BrainBuilder® Science References

INTRODUCTION

Advanced Brain Technologies (ABT) created BrainBuilder® technology to assess and train auditory and visual sequential processing or working memory (WM) capacity as well as attention and other cognitive functions. Working memory is the ability to retain and manipulate information during short periods of time. This ability underlies complex reasoning and has generally been regarded as a fixed trait of the individual (Klingberg, Forssberg & Westerberg, 2002).

Advanced Brain Technologies and collaborators developed the foundation for BrainBuilder technology based on over 30 years of clinical development with a non-profit organization that specializes in brain based approaches for improving human performance.

The rate at which individuals need to process information in the 21st Century high speed, information packed, constantly changing competitive environment, is overwhelming (Long, 2000). Information processing is a virtue which has been extensively investigated in brain research due to its relations with cognitive processes such as learning, reading, and comprehension (Moravcsik & Kintsch, 1993). For cognitive processes of learning, memory seems to be crucial because it associates incoming information with information previously retained (Cantor, Engle, & Hamilton, 1991). One of the most accepted forms of assessment in brain studies regarding this component of memory, working memory, is a digit/letter span test (La Pointe, & Engle, 1990). This test offers insight into memory, links to attention span, sequential abilities, and organization of information (Sylwester, 1997).

Studies have identified a relationship between poor performance on digit/letter span tests and diminished memory (Long, 2000). Individuals who experience reading/learning difficulties cannot keep information in the correct sequential order (Eslinger, 2003). No recall is possible because rapid articulation of information reaches a point of decay (Shmidt & Boshuizen, 1993). Unable to learn at a typical pace of instruction, these individuals miss learning skills/concepts (Watson & Willows, 1995). BrainBuilder is a cognitive training tool that is used in directing such individuals to reach their working memory capacity potential (Long, 2000).

BRAINBUILDER® APPLICATIONS

General Population

Memory plays a significant role in organizing thoughts and ideas, building outlines, hierarchical order plans, and creating schemas, for designed exercises (Parasuraman, 1998). In order for a higher-level process to use the output of a lower level process, that output must remain available for at least some minimal amount of time (Groeger, 1992). The human brain is the center for thought, emotion, actions-plan, and self-regulation of mind and body and has remarkable ability for plasticity based on the input processed (Eslinger, 2003). Brain metabolic activation of processing is measured by Positron Emission Tomography (PET) or functional Magnetic Resonance Imaging (fMRI) (Kintsch, Welsch, Schmalhofer, & Zimny, 1990). Glucose utilization reflects task engagement and greater verbal fluency is an indication of efficient strategies in cognitive operations where little effort is needed (Bontempi, Jaffard, & Destrade, 1996). Higher processing takes place in the area of the prefrontal cortex (Braver et al., 1997). This area shows activity during object working memory like in planning, focusing attention on an object, and switching between tasks (Schoubotz & von Cramon, 2001). However, it is not clear if high intelligence individuals differ from normal /low intelligence individuals in processing as a result of greater glucose utilization (Larson, Haier, Lacasse, & Hazen, 1995).

Neuroimaging studies yield that there is high metabolic activity in different brain areas activated in spatial object memory tasks compared to those in verbal working memory tasks (Eden, Stein, Wood, & Wood, 1995; Pazzaglia & Cornoldi, 1999; Vecchi, Monticellai, & Cornoldi, 1995). BrainBuilder exercises tax working memory to its capacity at these brain areas by presenting spatial object and verbal tasks. Good cognitive functions depend upon the brain’s ability to prioritize tasks and to switch from parallel processing to sequential processing when the processing load of the tasks is excessive (Humphreys, Tehan, O’Shea, & Bolland, 2000). Simulation experiments which tested the hypothesis that a single learning system is capable of presenting both serial and temporal structures, supported the fact that temporal structure is an integral part of the sequence and where it is altered, the sequence can also change (Dominey, Lelekov, Dominey, & Jeannerod, 1998; Schubotz & von Cramon, 2001). Temporal order is especially vital in everyday life where perceptual abilities and language skills (e.g. typing) must be precisely timed and put in the proper order. BrainBuilder exercises facilitate executive memory which is a function of temporal order processing (Eslinger, 2003; Weinberger & Gallhofer, 1997). BrainBuilder affects the central executive control systems which mediate attention and regulation of processes occurring in working memory (Narayanan, 2003).

Attention and refocusing are a function of the left hemisphere neural network and are especially important when there is interference with the main task or in multitasking (Meyer et al., 1997). In multitasking situations text comprehension is relatively unaffected by low and intermediate loads on memory and only becomes impaired when the resource demands of one of the tasks are maximal. BrainBuilder digit/letter span exercises were developed to increase the ease and speed with which critical elements are retrieved after the interruption (Ericsson, 1988). Ericsson and Linch (2003) reported that with digit/letter span training, individuals managed to remember more than 7 units and that text comprehension is not impaired by long interruptions between reading of consecutive sentences. However, many daily activities rely on memory interruptions and many concurrent activities demand attention simultaneously.

Reading Disabilities and Dyslexia

The development of reading relies upon the ability to map rapid speech sounds onto printed words and rate processing which means perceiving speech sounds accurately (Rosenbaum & Collyer, 1998; Schouten, 1987). Normal readers constantly identify and remember sounds that change within milliseconds, like "bye" and "pie" (Schouten, 1987). If they cannot process the sounds on time, they miss important grammatical functions (Temple et al., 2000). Without accurate rate processing, the 50 milliseconds difference between the two words is lost, and speech perverting becomes difficult (Temple et al., 2000). PET can be used to differentiate between neural activity patterns underlying visual, phonological, articular, and semantic analysis of words (Flitman, O'Grady, Cooper, & Grafman, 1997). Certain frontal and prefrontal brain areas are involved in directing attention, planning, holding stimuli in memory, and performing complex stimulus transformation (Eden et al., 1993). Verbal fluency scores are significantly correlated with brain metabolic activity in these cortical areas (Bontempi et al., 1996). BrainBuilder exercises seem to elicit such a positive change in reading shown by blood flow to the injured areas of the brain and electrical potentials on the scalp in response to exercises stimulations.

It is the first year of life that the basic soundstage of native language becomes mapped in the nervous system, providing the phonemic elements that evolve into language (Eslinger, 2003). Each meaning elements is generated, integrated with a previous element that is still held in the focus of attention (Martin, 1993). Once understanding the text, readers have memory of the important aspects even when retention is delayed (Temple et al., 2000). A structure of the text is constructed in long-term memory (Rolke, Heil, Hennighausen, Haussler, & Rosler, 2000; Watson & Willows, 1995). For this structure to be continually expanded to integrate new information from the text, relevant parts of it must remain accessible during reading. When the next sentence is processed, some elements of the current structure of the text are kept in short-term memory to provide context as well as to serve as retrieval cues for the accessible portions of the structure (MacAndrew et al., 2002). BrainBuilder technology recognizes that text comprehension is a sequence process and fosters comprehension via improvement in short-term memory capacity (Just & Carpenter, 1992).

Age and Alzheimer's

Standing and Curtis (1989) found that memory span was best predicted by age and subvocalization silent rehearsal time in chess players. When Schneider et al. (1993) compared memory span scores of chess players; they found a reverse age difference on digit span tasks. Subject knowledge correlated negatively with age. The younger players mastered the knowledge more than the older players. According to Margolis and Scialfa (1984), knowledge might not be the issue but the time, which took older players to retrieve and process the information, and then execute the correct response. This resulted in older participants not performing well on recognition tasks (Olson et al., 1984). Children young as 6 already start utilizing phonetic codes in picture memory (Olson et al., 1984). It seems that cognitive functions may improve until certain age point where adults use memory strategies more efficiently than youngsters.

Elderly demonstrate difficulty in encoding information (Bell, 1990; Margolis & Scialfa, 1984). Less processing time is available to them to store and interpret incoming information because they are slower to encode digits. Consequently, they are slower to retrieve names on naming tasks, including digits (Spafford, 1989). Normal elderly people are often found to be scored in what is considered a pathological range. In elderly, 4 digits forward and 3 digits backward are accepted as normal. Sensory deficits, decreased mobility, and increased fatigue may contribute to this diagnosis (Osterweil, Mulford, Syndulko, & Martin, 1994). Other age related factors, such as decline in simple reaction time and vision might be part of the problem, too. Declines in the 56-65 age range are more apparent in digit symbol, recognition, than in digit span. Margolis and Scialfa (1984) found that older performed better than youngsters on digit span tasks. Phonetic skills, non-word decoding and digit span, improved across age (Olson, Davidson, Kliegl, & Davies, 1984). Older readers were found to be more precise, leading to less rhyming confusion.

Although most research focuses on brain growth and changes which take place during the first 3 years, many higher intellectual skills are not fully formed until adulthood (Brownlee & Kalis, 2001). During the next decades, rigorous molecular and clinical examination of brain aging will become more common as developed nations confront a huge surge in the elderly population (Selkoe, 1992). It may still remain controversial, however, whether age related loss of memory could be reversed with coaching and support. Research indicates that as youth fades, certain molecules and cells in the brain become increasingly impaired or disappear (Mountcastle, 1998). Some of the changes disrupt cognition if they accumulate past critical thresholds (Selkoe, 1992). The number of cells may not change, but the architecture, complexity and connection between them do (Mountcastle, 1998). Neurons die every day, starting from the day we are born, and the body never replaces them. However, our brain may contain “progenitor cells” that could become neurons if exposed to growth stimulating hormones (Mountcastle, 1998). Even though neural loss continues as we age, older people retain capacity to generate new connections via mental exercises (Swerdlow, 1995). Moreover, not all neural changes are destructive (Bear, Connors, & Paradiso, 2002; Mountcastle, 1998). Some may present attempts by surviving neurons to compensate for loss or shrinkage of other neurons.

The brain is capable of dynamic remodeling of its neural connections. An attempt to compensate for gradual decrements in the number and structure of neurons is proliferation of cells which are capable of relaying diverse factors that promote neurotic growth. Unfortunately, even when neurons survive their cell bodies and their complex extensions, the axons and dendrites, may atrophy. In recent years, investigators have begun suspecting that DNA in special cell location, the mitochondria, may contribute to senescence of the brain. Genes carry the chemical instructions that inform cells precisely how to synthesize proteins. There is an abundant research indicating that as people age, many proteins accumulate unhelpful modifications. The enzymes responsible for degrading oxidized and other proteins themselves undergo oxidation and loss of activity (Bear et al., 2002; Mountcastle, 1998). These enzymes seem to become increasingly scarce at old age.

The cause of the progressive decline in function that occurs within Alzheimer's disease is the result of the abnormal accumulation of Beta amyloid within the brain (Institute for Brain Damage and Dementia, 1999). Beta amyloid accumulates and causes injury and cell death, which results in even more amyloid accumulation, and a vicious feedback loop, begins. Central protein within senile plaques, Beta amyloid, can directly activate complement protein, but Beta amyloid can initiate its own chronic inflammatory response (Institute for Brain Damage and Dementia, 1999). The immune response is very active in Alzheimer's disease and may contribute to the disease rather than help (Collette, Salmon, Van de, Linden, Degueldre, & Frank, 1997). In the process of trying to digest the material within plaques and tangles, microglia release proinflammatory proteins and free radicals which cause secondary damage (Baddeley, 1990). Many important non protein molecules in the brain also change significantly in structure or amount during aging and Alzheimer's disease (Verhaeghen, Kliegl, & Mayr, 1997). However, genetics is only about a third of what predicts brain dysfunction. The other two thirds may account for environmental and educational modes presented by interventions, like BrainBuilder (Steronko & Woods, 1978).

Attention Deficit Disorder (ADD)

Auditory and visual sequential processing problems of ADD individuals negatively affect academic ability, decision making skills, attention span, and behavior in children as well as social maturity, interaction, learning ability, and productivity of adults. Difficulties in taking in, retaining, and processing information forces the expenditure of valuable time, effort, and energy to compensate for these deficiencies. BrainBuilder training is used to improve the level of brain function within the ADD population by improving auditory and visual sequential processing skills, which are the two most fundamental building blocks for all cognitive processes.

Parents of children with ADD claim that whenever they try to get their children to do something their brains cannot do or do not want to do, it frequently results in misbehavior. The mechanism of guiding behavior by representational knowledge was found to be destroyed in monkeys having prefrontal lesions and not yet developed in human infants (Bear et al., 2002). Damage to the prefrontal cortex could spare knowledge about the outside world yet destroy the organism's ability to bring that stored knowledge to mind and utilize it. Much of brain research comes from injuries of the frontal part of the hemispheres as well as animal experiments (Greenlee, Lang, Mergner, & Seeger, 1995; Sternko & Woods, 1978; Smith et al., 1999). Working memory tasks activate an extended network of the prefrontal, parietal, and medial frontal cortices. Although, the parietal and prefrontal cortices make distinct contributions to complex processing (as revealed by lesions), they are interconnected that their activation patterns are nearly indistinguishable (Halgren, Boujon, Clarke, Wang, Chauvel, 2002).

Loge et al. (1989) found that individuals with ADD performed well on fluency tests and therefore there was no support for the hypothesis that frontal lobe dysfunction was a prominent feature of cognitive impairment. Moreover, the correlation between verbal IQ and measures of frontal lobe function was weak. The frontal lobe physiological abnormalities that occur in ADD children probably arise in frontal components of widely distributed circuits involved in the "executive" control of attention. Inability to control and sustain attention appeared to be the core of deficiency rather than other factors, such as impulsivity. The right parietal lobe seemed to have a role in sustaining attention (Loge, Staton, & Beatty, 1989). Although, ADD individuals have difficulty reading and perform poorly on recall tests of learning and memory, other memory dysfunctions in recognition, language production, comprehension, and mathematical reasoning may be the cause as part of spatial information processing that affect thinking and learning (Posada, Franck, Georgiff & Jeannerod, 2001).

Schizophrenia and Autism

Appropriate responses are guided by memory rather than by immediate sensory information. Clinical studies have shown that damage to the partial cortex in humans causes spatial neglect, a loss of awareness of the body and its relation to objects in the outside world (Bear et al., 2002; Mountcastle, 1998). This damage seemed to be apparent in individuals with autism and schizophrenia (Steronko & Woods, 1978). Much attention has been focused on alteration of neurotransmitters, such as increase/decrease in dopamine levels to treat autism and schizophrenia (Baddeley, 1990). Adult monkeys whose prefrontal cortex, were deficient in dopamine and norepinephrine seem to perform poorly on delayed-response tasks which is related to short term memory deficits. Short-term memory deficits are apparent at a very early age stage in the visual information processing system of individuals with autism and schizophrenia (Steronko & Woods, 1978). BrainBuilder training improves sequential processing and short-term working memory skills without the need for dopamine or other drugs.

The prevalence of individuals with autism and schizophrenia who use dopamine is higher than statistically reported. The numbers of people being diagnosed with autism is rising at a meteoric rate. Approximately 1 in 200 people have an autistic spectrum disorder and 1 out of every 1000 children, with as many as 1 in 500 persons affected with some form of this disorder. In the US and Puerto Rico alone, there was an increase of 544% from 12,222 to 78,717 cases within 1 year, 1999-2000 to 2000-2001 (24th Annual Report to Congress on the Implementation of the Individuals with Disabilities Education Act by the Office of Special Education Programs, Trenton, New Jersey, 2002). The incidents of schizophrenia reveal a likelihood of 1 out of 100 who suffers from the disease, with 1 out of 10 who will injure him/herself if not treated with drugs (Gershon & Rieder, 1992; World fellowship for Schizophrenia and Related Disorders, 2003). BrainBuilder researchers are aware that genes alone do not determine autism or schizophrenia because a high percentage of cases do not have parents who carry the illness (Steronko & Woods, 1978). In fact, only 15% of identical twins have individuals with autism and 50% of identical twins to individuals with schizophrenia escape the illness (Neergaard, 2001). If BrainBuilder implementation is aggressive at early age, much of the need for complimentary drugs disappears.

Sequential Processing

Information from the environment is stored (memory), then processed (information is coded-changes forms) (Anderson, 1995; Roediger & Craik, 1989). Some stages of processing occur at the same time (parallel) in different places of the brain, and some occur one at a time (sequential). Information processing requires three stages: (1) Stimulus identification. Acknowledge that the stimulus occurred and identification of that stimulus, (2) Response selection stage. Deciding on a response based on a contact with memory. The time required to make a decision about a response is linearly related to the amount of information that must be processed in making a decision. Visual stimulation takes between 20 to 40 msc. to result in cortical activity while auditory stimulation takes between 8 to 9 msc., and (3) Response programming stage which is execution of the chosen response. Memory systems hold information and location of processing. Three major memory systems exist: short-term sensory memory, short-term memory, and long-term memory (Anderson, 1995; Roediger & Craik, 1989). Short-term memory is important in cognitive processing as it serves as the link between sensory input of information and the storage of information in long-term memory (Atkinson & Shiffrin, 1971). Working memory is part of short-term memory and has roots in the mechanism of information processing (Engle, 2000). The speed with which individuals can memorize a list of a given length increases and matches the presentation rates in memory tasks designed to study short-term memory (Kane & Engle, 2000). Neuroscientists made great advances in understanding the relation between cognitive processes and the anatomic organization of the brain. For many years it was believed that memory was a single entity while today it is known that memory consists of multiple components. Recent research has shown that working memory consists of several subsystems that can be relied on to complete various types of tasks (Eslinger, 2003; Narayanan, 2003). Working memory capacity predicts performance in language comprehension, and reasoning at early ages of learning and skill acquisition (Kyllonen & Christal, 1990). Utilization of more than one sensory channel, like in BrainBuilder, leads to a successful and more in depth learning.

Long-term memory depends on working memory considerably (Engle, 2001). The combining of moment-to-moment awareness and instant retrieval of long-term information constitutes working memory, like in mental arithmetic (Rosen & Engle, 1997). Relevant information is stored in long-term memory during processing for a task and this information must be potentially accessible during the work on that task. The use of long-term memory as an extension of working memory is possible only under very restricted circumstances. Laboratory studies have shown that a wide range of cognitive exercises such as problem solving, concept formation, and decision-making can be successfully accounted for by models that permit storage of a very small number of products in short-term memory (Ericsson & Kintch, 2003). Individuals must be able to rapidly store information in long-term memory; an ability that requires extensive experience and a large body of relevant knowledge and patterns of the particular type of information involved. Because only a limited number of units/chunks are activated at a given time and are therefore distinguishable from the rest of the vast amount of information stored in long term memory, access of information from this small set of information in short term memory is not problematic.

Working memory based on storage in retrieval from long-term memory could be attained through practice storage and retrieval speed (Ericsson & Kinch, 2003). Ericsson and Kinch (2003) bring broad research support to emphasize that individual differences in the capacity of working memory is not fundamentally fixed and unchangeable, but rather acquired by the amount of available activation. Ericsson and Kinch (2003) suggest that the capacity of working memory must be far greater than the traditional short-term memory of 7 plus/minus 2. Expand working memory capacity occurs by developing methods for storing information in long-term memory in accessible form (Cantor et al., 1991; Crowder, 1993). Ericsson (1988) found that after 50 hours of practice in digit span, participants increased their memory performance from 7 to over 20. Correlations between span scores and performance on comprehension tasks appeared to be significant (Engle, 2001). BrainBuilder training increases digit spans.

Associative memory sometimes replaces available activation of working memory by providing short-term memory storage of symbolic information (Engle, 2000). The hippocampus controls associative or learned memory and the frontal cortex is associated with executive functions (Halgren, Boujon, Clarle, Wang, Chauvel, 2002). The primary goal of the hippocampus is to consolidate new associations whereas the prefrontal cortex is necessary for retrieving the products of such associative learning (facts, events, rules) from long-term working memory (Narayanan, 2003). Learned actions are controlled by the cerebral cortex, basal ganglia, and cerebellum (Hikosaka, 2002; Mountcastle, 1998). These brain regions are by no means independent (Hikosaka, 2002). A complex network of interrelating brain regions serves high brain processes, and by adding dynamics, a deep insight into the functioning of a neuronal network is gained (Hikosaka, 2002).

Most of the current knowledge about long-term working memory comes originally from studies of high brain processes of exceptional digits recall (Staszewski, 1990). Individuals with high working memory spans are able to keep more of the relevant information active in working memory as they comprehend the sentences (Just & Carpenter, 1992; Moravcsik & Kintsch, 1993). The rule of thumb for mental abacus, for example, is an increase of 1 digit per year with deliberate training effort (Engle, 2000). Low span subjects have difficulty blocking out attention to distracting information in unattended message. Engle (2001) reported that 65% of subjects with low working memory heard their names mentioned (Cocktail Party Effect) while working on a task compared to only 20% with high span.

Digit and Letter Span

The concept of digit/letter span working memory tasks was created from short-term memory and is considered to be the cognitive analogy of workspace to be used while working on such tasks. Span memory for words involves the articulary loop where items can be store for 2 sec. Therefore, articulation speed is an important determiner of span memory and processing efficiency as digit span is a measure of working memory (Brown, 1958; Peterson & Peterson, 1959). Two processes are involved in digit span: (a) the identification of the items, and (b) the retention of order information. Individuals who are slow in identification have a shorter memory span. In most research about short-term memory the battery of digit span of Wechsler Adult Intelligence Scale (WAIS) or Wechsler Intelligence Scale for Children (WISC) were employed. However, several researchers questioned the accuracy of the children revised version of the test as opposed to speed test when predicting reading disabilities (Colorado Perceptual Speed) and family history (Kerns & Decker, 1985). Digit span may not be a very stable indicator of learning disabilities except in extreme ranges (Vargo et al., 1995). No relationship between reading rate and digit span was found because item and order information are separately represented in working memory (Das, 1985).Working memory is important in reading. Reading deficits may reflect deficient phonological encoding or maintenance of a phonological code in working memory. When verbal information is stored in memory the stimuli are encoded by their phonological features. Deficiency in coding phonological information in working memory is related to retrieval of speech sound codes from long-term memory (Vargo et al., 1995). On short-term memory task, whether auditory or visual (reading) digit span, contact must be made with stored representation in the long-term memory during the encoding process (Spafford, 1989). Familiarity with the language affects articulation speed because speech of articulation and fluency in language are affected by digit span. In Elliott's (1992) study, fast natural speed of articulation was likely to be a source of advantage for mathematics in Chinese. However, Japanese who showed shorter digit span than the North Americans, scored better on mathematics. Reynolds and Kamphaus (1990) found that freedom from distractibility including arithmetic's, digit span, and coding, was not produced by normal groups of natives (Anglos and Chicanos) and blacks.

Visual vs. Auditory Digit/Letter and Digit/Letter Forward vs. Backward (Reverse)

Verbal information presented visually and auditory is not typically integrated into a unitary sequence for subsequent rehearsal (Whitehouse, 2002). There is a better short-term memory for verbal stimuli with auditory presentation than for visual stimuli (Vitulli & Mcneil, 1990). Bush and Geist (1991) reported that forward digit span has significant longer mean latency for the auditory channel. However, Selnes (1991) found that visual presentation in youngsters is significantly stronger than for auditory presentation of backward digit span (Powell & Hiatt, 1996). Digit span as a measure of short-term auditory memory and attention may be affected by the ability to relax (Sattler, 1988). In Chavez, Brandon, Trautt, and Steyart (1983) study, digit span forward indicated impairment in performance of female subjects while other neuropsychological tests were only affected by state anxiety (Chavez et al., 1983). Using the Minnesota Multi Personality Inventory (MMPI), there was no indication of apparent systematic effects of anxiety on digit span (Black, 1986). Women seemed to perform significantly better on digit symbols than men (Anger et al., 1993). Powell and Hiatt (1996) and Searls (1975) suggested that low scores indicated either high anxiety or hearing deficits such as disability in auditory sequencing. Spafford (1989) found gender differences, favoring women, in coding as part of the digit span test. An interaction of age and digit span became more apparent after women reached age 70 (Johansson and Berg, 1989). Vitulli, Laconsay, and Shepard (1996) found that noise, as itself did not alter short-term memory performance when played as a distracting mechanism in participants' ears during rehearsal. However, participants who heard digits at a rate of 2 sec. intervals did better because they had more time to process the information. Cohen and Sedlacek (1983) found that relaxation procedures affected attention by increasing digit span after 6 weeks of self-regulation strategies training (autogenic, biofeedback, and progressive). There was a significant correlation between magnitude of blood pressure reduction and the relaxation techniques even though the digit span training and tests measured auditory memory rather than employed the visual channel (Cohen & Sedlacek, 1983). Steele, Ball, and Runk (1997), reported no Mozart Effect on digit span. The researchers used backward digit test because it was highly correlated with memory scores, incorporating spatial and temporal transformation. It was impossible to conclude whether listening to Mozart improved performance or listening to a progressive relaxation tape reduced performance.

Digit forward is not sensitive to the early stages of dementia or brain damage as is digit backward. Digit/letter forward appears to involve primarily sequential processing whereas digit backward appears to involve both planning ability and sequential processing (Crowder, 1993). Digit/letter backward demands exceptional attention and concentration (Searls, 1975). However, the ability to repeat digits backward is not only dependent on attention-concentration, general cognitive, and short-term memory functioning, but also requires verbal and visual (nonverbal visualization) mediation. Also, improvement demonstrated in recall of reverse digit span tasks showed progress in areas of organization (Baddeley, 1990). Right hemisphere dysfunction reduces backward digits while left hemisphere dysfunction reduces forward digits performance (Steele et al., 1997). Even though digit repetition as a verbal function is predominantly subsumed by the left hemisphere, different neuropsychological functions play a role in digit repetition performance. Thus, digit repetition is not totally a left hemisphere function and backward digit repetition is not a specific right hemisphere function. Impairment of digits backward in patients with right hemisphere lesion might be due to visual or spatial deficits. In Black's (1986) study, the right hemisphere sample showed no significant impairment on forward and backward digit span, although performance was somehow inadequate on the backward digits. The left hemisphere sample demonstrated only a mild impairment on forward digits, but performed significantly poorly on the backward digits. The researchers concluded that the ability to repeat digits backward was not only dependent on attention-concentration, general cognitive and short-term memory functioning, but also required verbal and visual (nonverbal visualization) mediation.

No evidence with brain-damaged patients exists to support that forward digit repetition is more highly correlated with verbal measures than backward digits. Both hemispheres seemed to have a role in digit repetition with different neuropsychological functions associated with forward and backward digit. Digit span backward is more likely to help in diagnosing neurological learning disabilities because disabled readers show low digit span; poor readers have low scores on digit span (Searls, 1975). Spafford (1989) suggested that speed and accuracy of coding contribute to reading speed and comprehension. However, Standing and Curtis (1989) found no correlation between speed of encoding and memory span.

References:

Anderson, J. R. (1995). Learning and Memory: An Integrated Approach. New York: Wiley.

Anger, W. K., Cassitto, M. G., Liang, Y., Amador, R., Hooisma, J., Chrislip, D. W., Mergler, D., Keifer, M., Hortnagl, J., Fournier, L., Duder, B., Zsogon, E. (1993). Comparison of performance from three continents on the WHO-recommended neurobehavioral core test battery. Environmental Research, 62, 125-147

Atkinson, R. C., Shiffrin, R. M. (1971). The control of short-term memory. Scientific American, 225, 82-90

Baddeley, A. (1990). Human Memory: Theory and Practice. Boston, MA: Allyn and Bacon

Bear B. W., Connors, M. F., & Paradiso, M. A. (2002). Neuroscience: Exploring the Brain. Baltimore. Maryland: Lippincott Williams & Wilkins

Bell, T. K. (1990). Rapid sequential processing in dyslexic and ordinary readers. Perceptual Motor Skills, 71(3 pt 2), 1155-1159

Black, F. W. (1986). Neuroanatomic and neuropsychologic correlates of digit span performance by brain damaged adults. Perceptual and Motor Skills, 63, 815-822

Bontempi, B., Jaffard, R., & Destrade, C. (1996). Differential temporal evolution of post-training changes in regional brain glucose metabolism induced by repeated spatial discrimination training in mice: Visualization of the memory consolidation process? European Journal of Neuroscience, 8(11), 2348-2360

Braver, T. S., Cohen, J. D., Nystrom, L. E., Jonides, J., Smith, E. E., & Noll, D. C. (1997). A parametric study of prefrontal cortex involvement in human working memory. NeuroImage, 5(1), 49-62

Brown, J. (1958). Some tests of the decay theory of immediate memory. The Quarterly Journal of Experimental Psychology, 10, 12-21

Brownlee, S., & Kalis, L. (Dec-Jan, 2001). Can you raise a smarter kid? Scientific American, 85-93

Bruyer, R., & Scailquin, J. C. (2000). Effects of aging on the generation of mental images. Experimental Aging Research, 26(4), 337-351.

Cantor, J., Engle, R. W., Hamilton, G. (1991). Short-term memory, working memory, and verbal abilities: How do they relate? Intelligence, 15, 229-246.

Charness, N. (1991). Expertise in chess: The balance between knowledge and search. In K. A. Ericsson & J. Smith, Toward a general theory of expertise: Prospects and limits (pp. 39-63). New York: Cambridge University Press

Chavez, E. L., Brandon, A., Trautt, G. M., & Steyart, J. (1983). Effects of test anxiety of subject on neuropsychological test performance: Finger tapping, trail making, digit span and digit symbol tests. Perceptual and Motor Skills, 56, 923-929

Cohen, J., & Sedlacek, Sedlacek, K. (1983). Attention and autonomic self-regulation. Psychosomatic Medicine, 45(3), 243-257

Collete, F., Salmon, E. Van der, Linden, M., Degueldre, C., & Frank, G. (1997). Functional anatomy of verbal and visuospatial span tasks in Alzheimer’s disease. Human Brain Mapping, 5(2), 110-118

Cooke, N., J.Atlas, R. S., Lane, D. M., & Berger, R. C. (1993). Role of high-level knowledge in memory for chess positions. American Journal of Psychology, 106, 321-351.

Crowder, R. G. (1993). Short-term memory: Where do we stand? Memory & Cognition, 21, 142-145

Das, J. P. (1985). Aspects of digit-span performance: Naming time and order memory. American Journal of Mental Deficiencies, 89(6), 627-634

Demetriou, A., Christou, C., Spanoudis, G., & Platsidou, M. (2002). The development of mental processing: Efficiency, working memory, and thinking. Monograph of the Society for Research in Child Development, 67(1)

Dominey PF, Lelekov T, Ventre-Dominey J, Jeannerod M (1998) Dissociable Processes for Learning the surface and abstract structure sensorimotor sequences. Journal of Cognitive Neuroscience, 10, 6 734-751.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. Psychological Review, 66, 183-201

Eden, G. F., Stein, J. F., Wood, H. M., & Wood, F. B. (1995). Temporal and spatial processing in reading disabled and normal children. Cortex, 31(3), 451-468

Elliot, J. M. (1992). Forward digit span and articulation speed for Malay, English, and two Chinese dialects. Perceptual and Motor Skills, 74, 291-295

Elliott, S. G., & Rieder, R. O. (September, 1992). Major disorders of mind and brain. Scientific American, 127-133

Engle, R. W. (2000). What is working memory capacity? In H. L. Roediger, J. S. Nairne,I. Neath, & A. M. Surprenant (Eds.) The Nature of Remembering (pp. 297-314). Washington DC: APA

Engle, R. W. (2002). Working memory capacity as executive attention. Current Directions in Psychological Science, 11, 19-23.

Engle, R. W., Cantor, J., & Carullo, J. (1992). Individual differences in working memory and comprehension: A test of four hypotheses. Journal of Experimental Psychology: Learning, Memory and Cognition, 18, 972-992.

Ericsson, K. A. (1988). Analysis of memory performance in terms of memory skill. In R. J. Sternberg (Ed.), Advances in the psychology of human intelligence (Vol. 5) (pp.137-179)

Ericsson, K. A., & Kintch, W. (2003). Long term working memory. Retrieved from www.ecs.soton.ac.uk

Eslinger, P. J. (May-August 2003). Brain development and learning. Retrieved from www.epub.org

Faubert, S. M. (2000). Aging, perception, and visual short-term memory for luminance defined form. Ophthalmic Physiology, 20(4), 314-322

Fittman, S., O’Grady J., Cooper V., & Grafman, J. (1997). Neuropsychologia, 35(4), 409-420

Flitman, S., O’Grady, J., Cooper, V., & Grafman, J. (1997). PET imaging of maze processing. Neuropsychologia, 35(4), 409-420

Gazzaniga, M. S. (2000). The New Cognitive Neurosciences. Cambridge, MA: MA Institute of Technology

Gershon, E.S. & Reider, R.O. (1992) Major disorders of the brain, Scientific American, 267, 127-133

Goldman-Rakic, L. R. (1992). Association of storage and processing functions in the dorsolateral prefrontal cortex of the nonhuman primate. Journal of Neuroscience, 19(12), 5149-5158

Gould, D., & Tuffey, S. (1996). Zones of optimal functioning research: A review and critique. Anxiety, Stress, and Coping, 9, 53-68

Greenlee M. W., Lang H. J., Mergner T., & Seeger W. (1995). Visual short-term memory of stimulus velocity in patients with unilateral posterior brain damage. Journal of Neuroscience, 15(3 Pt 2), 2287-2300

Groeger, J. A. (1997). Memory and Remembering: Everyday Memory in Context. New York: Addison Wesley Longman

Halgreen, E., Boujon, C., Clarke, J., Wang, C., & Chauvel, P. (2002). Rapid distributed fronto-parieto-occipital processing stages during working memory in humans. Cerebral Cortex, 12(7), 710-728

Heil, Hennighausen, & Rosler (2000)

Hikosaka, O. (2002). A new approach to the functional systems of the brain. Epilepsia (Suppl 9, 9-15).

Humphrey, M. S., Tehan, G., O'Shea, A., & Bolland, S. W. (2000). Target similarity effects: Support for the parallel distributed processing assumptions. Memory Cognition, 28(5), 798-811.

Institute of Brain Aging and Dementia (1999). Areas of research focus. Retrieved from www.researchdetails.html

Johansson, B., & Berg, S. (1989). The robustness of the terminal decline phenomenon: Longitudinal data from the digit-span memory test. Journal of Gerontology: Psychological Sciences, 44(6), 184-186

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension. Psychological Review, 99, 122-149

Kane, M. J. & Engle, R. W. (2000). Working memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. Journal of Experimental Psychology: Learning, Memory, and Cognition, 26, 336-358

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual differences perspective. Psychonomic Bulletin & Review, 9, 637-671

Kane, M. J., & Engle, R. W. (2003). Working memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. Journal of Experimental Psychology: General, 132, 47-70

Kerns, K., & Decker, S. N. (1985). Multifactorial assessment of reading disability: Identifying the best predictors. Perceptual and Motor Skills, 60, 747-753

Kintsch, W., Welsch, D., Schmalhofer, F., Zimny, S. (1990). Sentence memory: A theoretical analysis. Journal of Memory and Language, 29, 133-159

Klinberg, T. , Forssberg, H, Westerberg, H, (2002). Training of working memory of children with ADHD. Journal of Clinical and Experimental Neuropsychology, 24, (6), 781-791.

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working memory capacity?! Intelligence, 14, 389-433

La Pointe, L. B., & Engle, R. W. (1990). Simple and complex word spans as measures of working memory capacity. Journal of Experimental Psychology: Learning, Memory and Cognition, 16, 1118-1133.

Larson, G. E., Haier, R. J., LaCasse, L., & Hazen, K. (1995). Evaluation of a "Mental Effort" hypothesis for correlations between cortical metabolism and intelligence. Intelligence, 21, 267-278

Lee Hotz, R. (April 3, 1997). Probing the workings of heart and minds. Los Angeles Times.

Long, E. M. (2000). The effects of BrainBuilder on digit span and reading performance of underachieving students. A thesis submitted in partial fulfillment of the requirements for MS, Department of Special Education, Illinois State University.

MacAndrew, D. K., Klatzky, R. L., Flez, J. A., McClelland, J. L., & Becke, J. T. (2002). The phonological-similarity effect differentiates between two working memory tasks. Psychological Science, 13(5), 465-468

Margolis, R.B., & Scialfa, C.T. (1984). Age differences in Wechsler Memory Scale performance. Journal of Clinical Psychology, 40, 1442-1449.

Mayer, U., & Kilegl, R. (1993). Sequential and coordinative complexity: Age based processing limitations in figural transformations. Journal of Experimental Psychology Learning Memory Cognition, 19(6), 1297-1320

McGrath, J. E. (1970). The influence of positive interpersonal relations on adjustment and effectiveness in rifle teams. Journal of Abnormal and Social Psychology, 65, 365-375

Meyer, B. J. F. (1997). The Organization of Prose and its Effect on Memory. Amsterdam: North Holland

Mountcastle, V. B. (1998). Perceptual Neuroscience: The Cerebral Cortex. Cambridge, MA: Harvard

Moravcsik, J. E., & Kintsch, W. (1993). Writing quality, reading skills, and domain knowledge as factors in text comprehension. Canadian Journal of Psychology, 47, 360-374

Narayanan, K. (2003). The neurological scratchpad: Looking into working memory. Retrieved from www.brainconnection.com

National Center of Learning Disabilities (2003). Information processing disorders. Retrieved from www.ld.org

Neergaard, L. (Oct. 2001). Training helps brain overcome problems. Cincinnati Enquirer

Nelson, C. A., & Luciana, M. (2001). Handbook of Developmental Cognitive Neuroscience. Cambridge, MA: MA Institute of Technology

Nideffer, R. (1976). Test of personal and interpersonal style. Journal of Personality and Social Psychology, 34, 394-404.

Olson, R. K., Davidson, B. J., Kliegel, R., & Davies, S. (1984). Development of phonetic memory disabled and normal readers. Journal of Experimental Child Psychology, 37, 187-206

Osterweil, D., Mulford, P., Syndullko, K., & Martin, M. (1994). Cognitive function in old and very old residents of a residential facility: Relationship to age, education, and dementia. Journal of American Geriatric Society, 42(7), 766-773

Parasuraman, R. (1998). The Attentive Brain. Cambridge, MA: MIT Press

Pazzaglia, F., & Cornoldi, C. (1999). The role of distinct components of visuo-spatial working memory in the processing of texts. Memory, 7(1), 19-41

Peterson, L.R , & Peterson, M. J. (1959). Short term retention of individual verbal items. Journal of Experimental Psychology, 58, 193-198

Posada, A., Franck, N., Georgieff, N., & Jeannerod, M. (2001). Anticipating incoming events: An impaired cognitive process in schizophrenia, Cognition, 81(3), 209-225

Ranpura, A. (Nov. 2003). Testing the brain: what neurological exams can tell us about ourselves. Retrieved from: www.brainconnection.com

Reynolds, C. R., & Kamphaus, R. W. (1990). Handbook of Psychological and Educational Assessment of Children: intelligence and Achievement. New York: Guilford Press

Roediger, H. L. & Craik, F. I. M. (1989). Variety of Memory and Consciences: Essays in honor of Endel Tulving. Hillsdale, N.J.: Erlbaum

Rolke B., Heil M., Hennighausen E., Haussler C., & Rosler F. (2000). Topography of brain electrical activity dissociates the sequential order transformation of verbal versus spatial information in humans. Neuroscience Letters, 17, 282(1-2), 81-84

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. Journal of Experimental Psychology: General, 126, 211-227

Rosenbaum, D. A., & Collyer, C. E. (1998). Timing of behavior: Neuropsychological, and Computational Perspectives. MIT Press.

Ruby, P., Sirigu, A., & Decety, J. (2002). Distinct area in the parietal cortex involved in long-term and short-term action planning. Cerebral Cortex, 38(3), 321-339

Saarilouma, P. (1990). Apperception and restructuring in chess players' problem solving. In K. J. Gilhooly, M. T. G. Keene, & G., Erdos (Eds.), Lines of Thought: Reflection on the Psychology of Thinking (Vol. 2, pp. 41-57). London: Wiley

Sattler, J. M.(1988). Assessment in Children. San Diego, CA: Sattler

Scanlan, T. K. (1986). Competitive stress in children. In M. R. Weiss & D. Gould (Eds.), Sport for children and youth (pp. 113-118). Champaign, IL: Human Kinetics

Schmidt (1971). Retroactive interference and amount of learning in verbal and motor tasks. Research Quarterly, 42, 314-326

Schmidt, H. G., & Boshuizen, H. P. A. (1993). On the origin of intermediate effects in clinical case recall. Memory & Cognition, 21, 338-351

Schubotz R. I., & von Cramon D. Y. (2001). Interval and ordinal properties of sequences are associated with distinct premotor areas. Cerebral Cortex, 11(3), 210-222

Schouten, M. E. H (1987). The psychophysics of Speech Perception. Martinus Nijhoff

Searls, E. F. (1975). How to Use WISC Scores. University of Florida: International Reading Association

Selkoe, D. J. (Sep. 1992). Aging brain, aging mind. Scientific American, pp. 135-142

Smith, T. E. (1999). The relative influence of symptoms, insight, and neurocognition on social adjustment in schizophrenia and schizoaffective disorder. Journal of Nervous Mental Disorders, 187(2), 102-108

Spafford, C. S. (1989). Wechsler digit span subset: Diagnostic usefulness with dyslexic children. Perceptual and Motor Skills, 69, 115-125

Spence, J. T., & Spence, K. W. (1966). The motivational components of manifest anxiety: Drive and drive stimuli. In C. D. Spielberger (Ed.), Anxiety and Behavior (pp. 3-22). New York: Academic Press

Spielberger, C. D. (1966). Theory and research on anxiety. In C. D. Spielberger (Ed.) Anxiety and behavior (pp. 3-22). New York: Academic Press

Standing, L., & Curtis, L. (1989). Subvocalization rate versus other predictors of the memory span. Psychological Report, 65, 487-495

Steronko, R. J., & Woods, D. J. (1978). Impairment in early stages of visual information processing in nonpsychotic schizotypic individuals. Journal of Abnormal Psychology, 87(5), 481-490

Staszewski, J. J. (1990). Exceptional memory: The influence of practice and knowledge on the development of elaborative encoding strategies. In W. (Wolfgang) Schneider & F. Weinert (Eds.), Interactions among Aptitudes, Strategies, and Knowledge in Cognitive Performance (pp. 252-285). New York: Springer Verlag

Steele, K. M., Ball, T. N., & Runk R. (1997). Listening to Mozart does not enhance backwards digit span performance. Perceptual and Motor Skills, 84, 1179-1184

Sternko, R. J., & Donald, J. W. (1978). Impairment in early stages of visual information processing in nonpsychotic schizoyypic individuals. Journal of Abnormal Psychology, 87(5), 481-490

Swerdlow, J. L. (June, 1995). Quiet miracles of the brain. National Geographic Magazine, pp.5-36

Sylwester, R. (Aug, 1997). A brainstorm is brewing. Learning, pp. 58-60

Sylwester, R. (2000). A Biological Brain in a Cultural Classroom. Thousand Oaks, CA: Corwin

Temple, E., Poldrack, R. A., Protopapas, A., Nagarajan, S., Salz, P., Tallal, P., Merzenich, M. M., & Gabrieli, J. D. E. (2000). Disruption of the neural response to rapid acoustic stimuli in dyslexia: Evidence from functional MRI. Proceedings of the National Academy of Science, 25, 13907-13912

Vargo, F. E., Grosser, G., & Spafford, C. S. (1995). Digit span and other WISC-R scores in the diagnosis of dyslexia in children. Perceptual and Motor Skills, 80, 1219-1229

Vecchi, T., Monticellai, M. L., & Cornoldi, C. (1995). Visuo-spatial working memory: Structures and variables affecting a capacity measure. Neuropsychologia, 33(1), 1549-1564

Verhaeghen P., Kliegl R., & Mayr U. (1997). Sequential and coordinative complexity in time-accuracy functions for mental arithmetic. Psychology of Aging, 2(4), 555-564

Vitulli W. F., Laconsay, K. L., & Shepard, H. A. (1996). Ganzfeld perceptual field and gender effects on short-term memory as a function of rate of digit presentation. Perceptual & Motor Skills, 82(3 Pt 2), 1331-1340

Watson, C., & Willows, D.M. (1995). Information processing patterns in specific reading disability. Journal of Learning Disabilities, 28(4), 216-231.

Weinberger, D. R., & Gallhofer, B. (1997). Cognitive function in schizophrenia. International clinical psychopharmacology (Supp 4, S29-36)

Whitehouse, D. (Dec. 31, 2002). Scientists see memory creation. Brain and Mind Magazine. Retrieved from www.epub.org

World Fellowship for Schizophrenia and Related Disorders (2003). Schizophrenia. Retrieved from: http://www.world-schizophrenia.org/