaining items in primary memory. Thus, at least some of these items must be retrieved from secondary memory. In contrast, simple span tasks (e.g., digit span) capture the ability to maintain a list of items in, and report them directly from, primary memory. This is the case unless the list exceeds approximately four chunks, at which point both primary and secondary memory abilities are involved. Taken together, these recent models reflect a growing consensus that WM tasks are not solely dependent on either system, thus placing WM at the intersection of STM and LTM, or the primary and secondary memory systems.
Nathan and Joel Myerson (2010) present a study to address the relationship between working memory and long term memory. They conducted two experiments which compared the effects of depth of processing on working memory (WM) and long term memory (LTM) using a levels-of-processing (LOP) span task, a newly developed WM span procedure that involves processing to-be-remembered words based on their visual, phonological, or semantic characteristics. Depth of processing had minimal effect on WM tests, yet subsequent memory for the same items on delayed tests showed the typical benefits of semantic processing. Although the difference in LOP effects demonstrates a dissociation between WM and LTM, they also found that the retrieval practice provided by recalling words on the WM task benefited long-term retention, especially for words initially recalled from supraspan lists. The latter result is consistent with the hypothesis that working memory span tasks involve retrieval from secondary memory, but the LOP dissociation suggests the processes engaged by WM and LTM tests may differ. Therefore, similarities and differences between WM and LTM depend on the extent to which retrieval from secondary memory is involved and whether there is a match (or mismatch) between initial processing and subsequent retrieval, consistent with transfer-appropriate-processing theory.

Ruchkin et al. (2009) find one advantage of the multiple-component working-memory concept is that it incorporates both on-line processing and temporary memory, allowing the concept of working memory as a mental workspace, rather than as a simple temporary storage device. The notion of working memory retention systems as comprising a state of activated long-term memory fails to capture, or to account for, this concept of orchestrated processing plus storage. A multiple-component working memory, as a mental workspace that is
separate from, but holds and manipulates the products of activated traces in long-term memory, retains the advantages of offering a testable theory, while accounting for a wide range of behavioural data, both from experimental manipulations and from neuropsychological dissociations. They argue that it is more parsimonious to assume that short-term memory reflects simply the activation of long-term memory traces, than to assume a separate, multiple-component working-memory system.

Moreover, a model that explains dual-task interference in terms of similarity of the codes used for each task sounds dangerously circular. Suggesting that two tasks interfere because they use similar codes has some difficulty in making predictions independently of the experimental outcome (Cocchini et al. 2002). In other words, assuming that working-memory retention systems and long-term memory arise from the same conceptual cognitive systems may well be theoretically sterile.

Christopher A. Was (2007) conducted two studies which tested relationships between listening comprehension and two conceptualizations of working memory (WM) capacity. Recently, some theorists have stressed that the empirically indicated limits of rehearsal-based WM storage components are inconsistent with the amounts of information needed to accomplish complex cognitive tasks, including language comprehension. Accordingly, they have proposed models of WM that include available long-term memory (ALTM) as part of the cognitive workspace. This study tested structural equation models (SEM) depicting relationships among factors representing ALTM, content specific background knowledge, listening comprehension, and conventional WM. The analyses revealed that ALTM mediated the relationships of both WM and background knowledge with listening comprehension. The incongruity posed by small-capacity, attention-
controlled WM components and theoretical models of comprehension that depict the integration of text information and background knowledge can, at least in part, be resolved by the models presented here.

In order to account for certain empirical findings that were difficult to explain with his original WM model, Baddeley (2000) introduced a new component. The episodic buffer is described as a limited capacity buffer which employs a multimodal code to allow integration of representations from the other WM components. Baddeley (2001) describes how comprehending a complex passage in the new version of his WM model is similar to LT-WM proposed by Ericsson and Kintsch (1995). Understanding requires access to representations in LTM and the integration of those representations with currently held information. The episodic buffer differs from other WM models that include activated LTM elements (e.g., Anderson, 1983; Cowan, 1995) in that LTM elements are stored in a specific temporary storage component.

Evidence from a series of experiments suggests that processing during the WM load phase of this task produces an increased availability of related LTM contents (Woltz & Was, 2006). The largest priming effects were seen in the focused category (i.e., the category to be remembered), and the magnitude of this priming was a function of the number of exemplars from the category in the memory load and the nature of the attention focus operation. Importantly, there were small but measurable priming effects even for ignored categories that had only one exemplar in the memory load. This suggests that even minimal processing in WM produces some increased availability of related LTM content.
Findings of a study by Nikolai (2008) indicate that regions in the medial temporal lobe (MTL) do not only play a crucial role in long-term memory (LTM) encoding, but contribute to working memory (WM) as well. However, very few studies investigated the interaction between these processes so far. In a new functional magnetic resonance imaging paradigm comprising both a complex WM task and an LTM recognition task, we found not only that some items were successfully processed in WM but later forgotten, but also that a significant number of items which were not successfully processed in the WM task were subsequently recognized. Activation in the parahippocampal cortex (PHC) during successful WM was predictive of subsequent LTM, but was correlated with subsequent forgetting if the WM task was not successfully solved. The contribution of the PHC to LTM encoding thus crucially depends on whether an item was successfully processed in the WM task. Functional connectivity analysis revealed that across-trial fluctuations in PHC activity were correlated with activation in extensive regions if WM and LTM tasks were correctly solved, whereas connectivity broke down during unsuccessful attempts to do the task, suggesting that activity in the PHC during WM has to be well controlled to support LTM formation. Interference of working memory load with long-term memory formation.

A number of other approaches describe WM as activated LTM (e.g., Cowan 2005; Ruchkin et al. 2003). Alan Baddeley’s view on this issue is that working memory involves the activation of many areas of the brain that involve LTM. This is also true of language, for which activated LTM is not taken as an explanation. He assumes that in the case of Cowan’s (2005) model, it is a way of referring to those aspects of WM that are not his current principal concern and not a denial of a need for further explanation. They agree that the phonological loop, the simplest
component of WM, is likely to depend on phonological and lexical representations within LTM as well as procedurally based language habits for rehearsal.

Radvansky and Copeland (2006) have found working memory capacity as a factor that is involved in long-term memory retrieval, particularly when that retrieval involves a need to overcome some sort of interference. Previous work has suggested that working memory is related to the acquisition of information during learning, along with the management of interference and the use of inhibition during long-term memory retrieval. This paper reports a study that further addressed the role of working memory capacity on long-term memory retrieval. Our results showed that working memory capacity is somewhat related to the integration of information into situation models, and the management of interference, but not to the ability to suppress irrelevant information. The role of other cognitive processes, such as general situation model processing and general inhibitory ability, were also explored.

The recent article of Schweppe and Rummer (2014) Schweppe and Rummer state that the multicomponent model conceives of working memory as a cognitive system separate from long-term memory. The crucial question, however, is whether this separation is structural or functional. Schweppe and Rummer seem to adopt the former view by stating that Baddeley’s (2000) modification of the original model maintains the structural separation of working memory and long-term memory. However, structural separation is nowhere asserted in Baddeley (2000) and, in fact, constitutes a frequent misunderstanding of the model. Baddeley and Logie (1999, p.47) explicitly state that they believe that working memory and LTM comprise two functionally separable cognitive systems. Baddeley (2012) adds that working memory
involves the activation of many areas of the brain that involve LTM.

Recently, Soemer (2015) criticized the theoretical review paper published in Educational Psychology Review journal by Schweppe and Rummer (2014). Soemer’s comment mainly concerned their description of the multicomponent model of working memory. More specifically, he criticized that, unlike suggested in article, the current version of the multicomponent model of working memory (Baddeley, 2000, and later) does not postulate structurally independent working and long-term memory systems but rather functionally independent systems. He concluded that this misunderstanding makes the entire argument in favor of a different perspective on working memory invalid because, when interpreted correctly, the difference between the two approaches is only minimal. If this were the case, the two accounts would not contradict each other but rather look at working memory from different angles and complement each other. According to Soemer there is, thus, no need for multimedia theories to refer to alternative models of working memory.

3. Fluid and Crystallized Intelligence

Cattell (1941) questioned the notion of Spearman’s general factor of intelligence and it seemed especially compelling to him to propose a theory of two general factors i.e. fluid and crystallized intelligence. Cattell (1943) realized that there is not one “general factor” as in the Spearman-Thurstone resolution, but more. Two of these general fluid (gf) and general crystallized (gc) are highly cooperative in the sense that they load positively most of the general ability primaries and have largely zero loadings outside the intelligence field. Cattell (1971) asserted that crystallized ability loads more highly on those cognitive performances in which skilled judgment habits have become crystallized
as a result of earlier learning application of some prior, more fundamental general ability to this field. Thurstone’s verbal and numerical primaries, or achievement in geography or history, would be examples of such production. Fluid ability, on the other hand, shows more in tests requiring adaptation to new situations, where crystallized skills are of no particular advantage.

Flanagan et al., 1997 concluded that there is a considerable differences in the measurement of gf and gc. Horn (1988, pp. 658–659), for example, described gc as follows: “The measured factor is a fallible indicator of the extent to which an individual has incorporated, through the systematic influences of acculturation, the knowledge and sophistication that can be referred to as the intelligence of a culture.” Here, the importance of knowledge (K) as an aspect of gc is very clear. With respect to gf, Horn (1988, pp. 660) wrote: “The factor is a fallible indicator of reasoning of several kinds, abstracting, and problem solving, when these qualities are acquired outside the acculturation process, through personal experience, and through learning that is not selectively restricted.” Here, reasoning seems to be the most important aspect of gf. In other words, tasks with a high loading on gf involve primarily reasoning and, to a lesser degree, knowledge of the culture, whereas tasks with a high loading on gc involve primarily cultural knowledge and, to a lesser degree, reasoning. This differentiation between reasoning and knowledge forms the basis for the gf–gc differentiation in a widely used German intelligence test “I-S-T 2000 R” (Amthauer, Brocke, Liepmann, & Beauducel, 2001). Yet, although the difference between reasoning and knowledge reflects an important aspect of the gf–gc differentiation, gf and gc can also be differentiated on the basis of several other aspects. For example, Lindenberger and Baltes (1997) based their differentiation of the mechanics and pragmatics of
intelligence on reasoning and memory on the one hand (mechanics), and knowledge and fluency on the other (pragmatics). Moreover, in the studies conducted by Horn and Cattell (1966), Hakstian and Cattell (1978), and Gilardi et al. (1983), reasoning and memory load on gf, whereas knowledge and fluency load on gc. In this broader perspective, gf cannot be reduced to “pure” reasoning and gc cannot be reduced to knowledge alone. The importance of the differentiation between reasoning and knowledge is acknowledged, but it also is recognized that other abilities may be significant in the gf-gc differentiation.

Schweizer and Koch (2002) Since the early years of the 20th century, several intelligence factors have been defined (see Sternberg, 1982). For instance, Cattell and Horn found in their empirical work that the single g factor is not sufficient to explain all variance of intelligence tests. Their widely confirmed theory claims that intelligence consists of two higher order factors, fluid and crystallized intelligence. However, some researchers (Undheim & Gustafsson, 1987) have suggested that fluid intelligence and general intelligence may be equivalent concepts. Fluid intelligence is defined as the ability to reason under novel conditions and crystallized intelligence is related to performance based on already learned knowledge and experiences. More specifically, fluid intelligence is said to reflect an ability to induce abstract relations (Carpenter, Just, & Shell, 1990) whereas crystallized intelligence is said to reflect scholastic achievement and cultural knowledge (Cattell, 1971). High fluid intelligence tends to predict high crystallized intelligence if educational opportunities are available (Cattell, 1971). In younger age groups, fluid and crystallized intelligence are more closely related than in older age groups, because school curriculum tends to standardize students’ knowledge base (Schweizer & Koch, 2002). In adulthood, the acquisition of specialized knowledge in
different professions decreases the relationship between fluid and crystallized intelligence.

The fluid intelligence is often measured with figural tests, whereas crystallized intelligence is often assessed with verbal tests. It is argued that construct irrelevant figural variance is included in \( gf \) and construct irrelevant verbal variance is included in \( gc \). This faceted view of \( gf \) and \( gc \) is regarded as more convincing than a purely hierarchical structure. Although the Cattell’s approach is partly similar to Guttman’s Radex model where no radial partitioning of the tasks is expected. Beauducel et al. (2001) too observed in smallest space analysis a simplex of \( gf \) and \( gc \) emerged as well it’s radial or a polar facet of verbal, numerical, and figural content. The faceted structure for \( gf \) and \( gc \) was also shown in confirmatory factor analysis and fitted the data more completely than the hierarchical model. The implications for the conceptualization and the assessment of \( gf \) and \( gc \) are discussed.

While questioning the validity of distinction between fluid and crystallized intelligence Guilford (1980) highlighted certain biases in Cattell’s data. Cattell and Horn cite factor analytic findings to support these two abilities, which they regard as second-order factors, demonstrated from intercorrelations of scores representing first order factors. In their analyses, the tested subjects varied widely in age and education and other conditions that are likely to bias intercorrelations of test scores. The two obtained factors purported to represent \( gf \) and \( gc \) could thus have been spurious. In other analyses with better controls, however, two such factors did also appear with two or three in addition. However, the author interprets these factors to be second or third-order abilities differing along the lines of the categories of the present author’s SOI model. The fanciful names do not appear to represent valid constructs.
Beauducel and Kersting (2002) also found the relationships to gf and gc are expected. Processing capacity is very close to reasoning, which is usually related to gf (e.g., Hakstian & Cattell, 1978). Carroll (1993, p. 64) directly relates the processing capacity described in Jäger (1967) to gf. However, when knowledge is required for the solution of tasks (e.g., when the terms in analogies are not very common), parts of reasoning tasks can also be related to gc (e.g., Horn, 1988). Thus, tasks representing processing capacity can be assumed to be related mainly to gf and, to a lesser degree, to gc. Horn and Cattell (1966), Hakstian and Cattell (1978), and Gilardi et al. (1983) found associative memory to be related to gf. Therefore, associative memory is also expected to be related to gf in the present context. With respect to creativity, no correlations with gf or gc have yet been reported. However, correlations have been reported between fluency, which can be regarded as a part of the BIS creativity construct, and gc (Gilardi et al., 1983; Hakstian & Cattell, 1978; Horn & Cattell, 1966).

Furthermore, in Lindenberger and Baltes (1997), fluency is seen as part of the pragmatics of intelligence, which is close to gc. Of course, fluency is only a weak measure of creativity. Therefore, the results reported in the respective studies should not be generalized to the broad construct of creativity, although a correlation with gc is assumed for the fluency part of the creativity construct. Since some speed and flexibility is necessary to produce words in fluency tasks, fluency could also be expected to be related to gf; this, however, has not yet been reported in the literature on gf and gc. We therefore decided not to formulate an explicit hypothesis in this regard, but rather to explore the relation of fluency to gf in a post-hoc analysis. According to Horn and Cattell (1966), relationships to gc can also be assumed for processing speed, which is close to Carroll’s (1993) broad cognitive speediness.
In agreement with Cattell’s earlier findings, Horn (1980) suggests that findings converge toward support of theories stipulating a hierarchy of intellectual functions. It is noted that near the top of this hierarchy, most related to intelligence are the two broad set of abilities known as gf and gc. Horn focuses on the decline of gf through adulthood (20-60 years of age). Outlined are conclusions that pertain to the procedures for analyses, sensory detectors in relation to gf-gc decline and short period learning and memory, LTM, speediness, and aging increments in gc.

Psychometric studies have shown that “general intelligence” should be broken down into the ability to apply learned solutions to new problems, i.e., gc, and the ability to deal with novel intellectual problems i.e., gf (Hunt, 1998). This distinction has been amplified upon by studies of individual differences in information processing. The gc depends on the problem-solving schema that people have acquired and upon their efficiency in accessing information in LTM. The gf is associated with the ability to access and manage relatively large amounts of information in working memory. Measures of gf and gc are important predictors of objectively measured workplace performance. Studies of actual and simulated workplaces have shown that this is largely due to differences in people’s ability to manage information and the speed with which the details of a job can be grasped.

Altogether, the relationships of speed to gf and gc are complex. It is therefore assumed that speed is related to both gf and gc. Carroll, 1993 demonstrated that Verbal abilities are often assumed to be related to gc (e. g., Carroll, 1993), whereas figural abilities (especially topographies and matrices) are thought to be related to gf (see Cattell,1987). However, these tendencies do not follow directly from Horn’s (1988) descriptions of gf and gc cited above. The degree of
Acculturation can be assessed with verbal tasks, although verbal tasks are not always related to gc. According to Cattell (1987), verbal reasoning tasks in which the words are familiar to the participants may be mainly related to gf. Sternberg and Gastel (1989) used verbal reasoning tasks to measure gf, and in Amthauer et al. (2001) verbal reasoning tasks had their main loadings on gf. Therefore, the assumption that verbal abilities are mainly related to gc holds only on the condition that the vocabulary or verbal knowledge required for the specific tasks is not familiar to all participants, and that only a low amount of reasoning is required. Figural abilities are assumed to be substantially related to gf (e.g., Horn, 1988) and are generally not found to be related to gc. This could be because of knowledge as a basis for gc is generally assessed with verbal tests.

In Amthauer et al. (2001) knowledge is assessed by means of verbal, numerical, and figural tests, and the figural knowledge tests also load on gc, indicating that figural tests do not necessarily have to mark gf. Numerical calculations are related to gf when they require reasoning rather than mathematical knowledge (Horn, 1988). When they demand mathematical knowledge, numerical calculations load primarily on gc. According to Horn (1988), broad mathematical ability can indicate gf as well as gc. Because numerical reasoning tasks usually involve high levels of both reasoning and knowledge, they will be assumed to be related to both gf and gc in this study. In sum, we follow the approach taken by Horn (1988) and regard gf and gc as differing mainly in the degree of acculturation involved in the tasks.

Horn and Cattell (1966) and Hakstian and Cattell (1978), and in Horn’s (1988) description of gc, knowledge was regarded as an important aspect of gc. Moreover, in Horn and Cattell (1966) and Hakstian and Cattell (1978), knowledge scales load on the gc factor. This
is in line with Cattell’s (1987) investment theory, since the investment of gf should at least result in the acquisition of some testable knowledge (cf. Beauducel, Brocke,&Liepmann, 2001). Thus, knowledge can be regarded as a core of gc (see Horn, 1988), but at the same time gc could also comprise further aspects of acculturation,such as general problem-solving strategies.

The nature of fluid intelligence was investigated by Salthouse (2008) identifying variables that were, and were not, significantly related to this construct. He suggested that fluid intelligence represents a broad individual difference dimension contributing to diverse types of controlled or effortful processing. The analyses also revealed that very few of the age-related effects on the target variables were statistically independent of effects on established cognitive abilities, which suggests most of the age-related influences on a wide variety of cognitive control variables overlap with age-related influences on cognitive abilities such as fluid intelligence, episodic memory, and perceptual speed.

To extend research by assessing whether the gf/gc distinction commonly discussed in the academic intelligence literature was applicable to the domain of social intelligence, Lee et al. (2000) conducted a study on 18-22 year old university students. The subjects completed verbal, pictorial and self report measures of 4 constructs: social knowledge (hypothesized to reflect crystallized SI), social inference (hypothesized to reflect fluid SI), crystallized AI and fluid SI’s. In addition other report measures were collected for these constructs in the multitrait-multimethod study. Confirmatory factor analysis replicated previous research, documenting that the 4 trait constructs showed convergent and discriminant validities. Similar analyses also extended prior research by showing that gf/gc distinction might be applicable in the SI domain and that a hierarchical model fits the data well.
Ziegler and Matthias (2015) Explaining cognitive decline in late adulthood is a major research area. Models using personality traits as possible influential variables are rare. This study tested assumptions based on an adapted version of the Openness-Fluid-Crystallized-Intelligence (OFCI) model. The OFCI model adapted to late adulthood predicts that openness is related to the decline in fluid reasoning (Gf) through environmental enrichment. Gf should be related to the development of comprehension knowledge (Gc; investment theory). It was also assumed that Gf predicts changes in openness as suggested by the environmental success hypothesis. Finally, the OFCI model proposes that openness has an indirect influence on the decline in Gc through its effect on Gf (mediation hypothesis). Using data from the Berlin Aging Study (N = 516, 70–103 years at T1), these predictions were tested using latent change score and latent growth curve models with indicators of each trait. The current findings and prior research support environmental enrichment and success, investment theory, and partially the mediation hypotheses. Based on a summary of all findings, the OFCI model for late adulthood is suggested.

Aichele and Stephen (2015) they examined life span changes in 5 domains of cognitive performance as predictive of mortality risk. Data came from the Manchester Longitudinal Study of Cognition, a 20-plus-year investigation of 6,203 individuals aged 42–97 years. Cognitive domains were general crystallized intelligence, general fluid intelligence, verbal memory, visuospatial memory, and processing speed. Life span decrements were evident across these domains, controlling for baseline performance at age 70 and adjusting for retest effects. Survival analyses stratified by sex and conducted independently by cognitive domain showed that lower baseline performance levels in all domains—and larger life span decrements in general fluid intelligence and processing
speed—were predictive of increased mortality risk for both women and men. Critically, analyses of the combined predictive power of cognitive performance variables showed that baseline levels of processing speed (in women) and general fluid intelligence (in men), and decrements in processing speed (in women and in men) and general fluid intelligence (in women), accounted for most of the explained variation in mortality risk. In light of recent evidence from brain-imaging studies, we speculate that cognitive abilities closely linked to cerebral white matter integrity (such as processing speed and general fluid intelligence) may represent particularly sensitive markers of mortality risk. In addition, we presume that greater complexity in cognition–survival associations observed in women (in analyses incorporating all cognitive predictors) may be a consequence of longer and more variable cognitive declines in women relative to men.

Christensen, Batterham, and Mackinnon (2013) defined Gc quite narrowly by a verbal ability test. They used latent growth models to analyse the effect of initial levels and increases in levels of Gf on the development of Gc during an 8-year follow-up period during which 2,350 participants in the age range 20 to 24 years were followed up at three occasions. As a measure of Gf, a test of perceptual speed was used and a lexical decision task test was used as a measure of Gc. However, the Investment hypothesis was not supported, and the differential increases in Gc were not found to be a function of Gf.

Cecilia Thorsen (2015) their aim was to investigate the influence of Gf and Gc on the development of knowledge and skills in a sample of children in compulsory school who are homogenous with regard to level of education, age, and cultural background. Totally, 9,002 individuals from the evaluation through follow-up database born in 1972 and who left compulsory school in 1988 were included. These individuals were
followed up in Grades 3, 6, and 9. Structural equation modeling was used, and autoregressive path models were fitted. All modeling was performed using Mplus version 6.1. In the first step, a path model with a simplex structure was defined. However, a second model with direct relations of Gf on Gc in Grades 6 and 9 had better model fit, suggesting a continuous influence of Gf on Gc. However, no direct influence of Gf was found for the subject grades. Due to the continuous influence of Gf on the measures of Gc throughout compulsory school, support for Cattell’s (1987) Investment theory was found.

4. Working memory and Intelligence:

Working memory (WM) plays an important role in predicting general intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Laughlin, Tuholski, & Conway, 1999). Based on the WM model proposed by Baddeley and Hitch, there seemed to be two basic processes that were foundation to the execution of WM processes. An individual who could remember more items at one time would not only perform well on STM tasks but also more likely to engage their WM better in tasks that required switching their attention back and forth, constantly updating a stream of information and mentally inhibiting irrelevant responses. These researchers have suggested that the efficiency with which individuals maintained and manipulated information in their WM is the basis for reasoning ability, a skill highly associated with g.

There are many studies that contributed to establishing the relationship between working memory (WM) and g. Kyllonen and Christal (1990) published a seminal paper that started the excitement for the potential of the relationship between WM and g. The data reported in their studies suggested that reasoning ability, which was
most strongly associated with \( g \), could be a little more than working memory capacity (WMC). Their confirmatory factor analysis revealed a high correlation (\( r = 0.8 \) to 0.9) between WMC and reasoning ability factors. Though a one-factor model that combined the two constructs did not fit their data as well as a two-factor model, the authors were convinced that working memory may be the driving force behind reasoning ability. Since then, there have been various publications in the literature to identify the link between WM and \( g \).

The first investigation of the individual-differences correlates of WM measures was provided by two small studies of reading comprehension (\( N = 20 \) and \( N = 21 \)) reported by Daneman and Carpenter (1980). WM was assessed by the reading span method, which involves reading a series of sentences and later being asked to recall the last word of each sentence. The authors found a substantial correlation (.72) between the WM measure and the reading comprehension measure. However, this correlation was likely much higher than would be obtained if the measures did not share common content or method variance (i.e., both the measure of WM and the reading comprehension tests shared the same content of reading and verbal memory). Subsequent studies (see, e.g., Baddeley, 1986, for a review; see also Daneman & Merikle, 1996) that used a wider variety of WM measures reported significant but relatively smaller correlations between WM and reading. In linking the WM factors with the intellectual ability scales, Oberauer et al. (2000) found correlations between Verbal/Numerical WM factor scores and a numerical test composite of .46 and correlations between Verbal/Numerical factor scores and a reasoning test composite of .42. The Spatial-Figural WM factor scores correlated highest with the reasoning test composite (.56), the spatial test composite (.52), and the numerical test composite (.48). The Supervisory/Speed WM factor
correlated at .61 with a speed test composite from the intellectual ability test battery. However, all three WM factors correlated significantly with the speed test composite. Oberauer et al.’s (2000) results further suggest that the relationship between measures of WM and intelligence may be more complex than previously considered.

From a developmental perspective, one could find evidence that processing speed plays a role in WM and fluid intelligence (Fry & Hale, 1996). When age-related differences in speed, WM and fluid intelligence were statistically controlled, Fry and Hale (1996) found that individual differences in speed directly influenced WM capacity, which in turn predicted individual differences in fluid intelligence as suggested in their path analyses. They concluded that as one’s processing speed increased with age, WM became more efficient and after variance from processing speed was removed from WM, it still significantly predicted fluid intelligence.

The study by Ackerman et al. (2002) further examined the relations between WM and intellectual abilities and provided an additional perspective on the specific relations between WM and PS abilities. They administered 36 ability tests together with 7 WM tests to a sample of 135 adults. They found that a single underlying WM factor correlated substantially with a g factor (r = .70), but the WM factor also correlated highly with a general PS factor (r = .55). In addition, they examined differential relations between WM, performance on the Raven test, and a g composite that did not include Raven test performance. The Raven test correlated .58 with a broad g composite, while the WM composite correlated .47 with the g composite. In contrast, the Raven correlated only .25 with a PS composite, whereas the WM composite was significantly more highly correlated with the PS composite (r = .47).
Working-memory capacity explains reasoning ability and a little bit more.

Ackerman, Beier, and Boyle (2005) conducted a meta-analysis of 86 such studies that related WM and $g$ and concluded that the average correlation between the two constructs was 0.48 – that they only shared about 25% common variance. Studies included in the meta-analysis reported correlation between performance on WM tasks and measures of $g$ that ranged from .50 to .90.

However, the conclusion drawn by Ackerman et al. (2005) did not reflect the bulk of contemporary views of the relationship between WM and $g$ and the data that supported the correlation. Kane, Hambrick, and Conway (2005) reanalyzed 10 latent variable studies and suggested that WMC and reasoning abilities shared 50% of their variance. Oberauer, Wilhelm, Schulze, and Süß (2005) also reanalyzed the studies that employed structural equation modeling published in Ackerman et al. (2005) meta-analysis, and they suggested an even stronger correlation between the two constructs ($r = .85$). The compilation of the latent-variable analysis seemed to indicate that WM and $g$ shared between 50-70% common variance.

Besides the strong correlation between WM and $g$, numerous studies such as latent variable analyses also indicated WM as a good predictor of $g$. Results from these analyses provided support and explanation to the high correlations between working memory and general intelligence established in the literature Conway et al. (2002) suggested that short term memory (STM) is a subset of WMC as supported by the definition of WMC, which included both executive functions and the storage of information. In their analyses, after they had removed the shared variance between STM and WMC, the
remaining variance in WMC was still a significant predictor of general intelligence, \( g \). They reported a correlation of .49 (\( p < .05 \)) between \( g \) and the unique variance of WMC independent of STM. The significant correlation between variances from WMC and \( g \) in simple correlational studies and latent variable analyses provided strong support that the two constructs were related through sharing a common underlying ability that manifested itself in measures of WMC and \( g \).

Fluid intelligence, crystallized intelligence and their relationships to verbal and visuo spatial working memory (WM) were studied by Haavisto and Lehto (2005). Fluid/Spatial intelligence was assessed using four different tasks, while crystallized intelligence was defined with the help of test scores of upper secondary school on National Matriculation Tests in three different academic subjects and one additional verbal relations task. Complex WM span tasks were used to measure visuo spatial and verbal WM capacities. Structural equation modeling indicated that verbal WM was related to crystallized intelligence when both WM tasks were included in the model, whereas performance on the visuo spatial WM task was related to fluid/spatial intelligence, but not to crystallized intelligence. Verbal WM was not related to fluid intelligence when used as a single WM predictor. The results indicate that verbal WM might be related to verbal ability and learning at school, while visuospatial WM is relatively strong related to non-verbal WM reasoning and spatial visualization. The current results further suggest that WM capacity is not a unitary system.

Kane et al. (2005) opined that Working Memory Capacity (WMC) is not isomorphic with general fluid intelligence (Gf) or reasoning ability. However, the WMC and Gf reasoning constructs are more strongly associated than Ackerman et al. (2005) indicate, particularly when considering the outcomes of Latent-variable studies. Their reanalysis of
14 such data sets from to published studies, representing more than 310 young – adult subjects, suggests a strong correlation between WMC and Gf/reasoning factors (median r = .72), indicating that the WMC and Gf constructs share approximately 50% of their variance. This comment also clarifies the authors’ “executive attention” view of WMC, it demonstrates that WMC has greater discriminate validity than Ackerman et al. (2005) implied, and it suggests some future directions and challenges for the scientific study of the convergence of WMC, attention control, and intelligence. On a conceptual level, Oberauer (2005) pointed out that WMC should be regarded as an explanatory construct for intellectual abilities. Theories of working memory do not claim that WMC is isomorphic with intelligence factors but that it is a very strong predictor of reasoning ability and also predicts general fluid intelligence and g.

An example of studies in cognitive psychology and neuroscience that tried to explain the relationship between WM and intelligence is one by Halford, Cowan, and Andrews (2007). The authors suggested that WM and reasoning ability shared related capacity limits, and the two functions were related through the shared requirement that binds elements to slots of a hypothetical coordinate system in one’s memory. The process of maintaining the bindings between elements required attention that was essential to WM and reasoning abilities. The authors believed that “the common demand for attention when binding elements into slots is a possible explanation for common capacity limitations in WM and reasoning” (p. 236). These limits are most likely based on a restrained capability to form and preserve bindings of elements in memory. Research in the field of neuroscience also suggested that attention is a function of the prefrontal cortex, and that the relation between fluid intelligence (gf) and WM was mediated by activities in the lateral prefrontal and parietal regions.
Further Jung and Haier (2007) reviewed 37 neuroimaging studies on the location of $g$ in the brain. The product of their extensive review was that $g$ is most likely distributed across several regions in the brain – specifically, the areas most relevant to intelligent behavior may be concentrated in the parietal and frontal lobes of the brain. This led Jung and Haier (2007) to propose the Parietal-Frontal Integration Theory (P-FIT), which suggested that $g$ is not specific to any area but an integration of several regions in the brain. These areas were also commonly associated with WM, control of attention, planning, reasoning, decision making, memory retrieval and executive functioning. The postulated shared neural network between $g$ and WM provided further support that they may share something fundamental to higher order cognition.

Changes in neural activity after practice on WM tasks added support to the P-FIT model and the common neural network between WM and $g$ when Jolles et al. (2010) detected changes in the left ventrolateral prefrontal cortex, bilateral dorsolateral prefrontal cortex and left superior parietal cortex. Increased activation was observed in the striatum area during manipulation trials in WM tasks. The brain-behavior studies that explored the relationship between WM and $g$ seemed to advocate that WM is an important sub-component of general cognitive ability when viewed from a biological point of view, and this principle further strengthened the relationship between WM and $g$.

The recent attempts to raise intelligence through improving WM processes (Morrison & Chein, 2011) have created much controversy in the field of cognitive psychology. Although results seemed to be encouraging and positive, more research needed to be done to replicate and explain the generally inconclusive results obtained from these early efforts especially when there are currently more studies that reported
near transfer effects compared to far transfer effects. Efforts to improve general cognitive ability such as \( g \) has a long history of minimal success (Spitz & Johnstone, 1986). The notion of improving \( g \) through WM training should be further scrutinized as the evidence provided thus far is weak. Additionally, a major limitation in current research involved measuring improvements in \( g \) with only one single task. The latent ability should be targeted and measured with several tasks of \( g \) to study whether effects of WM training could generalize to other cognitive abilities (Shipstead, Redick, & Engle, 2012).

Heinz-Martin Süss et al. (2001) Working-memory capacity was conceptually differentiated according to functions and contents. The resulting two-faceted structure parallels the structure of intellectual abilities in the Berlin Intelligence Structure Model (Diagnostica, 1982). A battery of 17 working-memory tasks, chosen to represent the proposed facet structure of working memory, was administered together with a test for the BIS to 128 young adults. General working-memory capacity was highly related to general intelligence. The prediction of intellectual abilities by working-memory capacity was also tested by differentiating predictor and criterion according to the functional and to the content facet. Moreover, the paths from working memory to intelligence factors appear to be highly specific. This suggests that specific working memory resources, as opposed to a general capacity, are the limiting factors for their corresponding counterparts in the structure of mental abilities.

Colom, et al (2004) found a mean structural coefficient of .96 between \( g \) and working memory across three separate large scale studies. They reported a structural coefficient of .86 between \( g \) and working memory. Later Colom, Abad, Rebollo and Shih (2005) found a structural coefficient of .89 between working memory and \( g \). However, most of these studies have employed a latent-variable approach. When
the raw correlations between intelligence measures and working memory tasks are considered, the results are sharply different. Thus, for instance, there is a correlation of .24 between the Progressive Matrices Test and the working memory computation span task on the Ackerman et al.’s (2002) study, and a correlation of .32 between the Progressive Matrices Test and the working memory mental counters task on the Colom et al.’s (2004) study.

Miyake, Friedman, Rettinger, Shah and Hegarty (2001) considered two key measures of executive functioning, namely the Tower of Hanoi and the random number generation tasks. Those researchers measured working memory through the letter rotation and dot matrix tasks. Further, they assessed spatial intelligence through the paper folding and space relations tests. The correlation between their executive measures and the working memory tasks ranged from .17 to .26, the correlation between the executive measures and the intelligence measures ranged from .21 to .44, and the correlation between the intelligence measures and the working memory tasks ranged from .31 to .49.

Working memory and the general factor of intelligence (g) were found to be highly related constructs (Roberto Colom, 2008). However, we still don't know why. Some models support the central role of simple short-term storage, whereas others appeal to executive functions like the control of attention. Nevertheless, the available empirical evidence does not suffice to get an answer, presumably because relevant measures are frequently considered in isolation. To overcome this problem, here we consider concurrently simple short-term storage, mental speed, updating, and the control of attention along with working memory and intelligence measures, across three separate studies. Several diverse measures are administered to a total of 661 participants. The findings are consistent with the view that simple short term storage
largely accounts for the relationship between working memory and intelligence. Mental speed, updating, and the control of attention are not consistently related to working memory, and they are not genuinely associated with intelligence once the short-term storage component is removed.

N.J. Mackintosh and Bennett (2003) tested one hundred thirty-eight sixth grade students, aged 16–17, took tests of vocabulary, mental rotation, and abstract reasoning as markers of Gc, Gv, and Gf and also three working memory tests, one verbal, one spatial, and one numerical (mental counters). Consistent with a number of earlier results, they found that verbal working memory correlated with the vocabulary test and spatial working memory with the mental rotation test, but there was only a weak relationship between these two domains. Performance on the reasoning test was associated most strongly with the mental counters working memory test but was also related to performance on both verbal and spatial tests. Confirmatory factor analysis supported a three-factor solution of these data, with one ability test and one working memory test loading onto each factor. This suggests that although working memory may be partly general, it is also at least in part domain-specific with three of these domains corresponding to Gc, Gv, and Gf.

Oberauer (2008) hypothesis about why WMC is closely related to reasoning can be contrasted with two other popular views. One is that WMC tasks and reasoning tasks have in common the requirement of simultaneous storage and processing of information. To test this view, they compare the predictive power of relational-integration tasks with a storage component (thus matching the description of “simultaneous storage and processing”) with that of parallel tasks without a storage component. The storage and processing view predicts that only the tasks
with a storage component should be good predictors of reasoning, whereas we predict that the storage demand makes little difference for the predictive power of relational-integration tasks for reasoning tests.

Colom et al. (2008) explored the reasons behind the high correlation between WM and \( g \). They conducted a study in which participants completed several reasoning ability tests, WM tasks, STM tasks, measures of mental speed and executive functioning tasks such as updating and those that could assess one’s control of attention. Their confirmatory factor analyses revealed that the simple short-term storage largely accounted for the relationship between WM and \( g \). The other measures were not related to WM, and they remained insignificant with their relation to \( g \) after variance from the STM latent variable was removed.

Colom et al.’s (2010) conducted a study and acknowledged high relationship between working memory and intelligence suggests common underlying cognitive mechanisms and, perhaps, shared biological substrates. If this is the case, improvement in working memory by repeated exposure to challenging span tasks might be reflected in increased intelligence scores. Here they report a study in which 288 university undergraduates completed the odd numbered items of four intelligence tests on time 1 and the even numbered items of the same tests one month later (time 2). In between, 173 participants completed three sessions, separated by exactly one week, comprising verbal, numerical, and spatial short-term memory (STM) and working memory (WMC) tasks imposing high processing demands (STM–WMC group). 115 participants also completed three sessions, separated by exactly one week, but comprising verbal, numerical, and spatial simple speed tasks (processing speed, PS, and attention, ATT) with very low processing demands (PS-ATT group). The main finding reveals increased
scores from the pre-test to the post-test intelligence session (more than half a standard deviation on average). However, there was no differential improvement on intelligence between the STM-WMC and PS-ATT groups.

Jaeggi, Buschkuehl, Jonides, and Perrig (2008) also have shown that improvements in working memory performance are related to higher fluid intelligence scores. This study identified a cognitive task thought to share relevant underlying mental processes with fluid intelligence tests. Importantly, the cognitive task was different enough to avoid simple coaching. The main framework for this study is based on Halford, Cowan, and Andrews (2007) hypothesis: working memory and intelligence share common capacity limitations. The limitations come from the number of items that can be kept active in working memory or the number of relationships between elements that can be kept active during the reasoning process necessary for solving problems comprised on standard intelligence tests. The latter impose processing loads also required by working memory tasks. These shared limitations could be based on the ability to build and keep bindings among items in the short-term.

Colom et al. (2004) replicated the very high relationship between WMC and intelligence across samples from different countries and different test batteries, concluding, like Kyllonen and Christal, that these constructs are almost isomorphic. This general conclusion remains unchallenged, when, and only when, the constructs are appropriately tapped. Nevertheless, there are some researchers claiming that the correlation is not that large.

Halford et al. (2007) proposed that the large correlation between WMC and intelligence reflects a common capacity limitation: (a) WMC
temporarily binds elements to a system associated to relational representations necessary for reasoning, (b) the shared capacity limit depends on the number of bindings (approx 4 on average), and (c) WMC comprises a domain-general component accounting for the correlation between WMC and intelligence. Consistent with this approach, Colom et al. (2008) found, across three related studies using progressively more relevant measures (short-term storage, processing speed, updating executive processes, and attention) that the high relationship between WMC and intelligence can be accounted for by simple short-term storage (STM). In their last study comprising all the relevant constructs, STM was the main predictor of intelligence.

O'Connor, et al. (2003) observed one-hundred and forty-four Year 1 children (51% boys and 49% girls, mean age 6) from Queensland State primary schools participated in a study to investigate the relationship between working memory and cognitive functioning. Children were given two tests of cognitive functioning (the School-Years Screening Test for the Evaluation of Mental Status (SYSTEMS) and the Kaufman Brief Intelligence Test (K-BIT)) and the Phonological Loop (PL) subtests of working memory from the Working Memory Test Battery for Children (WMTB-C) (Digit Recall, Word List Matching, Word List Recall and Non-word List Recall). The two cognitive tests correlated at $r = .59$. Results showed a high correlation between SYSTEMS and the Phonological Loop (PL) component of working memory ($r = .67$). The K-BIT also correlated reasonably with the PL component ($r = .54$). The SYSTEMS and K-BIT showed various levels of correlation with the working memory subtests. A recursive measurement model showed a strong relationship between working memory and cognitive functioning ($\beta = .83$), the degree of fit for the model was very high at GFI = .965. Unsworth et al. (2004) realized that no task is a pure reflection of the construct of interest, they
examined the relation between Ospan and Raven for several reasons. Factor analyses demonstrate that Ospan loads highly on a WM factor and Raven loads highly on a gF factor, with the path coefficient between the two hovering around .60.

Tillman et al (2007) investigated, in children aged 6–13 years, how different components of the working memory (WM) system (short-term storage and executive processes), within both verbal and visuospatial domains, relate to fluid intelligence. We also examined the degree of domain-specificity of the WM components as well as the differentiation of storage and executive components. The short term memory (STM) and WM tasks used allowed us to statistically separate the executive from the storage processes, enabling examination of separate processes in relation to intelligence. Our results demonstrated that all four WM components (verbal- and visuospatial short-term storage and verbal- and visuospatial executive processes) provided significant, independent contributions to intelligence, indicating that, in children, both storage and executive processes of the WM system are relevant to intelligence. Especially intriguing are our findings showing that verbal and visuospatial executive processes independently predicted intelligence, suggesting that, in children, the executive processes may rely on separate resources for the verbal and visuospatial domains.

Coloma (2004) analyses if working memory (WM) is especially important to understand g. WM comprises the functions of focusing attention, conscious rehearsal, and transformation and mental manipulation of information, while g reflects the component variance that is common to all tests of ability. The centrality of WM in individual differences in information processing leads to some cognitive theorists to equate it with g. There are several studies relating WM with psychometric abilities like reasoning, fluid intelligence, spatial
visualization, spatial relations, or perceptual speed, but there are very few studies relating WM with g, defined by several diverse tests. In three studies, we assessed crystallized intelligence (Gc), spatial ability (Gv), fluid intelligence (Gf), and psychometric speed (Gs) using various tests from the psychometric literature. Moreover, we assessed WM and processing speed (PS). WM tasks involve storage requirements, plus concurrent processing. PS tasks measure the speed by which the participants take a quick decision about the identity of some stimuli; 594 participants were tested. Confirmatory factor analyses yielded consistently high estimates of the loading of g over WM (.96 on average). WM is the latent factor best predicted by g. It is proposed that this is so because the later has much in common with the main characteristic of the former.

Oberauer, Wittmann, Wilhelm, and Schulze (2002) administered a battery of 17 WM tasks, together with several psychometric tests of cognitive ability. They found that a good predictor of complex cognitive performance need not necessarily be a combination of storage and processing. Simple span tasks are equally related to reasoning than typical WM tasks. This finding is contrary to those reported by Engle et al. (1999) or by Conway, Cowan, Bunting, Therriault, and Minkoff (2002). Su¨b et al. hypothesized that WM is a causal factor for intelligence, although they recognised that “a correlational study like this one cannot decide between these alternatives” (p. 276). The S.E.M. model displayed in Fig. 8 of Su¨b et al. shows that WM is related to g in a relatively weak way: .38 with spatial WM and .58 with verbal-quantitative WM. These are weak relations compared with those observed in some previous studies. It is difficult to make a strong case from these values.

Wongupparaj (2015) examined the relationship among multifaceted functions of working memory, namely central executive
functions (shifting, inhibition and updating) and short-term storage components (phonological loop and visuo-spatial sketchpad), and general intelligence in 110 healthy participants using structural equation modelling. The key findings support a multidimensional model of the central executive in showing that updating, inhibition and short-term storage differentially correlate with general intelligence, including both fluid and crystallized intelligence. These results suggest that both processing and storage components of working memory contribute to the relation with general intelligence.

Marja-Leena Haavisto, et al. (2004) examined fluid/spatial intelligence, crystallized intelligence and their relationships to verbal and visuospatial working memory (WM) were studied. A total of 120 Finnish Air Force recruits participated in this study. Fluid/spatial intelligence was assessed using four different tasks, while crystallized intelligence was defined with the help of test scores of Finnish upper secondary school National Matriculation Tests in three different academic subjects and one additional Verbal Relations task. Complex WM span tasks were used to measure visuospatial and verbal WM capacities. Structural equation modeling indicated that verbal WM was related to crystallized intelligence when both WM tasks were included in the model, whereas performance on the visuospatial WM task was related to fluid/spatial intelligence, but not to crystallized intelligence. Verbal WM was not related to fluid intelligence when used as a single WM predictor. The results indicate that verbal WM might be related to verbal ability and learning at school, while visuospatial WM is relatively strongly related to nonverbal reasoning and spatial visualization. The current results further suggest that WM capacity is not a unitary system.