AUDITORY SHORT-TERM MEMORY, VISUAL SEQUENTIAL MEMORY AND INDUCTIVE REASONING MATTER FOR ACADEMIC ACHIEVEMENT

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Abstract

Parents and researchers alike are interested in how to nurture children's academic capabilities. Academic achievement has been linked to parental involvement and parenting styles, family income, media and digital exposure, sleep quality and patterns, school and neighbourhood safety, gender, social responsibility, intrinsic motivation, self-discipline, self-belief, emotional intelligence, physical fitness, vocabulary size, IQ and cognitive abilities. Many studies on cognitive abilities have linked working memory, processing speed, verbal, visual-spatial abilities and attentional control to academic success. In this study 64 Grade 2 students of an inner-city school took an online test designed to assess auditory short-term memory, visual sequential memory, iconic memory and inductive reasoning, after which their test scores were correlated with their academic grades. The study confirms the importance of strong cognitive skills for academic achievement; the cognitive skill with the strongest correlation was auditory short-term memory. The auditory short-term memory scores correlated significantly with the students' total academic grades ($p \le .01$), English language grades ($p \le .05$) and maths grades ($p \le .01$). The visual sequential memory sub-test correlated significantly with the students' maths grades ($p \le .01$) and their scores on inductive reasoning with their English language grades ($p \le .05$), while iconic memory did not correlate with any school subject.

Keywords: Auditory short-term memory, visual sequential memory, inductive reasoning, cognitive skills, academic achievement, online cognitive skills test

1 INTRODUCTION

Academic achievement has become an indicator of a child's future in the present extremely competitive world and has therefore been recognised as one of the important goals of education. Research has, convincingly, demonstrated that academic achievement is the product of several factors operating within as well as outside the individual [1]. Broadly speaking, the factors which influence academic achievement can be categorised into four types: *physical*, such as sleep quality and physical fitness; *emotional*, for example self-discipline and self-belief; *environmental*, which includes parental involvement and school safety; and *intellectual*, of which the most important is probably cognitive abilities. In this paper we investigate memory, especially auditory short-term memory, visual sequential memory and iconic memory, as well as inductive reasoning as determinants of academic achievement.

Memory is the process by which knowledge is encoded, stored, and later retrieved [2]. The main categories of memory are *sensory memory*, *short-term memory* (or working memory) and *long-term memory*, based on the amount of time the memory is stored. Sensory memory, the ability to retain impressions of sensory information after the original stimuli have ended, is the shortest-term element of memory. The visual component is known as *iconic memory*, the auditory component as *echoic memory*, and that for touch as *haptic memory*.

The distinction between short-term memory and working memory is an ongoing debate, and the terms are often used interchangeably. Some scholars assert that some kind of manipulation of remembered information is needed in order to qualify the task as one of working memory [3]. Repeating digits in the same order they were presented would thus be a short-term memory task, while repeating them backwards would be a working memory task.

When it comes to memory, one's senses are involved too. *Visual memory* involves the ability to store and retrieve previously experienced visual sensations and perceptions when the stimuli that originally evoked them are no longer present [4]. *Auditory memory*, on the other hand, involves being able to take in information that is presented orally, to process that information, store it in one's mind and then recall what one has heard. Basically, it involves the skills of attending, listening, processing, storing, and recalling [5]. *Sequential memory* requires items to be recalled in a specific order.

Memory is a gateway to learning, and students with poor memories are known to struggle in school. Hoerig, David and D'Amato explored the relationship between memory and intelligence in learning-disabled children, known to underachieve in school. Memory was evaluated using the Test of Memory and Learning, a comprehensive measure of global memory functioning composed of 10 sub-tests including measures of verbal memory, non-verbal memory, auditory memory, semantic recall, and visual sequential memory. This, and the Wechsler Intelligence Scale for Children Third Edition, used to assess intelligence, were given to 80 students with learning disabilities. The correlation between a global measure of memory and a global measure of intelligence was significant ($r = .59$), indicating that deficits in memory may account for some of the lower academic performance of children with learning disabilities [6].

Research has confirmed that *auditory memory* plays a crucial role in literacy as it directly impacts reading, spelling, writing and maths skills. Kurdek and Sinclair measured auditory memory in kindergarteners and found readiness in auditory memory predicted later reading achievement as well as mathematics achievement in fourth grade [7]. A study by Abraham, George and Kunnath on the relationship between auditory short-term memory and academic achievement revealed that children with poor academic performance have a significant deficit in auditory short-term memory [8].

Students with auditory memory deficiencies will often experience difficulty developing a good understanding of words, remembering terms and information that have been presented orally, for example, in history and science classes. A study by Tirosh and Cohen found that auditory short-term memory was significantly related to ADHD and language problems [9]. Riccio, Cash and Cohen examined learning and memory in children with Specific Language Impairment (SLI) as compared to 30 normally functioning children on the Children's Memory Scale. Results indicated that children in the SLI group exhibited significantly lower scores on auditory indices and sub-tests relative to the control group. In contrast, no between-group differences emerged for the visual indices and sub-tests [10].

Children who have poor auditory memory skills may struggle to recognise sounds and match them to letters — a common symptom of a reading disability or dyslexia. Research by Plaza, Cohen and Chevrie-Muller found that dyslexic children exhibited a significant deficit in nearly all tasks involving auditory memory skills (digit span, unfamiliar word repetition, sentence repetition, etc.), compared with their age-mates [11]. Howes, Bigler, Lawson and Burlingame compared 24 readers with auditory dyslexia and 21 with visual dyslexia to 90 control group participants and revealed auditory sequential memory impairments for both types of readers with dyslexia, and multiple strengths for good readers [12].

Research has also confirmed that *visual memory*, often considered to be a subset of visual perception rather than a separate skill, plays a crucial role in literacy, especially mathematics. One hundred seventy-one children with a mean age of 10.08 years participated in a study by Kulp et al [13]. The study, conducted at the Ohio State University College of Optometry, was designed to determine whether performance on tests of visual perception could predict the children with poor current achievement in mathematics. Controls for age and verbal cognitive ability were included in all regression analyses because the failure to control for verbal cognitive ability/intelligence has been a criticism of some literature investigating the relation between visual perception and academic skills [13]. Scholars have argued that a relation between visual perception — a non-verbal cognitive skill — and maths achievement are merely due to the confounding effects of verbal cognitive ability/intelligence. The authors conclude: "Poor visual perceptual ability is significantly related to poor achievement in mathematics, even when controlling for verbal cognitive ability. Therefore, visual perceptual ability, and particularly visual memory, should be considered to be amongst the skills that are significantly related to mathematics achievement" [13].

Guthrie and Goldberg investigated relationships between *visual sequential memory* and reading in 81 normal and 43 disabled readers. The children had normal intelligence and a mean reading grade of 2.5 (= fifth month of second grade in the US). The mean chronological age of the normal readers was 8.5

years, and the mean of the reading disabled 10.3. Partial correlations between three tests of visual sequential memory and three tests of reading were computed. Significant, positive associations were identified between visual sequential memory and paragraph comprehension, oral reading and word recognition [14]. A study by Stanley, Kaplan and Poole compared 33 dyslexic and 33 control eight- to 12-year-old children and found the dyslexic children to be inferior to controls on tasks involving visual sequential memory and auditory sequential memory [15]. Wood, Black, Hopkins and White compared the vision function and visual information processing — including visual sequential memory — measures of 108 Grade 3 primary school children in South-East Queensland to their National Assessment Program for Literacy and Numeracy (NAPLAN) scores in reading, writing, spelling, grammar/punctuation and numeracy. The students' visual sequential memory measures correlated significantly with their numeracy scores (.01 level), but not with any of the other scores [16].

Iconic memory, the short-lasting visual memory of a briefly flashed stimulus, is an important component of most models of visual perception [17]. Riding and Pugh gave 36 nine-year-old children a test of image persistence in iconic memory, as well as the Neale Analysis of Reading Ability. The reading test gave scores for fluency, accuracy and comprehension. All three measures of reading performance were found to be significantly related to icon persistence [18]. Ahmadi et al. compared 30 six- to nine-year-old children with ADHD — known to show significant academic underachievement, poor academic performance, and educational problems [19] — to 30 of a matching age group without ADHD on an iconic memory task. The mean score of ADHD children on the iconic memory task was significantly lower than that of children without ADHD ($p < .001$) [20].

Logical reasoning is the process of using a rational, systematic series of steps based on sound mathematical procedures and given statements to arrive at a conclusion [21]. In logic, there are two broad methods of reaching a conclusion: *deductive reasoning* and *inductive reasoning*. Deduction begins with a major premise, followed by the minor premise and a conclusion. If the major premise is true and the minor premise is true, the conclusion cannot be false. In inductive reasoning, on the other hand, broad conclusions are drawn from specific observations; data leads to conclusions. In a proper inductive argument, the conclusion follows with a high degree of probability, but not with certainty [22].

Inductive reasoning is considered a basic component of thinking [23], appears as one of the components of critical thinking [24], and has been identified as a core cognitive process of fluid intelligence [25], defined as "the use of deliberate mental operations to solve novel problems (i.e. tasks that cannot be performed as a function of simple memorisation or routine)" [26]. In contrast, crystallised intelligence is defined as the ability to use learned knowledge and experience [27]. Several studies have shown fluid intelligence to be an important predictor of maths achievement [26, 28] as well as verbal performance [28].

There is little doubt that inductive reasoning can be developed and improved. Following a review and meta-analysis summarising the results of 74 training experiments with nearly 3,600 children, Klauer and Phye concluded that training in the use of procedural inductive reasoning strategy improves cognitive functioning in terms of increased fluid intelligence performance and better academic learning of classroom subject matter [29].

2 METHODOLOGY

Edublox Online Tutor (EOT) houses several multisensory brain-training programs that aim to enhance cognitive skills such as focused and sustained attention; visual and auditory processing and processing speed; visual, auditory, sequential, iconic and working memory; and logical thinking. EOT also offers a free online assessment to measure a number of cognitive skills and reading: The Visual Sequential Memory test assesses visual sequential memory, the Auditory Memory test auditory short-term memory, the Eye-span test visual sensory (iconic) memory, the Logical Thinking test inductive reasoning, and the Reading test reading age.

Before every sub-test the student must watch a video to see how the test works, and must also complete a trial run. A brief description of every sub-test, excluding the Reading test, can be found in Table 1.

Table 1. Brief description of EOT sub-tests

Sub-test	Number of items	Description
Visual Sequential	N/A	This is a timed exercise with nine rounds. A sequence of colours is displayed, and more colours are added each time the student gets the answer correct.
Auditory Memory	9	Starting with two, four directions — left, right, up and down — are called out and must be answered in the same order. The test is discontinued after two consecutive mistakes.
Eye-span	9	A sequence of coloured blocks is flashed. Rehearsal is not allowed, and the test is discontinued after two consecutive mistakes.
Logical Thinking	9	The student must complete logical sequences, for example: red, blue, green, white, black, yellow, red, blue, green ? ? ? The test is discontinued after two consecutive mistakes.

Participants were 64 Grade 2 students — 39 (61%) girls and 25 (39%) boys — who took the EOT test, excluding the Reading test, in 2017, after which their test scores were correlated with their academic grades using the Pearson Correlation. The average age of the sample was 7.66 years (SD = 0.54) ranging from 7 to 9 years.

Academic grades in South African schools are scaled from 1-7, 7 being “outstanding achievement” and 1 being “not achieved”.

Table 2. Academic scales

Level	Description	Percentage
7	Outstanding achievement	80-100%
6	Meritorious achievement	70-79%
5	Substantial achievement	60-69%
4	Adequate achievement	50-59%
3	Moderate achievement	40-49%
2	Elementary achievement	30-39%
1	Not achieved	0-29%

The 64 students’ Term 4 *consolidated* academic grades were used in this study, which is a score that combines a student’s academic achievement of all four school terms. The academic grades of the four subjects, English language, second language (in this case Afrikaans), maths and life skills were added together to derive a Total Academic Score.

3 RESULTS

Table 3 provides the distribution of academic scores consisting of two languages, mathematics and life skills all graded on the scale indicated in Table 2. The scores are distributed around a mean of 5, which is slightly higher than the average academic level of 4. The range of the distributions and standard deviations of one and higher show adequate variation for analysing scores.

The EOT test scores are indicated in Table 4. EOT scores range from 1 to 5 with a mid-score of 3. Mean scores and standard deviations of each test are also indicated in Table 4. Sequencing, auditory and eye-span scores had low mean scores of approximately 2 while logical thinking had a mean of 3.

The students' scores on the Auditory Memory test correlated significantly with their total academic grades ($p \leq .01$), English language grades ($p \leq .05$) and maths grades ($p \leq .01$) (Table 5). The students' scores on the Visual Sequential Memory test correlated significantly with their maths grades ($p \leq .01$) and their scores on the Logical Thinking test with their English language grades ($p \leq .05$), while the Eye-span test that assesses iconic memory did not correlate with any school subject (Table 5).

From the correlation matrix two issues can be inferred (Table 5). First, the correlation between total academic score and auditory memory is constituted by mostly English language and maths with the strongest impact on maths. Secondly, maths score is impacted by visual sequential memory and auditory memory.

Table 3. Distribution of academic scores

Level	**Total**		**English**		**2nd L**		**Maths**		**Life Skills**	
	Freq	**%**	**Freq**	**%**	**Freq**	**%**	**Freq**	**%**	**Freq**	**%**
2			2	3.1			3	4.7		
3					4	6.3	14	21.9		
4	21	32.8	22	34.4	30	46.9	14	21.9	3	4.7
5	23	35.9	19	29.7	18	28.1	17	26.6	27	42.2
6	12	18.8	9	14.1	4	6.3	11	17.2	24	37.5
7	8	12.5	12	18.8	8	12.5	5	7.8	10	15.6
Total	64	100.0	64	100.0	64	100.0	64	100.0	64	100.0
Mean	5.64		5.08		4.72		4.53		5.64	
SD	1.01		1.24		1.11		1.35		0.80	

Table 4. Descriptive statistics for EOT tests

	N	Minimum	Maximum	Mean	Std. Deviation
Visual Sequential Score	64	1	5	2.37	1.09
Auditory Memory Score	64	1	5	1.88	1.18
Eye-span Score	64	1	4	1.78	0.92
Logical Thinking Score	64	1	5	3.08	0.84

Table 5. Pearson correlations

	Total Academic Score	English Language Score	2nd Language Score	Maths Score	Life Skills Score
Visual Sequential Memory				.327**	
Auditory Memory	.340**	.290*		.404**	
Eye-span					
Logical Thinking		.283*			

** Correlation is significant at the .01 level (2-tailed)
* Correlation is significant at the .05 level (2-tailed)

4 DISCUSSION AND CONCLUSIONS

The study confirms the importance of strong cognitive abilities for academic achievement; the cognitive skill with the strongest correlation was auditory memory, which correlated significantly with the students' total academic grades (.01 level), English language grades (.05 level) and maths grades (.01 level). This study thus affirms the conclusions reached by Kurdek and Sinclair [7], as well as Abraham, George and Kunnath [8] on the relationship between auditory short-term memory and academic achievement. Education authorities should take note and take heart, as improving this cognitive ability in students on a wide scale will, most likely, hugely impact overall academic outcomes.

The Eye-span test, which measures iconic memory, most probably did not correlate with any school subject as iconic memory is a cognitive skill required mainly for reading [18], and none of the school subjects rely exclusively on reading. English language grades, for example, are also dependent on spelling, writing, handwriting and oral ability.

The same type of reasoning might apply to the Visual Sequential Memory test, which correlated with maths grades (.01 level) but not with English language as a whole. On the other hand, one needs to consider the results of the *Wood, Black, Hopkins and White-study* that compared visual sequential memory scores to reading, writing, spelling, grammar/punctuation and numeracy, and — unlike studies dealing exclusively with reading-disabled children [14, 15] — found that visual sequential memory measures correlates significantly *only* with numeracy scores [16]. Perhaps, when it comes to reading disabilities, only a *severe* visual sequential memory deficit is involved. Based on this study, however, visual sequential memory is confirmed as a crucial cognitive skill in the average student for performance in maths.

The Logical Thinking test correlated with the Grade 2 students' English language scores, but not — as one would expect — with their maths scores. The authors predict that a correlation between this test and maths scores will become more and more apparent in the higher school levels, as stronger and stronger problem-solving abilities become a growing requirement over and above basic mathematical skills and knowledge.

ACKNOWLEDGEMENTS

The authors thank Confidence College, the inner-city school where the study took place; QRent, a computer rental company that made 30 work stations available to conduct this study as well as a second study, to be published later; Flordis SA, a developer of natural medicine that gave valuable insight and partially funded both studies.

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