

Cognitive Assessment of Movement-Based Games

by

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Abstract. This paper examines the possibility that dance games such as *Dance Dance Revolution* or *StepMania* enhance the cognitive abilities that are critical to academic achievement. These games appear to place a high cognitive load on working memory requiring the player to convert a visual signal to a physical movement up to 7 times per second. Players see a pattern of directions displayed on the screen and they memorise these as a dance sequence. Other researchers have found that attention span and memory ability, both cognitive abilities required for academic achievement, are improved through the use of physical movement and exercise. This paper reviews these claims and documents tool development for on-going research by the author.

Introduction.

There are many theories and varied opinions of what “working memory” consists of and how it is used in the learning process. Atkinson and Shiffrin [1] proposed that information selected by a person’s attention from sensory memory would move into working memory, often termed as short-term memory. This would allow people to retain information long enough to use it; for example, looking up a telephone number and remembering it long enough to dial it, or remembering the sentence that they have just read long enough to connect it to the next one. Peterson and Peterson [2] demonstrated that short-term memory lasts approximately 15 to 30 seconds, unless people rehearse the material at which time it is committed to long-term memory.

However, the Atkinson-Shiffrin model has been the object of much criticism. It fails to account for when short-term memory or attention (these terms are sometimes used synonymously) are impaired, yet long-term memory functions normally.

Conrad [3] suggested that short-term memory is mostly acoustically encoded memory (in terms of sound) but can also retain visuo-spatial images. However, the most common theory of working memory is based upon the Baddeley and Hitch [4] model, which was later updated by Baddeley [5] to include a component called the episodic buffer.

Baddeley’s model (*figure 1*) consists of four components – the central executive, the phonological loop, the visuo-spatial sketchpad, and the episodic buffer.

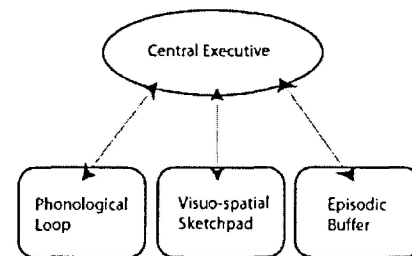


Figure 1: Baddeley's working memory model.

The phonological loop is said to be responsible for storing auditory information for up to 30 seconds, although other models show this retention period being anywhere between 2 seconds and 2 weeks. The visuo-spatial sketchpad is suggested to store spatial and visual information and is used for spatial manipulation and short-term storage of colours, shapes, and images. Baddeley suggested a further component to the original model called the episodic buffer and proposes that it is used to link information between the phonological loop and the visuo-spatial sketchpad. The central executive component is responsible for the supervision of the cognitive process and the co-ordination of the other three components.

The capacity of working memory is said to be limited and Miller [6] argues that around 7 elements can be stored regardless of what they are; digits, letters, words, images, etc. However, subsequent research suggested that span depends on the type of elements to be stored, and it is now assumed that the working memory capacity is between 6 and 8 for digits, between 5 and 7 for letters, and approximately 5 for words. Hence we refer to Miller's theory as 7 elements, plus or minus 2.

Other theorists such as Ericsson and Kintsch [7], state that some individuals can store much more than seven digits through the use of grouping or “chunking”, and Cowan [8] argues that short term or working memory is merely part of long term memory and it is the processing of such that differs. Cowan suggests that it is the focus of attention that limits the number of elements that can be recalled, hence the terms attention and working memory sometimes being used synonymously.

For the purpose of this project, the concept of working memory is based upon the work of Baddeley and Miller, and what is generally accepted as the “magic number” – that is 7.

Working Memory and Academic Achievement.

Published research showing that academic achievement can be predicted through the use of cognitive assessments including the testing of working memory, is widely available ([9], [10], [11]). Jaquith [12] shows a direct correlation between the results of digit span tests (a widely accepted test of working memory capacity) and academic test scores; the greater the working memory capacity, the higher the academic test scores. Students that had participated in the Stanford Achievement Test (SAT) for Total Reading, Math, Listening, Thinking, Word Reading, Language, Letters/Sounds, and Spelling, had their scores compared with their digit span test scores (Auditory and Visual tests). Jaquith concluded that if “one improves one’s auditory and visual digit span, and thus auditory and visual processing, the individual’s academic function relative to grade level will improve” (p. 1). Hence it would appear that the improvement of working memory is critical to academic achievement and likewise, Gathercole, Lamont, and Alloway suggest that poor working memory is associated with learning deficits in daily classroom activities.

The digit span test is defined by Wechsler Intelligence Scale for Children [13] and includes a Digit Span Forward (DSF) and Digit Span Backward (DSB). The DSF requires the participant to repeat numbers back to an examiner in the sequence that they were said. The DSB requires the numbers repeated back in the reverse order. The DSF test is designed to test the phonological loop capacity involving rote learning, attention span, encoding, and auditory processing. The DSB test requires mental manipulation, transformation of information, and visuo-spatial imaging. The scores correlate with Millar’s theory of the ability to store 7 elements, i.e. a score of 6 in

the DSF test would mean the participant repeated 6 numbers in sequence back to the examiner.

The Wechsler Intelligence Scale also includes a Visual Digit Span (VDS) test where the participant is shown numbers in sequence before repeating them back to the examiner. This test is not normally done in the reverse order and is designed to measure visual short-term memory, sequencing skills, working memory capacity, attention span, and concentration. Other tests in the Wechsler Intelligence Scale for Children (Fourth Edition – Integrated) and their expected standard results are as follows:

Table 1: WISC Fourth Edition Integrated

WISC Test	Standard Score
Vocabulary Multiple Choice	9
Picture Vocabulary	11
Block Design Multiple Choice	14
Elithorn Mazes	8
Digit Span Forward	7
Digit Span Backward	6
Visual Digit Span	11
Spatial Span Forward	11
Spatial Span Backward	12
Letter Span Non-Rhyming	7
Letter Span Rhyming	3
Letter-Number Sequencing	8

Note: Digit span and letter span both use “7” as a standard score.

Doman [14] suggested that both auditory and visual working memory could be improved merely by repeatedly doing tests similar to the DSF and VDS over a long period of time. Klingberg, Forssberg, & Westerberg [15] agree and suggest that the improvement of working memory will help children with Attention Deficit disorders, as well as rehabilitation after stroke and traumatic brain injuries. Klingberg et al. are now the scientific advisors for the commercial company “Cogmed” who created and market the game-based learning product “RoboMemo” – a computer program designed to assist the improvement of work memory.

“RoboMemo” is based on DSF, DSB, VDS and Letter Span Non-Rhyming tasks, all with a game-like interface. The object of the game is to repeat back the numbers of images shown on the screen or letters and numbers sounded, in the same order or reverse order. As with the Doman’s theory of repetition, CogMed suggest that the participant uses “RoboMemo” for 30 minutes per day, for five weeks. At the end of

this period, the company reports that 80% of participants not only have increased attention span, but also report an increase in academic achievements (although not quantified) due to an increase in working memory.

Doman [14] argues that "how well we learn is a direct reflection of how well we receive, process, store and utilize information", all functions of working memory. Jaquith [12] also suggests that a one-digit increase in score from DSF and VDS tests correlates to a significant increase in academic achievement, specifically an improvement in an individual's academic function relative to their suggested grade level.

Academic Achievement and Movement.

Gardner's [16] theory of multiple intelligences suggests eight core intelligences, these being linguistic, logical-mathematical, spatial, bodily-kinesthetic, musical, interpersonal, intrapersonal, and naturalistic intelligence. He argues the students with bodily-kinesthetic intelligence remember things through their body, rather than through words or images. He states that these people are adept at being athletes, craftsmen, and surgeons where skills and dexterity for fine motor movements are required.

Linksman [17] suggests that it is often difficult to differentiate between bodily-kinesthetic learners and learners with attention deficit disorder. She suggests that "Kinesthetic learners require body movement and action for optimal results: they need to move around, use their muscles" (p.1). Hands-on teaching techniques using movement gained recognition because they address the needs of kinesthetic learners, while at the same time catering to the needs of auditory and visual learners. Differing from constructivism, where the learner explores the task at hand to assimilate the knowledge into the learners already existing world, kinesthetic teaching allows the learner to perform physical activities while learning, activities not always directly connected to the knowledge or skill being taught. Jensen [18] argues that learning while doing physical movement creates more neural networks in the brain and therefore has a longer lasting effect. At the very least physical movement improves the blood circulation and thus the oxygen supply, and therefore maintains the metabolism in the brain; thus improving attentiveness and concentration, both of which are required for academic achievement.

Attention span and memory ability can also be improved through physical movement and exercise. Rutherford, Nicolson, & Arnold [19]

tested 895 participants with attention deficit disorder. They found that symptoms of inattention and hyperactivity were reduced by 60% through a 10 minute, twice per day physical exercise program. They suggest that exercise stimulates the cerebellum associated with attention deficit leading to learning disabilities and therefore reduces the symptoms of inattention, thereby improving concentration.

Movement and Commercial Computer Games.

Physically interactive computer games became popular with the introduction of the "Eye Toy" from Sony; physically interactive by using the whole body to control parts of the game. The *Eye Toy* is a camera mounted on the game console which monitors the body movements of the player to control the game on the screen. More recently, arcade style games have increased in popularity, games that involve dancing on a pad, playing an electronic guitar, and playing sports such as football, golf, and snowboarding all while standing on an electronic device connected to the computer.

Recreational computer games that involve physical movement are often used for physical therapy applications. The University of Manchester researched the use of computer games that use a force feedback joystick for the therapy of cerebral palsy [20] and for rehabilitation after a stroke. A force feedback joystick is a device that is used in computer games to fly planes or drive cars. The game can be programmed to enable the player to feel a resistance in the joystick depending on what is happening in the game. Initial results show an increase of up to 40% in movement precision and movement speed using this technique.

Denise Reid, from the University of Toronto, has written several papers on her work with cerebral palsy children, in which she focuses on Virtual Reality (VR) environments using equipment similar to Sony's Eye-toy and games such as Snowboarding, Volleyball and Soccer. The players view themselves on the screen and in the game. Arm movements are required to play the game with the program detecting collisions between the player and the screen objects. Reid found that participants in the research experienced an increase in self-esteem, a perceived physical change, and reported increased social acceptance from peers and family [21].

Dance Dance Revolution (DDR) is a music computer game originally created by the game developer Konami. There are now many clones available including the open source version *StepMania*. The game is usually played on a

platform know as a dance pad that has four arrow panels: left, down, up, and right. These panels are pressed using the player's feet, in response to arrows that appear on the screen in front of the player. The arrows are synchronized to the general rhythm or beat of a chosen song. The success is dependent on the player's ability to time and position his or her steps accordingly and the result is a simulated dance. This game has been used extensively for physical therapy to treat both obesity in children and for general exercise of young and old alike ([22], [23], [24]). However, there has been no research linking any of these movement games with an improvement in cognitive abilities.

DDR songs typically play anywhere between 120 and 400 beats per minute. The pad must be pressed in the correct order (usually with the feet but can be played on the keyboard instead of a dance pad), which means the player is converting a visual signal to a physical movement up to 7 times per second. Preliminary observation for this research found that 7 moves per second is possible when playing with a keyboard as the dance pad and using the fingers, and 4 moves per second can be sustained when standing on a dance pad and using the feet for movement (*figure 2*).

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 2: Dance Pad

Players watch the screen (*figure 3*) as the arrows rapidly scroll upwards in time to the music at a rate of up to seven rows (or one screen full) per second. Players suggest that they see a pattern of directions displayed on the screen and they memorise these as a sequence. Patterns can be up to eight moves and players propose that they would “chunk” these into sequences of 4 moves each before dancing them.



Figure 3: StepMania Screenshot

Working Memory and Movement.

It is suggested that these dance games place a high cognitive load on working memory. A 4-minute song would require over 1600 dance pad moves. Each move is observed, recognised, converted, memorised, and then actioned; up to 7 times per second. Pattern recognition and the rapid conversion to a sequence, chunking these sequences, and storing temporarily would involve the visuo-spatial sketchpad component of working memory.

The game is played to music. The players must listen to and be aware of the song as moves are usually executed on the beat or sometimes half beat. It is suggested that the phonological loop would be used for this. The episodic buffer would be required to link the two processors. If the hypothesis that dance games place a high cognitive load on working memory is correct, and if exercising working memory improves this cognitive process, then a dance game such as DDR or *StepMania* would surely enhance the cognitive abilities that are critical to academic achievement.

Current Project Design.

Development is underway to create a computerised assessment tool for assessing working memory with a game like interface. The assessment tasks to be included are shown in table 2.

Table 2: Included Assessment Tests

WISC Test	Score
Digit Span Forward	7
Digit Span Backward	6
Visual Digit Span	11
Visual Digit Span Backward	n/a
Letter Span non-Rhyming	7
Letter Span non-Rhyming Backward	n/a
Letter-Number Sequencing	8

This tool has is being created using a 3D game engine and based on the Dance game concept. Users are able to choose the character to be displayed and the viewed camera angle, and the virtual dance pads will be varied depending on the type of test being executed (figure 4).

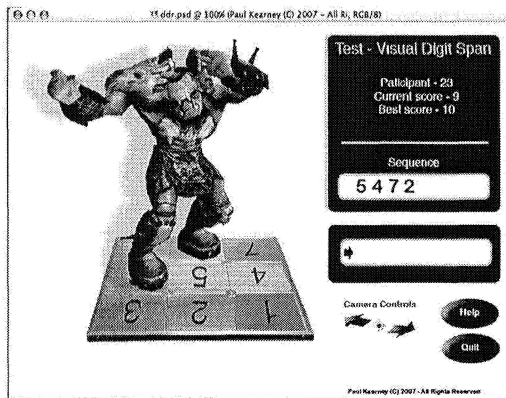


Figure 4: Project Screenshot

Tests are both visual and auditory, with results stored in an encrypted database for security and confidentiality. The tool includes a configuration screen, a demonstration mode, and a game mode that will allow the user to freely dance the character.

The assessment software will be validated with participant trials using standard WISC-IV tests to obtain the same results. Results will be collated and analysed with one-way analysis of variance (ANOVA) tests using SPSS statistical software. It is expected that participants using the software assessment would achieve the same standard scores as those completing the traditional verbal/visual examiner test.

Once the assessment tool has been successfully validated, participants will be recruited to play the dance game in an experiment to test the potential of movement-based games to enhance working memory. The open source game *StepMania* will be used for this purpose as it can be run on multiple platforms and directly imitates the arcade version known as DDR.

The experiment will be conducted with 3 groups, each participating over a period of 4 weeks. All participants in each group will be tested using the validated assessment tool to assess their baseline working memory. A control group will be tested again at the end of the four-week period to ascertain any changes in their baseline – no intervention will occur in the form of movement-based computer games.

The second group will be tested twice each week during four-week period to ascertain any improvement in working memory through repeated use of the assessment tool, and the third will play *StepMania* twice per week for one hour. At the end of the four-week period, they will be tested with the assessment tool to ascertain any change in their baseline working memory scores.

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Biographics.



Paul Kearney has a Masters degree in Computer Technology (1st class honours) with specific emphasis on digital games. His thesis showed that multitasking skills are enhanced from player immersive computer games. He has over 30 years experience in the computing industry, a graduate diploma in higher education, and is currently working on his PhD at Deakin University, Melbourne, Australia.