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Visual memory improvement in recognition

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Edith Cowan University

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A report submitted in partial fulfilment of the requirements for the award of Bachelor of Arts (Psychology) Honours

Faculty of Computing, Health and Science

Edith Cowan University

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Abstract

Fluid intelligence and working memory has been improved by training on a visual working memory *n*-back task (Jaeggi, Buschkuehl, Jonides & Perrig, 2008). The present study investigated whether *n*-back training can improve visual memory using a test of visual recognition. A sample of 47 participants were trained for 20 days on either the single *n*-back task (n = 26) or a general knowledge and vocabulary task (n = 21). The results showed that training using the single *n*-back task did not significantly increase scores on a test of visual recognition when compared with general knowledge and vocabulary training. However, when initial scores were compared with final scores at completion of the training period, participants who had a high gain in scores on the vocabulary training task improved their visual recognition scores significantly more than those participants who had a low gain in scores on the vocabulary training task. This pattern was not repeated for those participants who were trained in the *n*-back task. During debrief, participants in the high gain vocabulary training group described shape recognition strategies which they used to improve their performance. It was concluded that the vocabulary task was more successful at training visual recognition than the *n*-back task which suggested the vocabulary task had a confounding effect on the results of this experiment.

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Signed ______________________

Dated 29 October 2012

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Contents

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Intelligence is generally associated with the ability to learn and adapt (Sternberg, 2012). Charles Spearman (1927) was the first theorist to scientifically explain intelligence in terms of an overall intellectual capacity (*g*), and it is generally accepted today that *g* can be divided into two parts: fluid intelligence (*Gf*) and crystallised intelligence (*Gc*) (Cattell, 1963; McGrew, 2008). While crystallised intelligence may be trained, it is considered that fluid intelligence cannot, and thus it has been argued that crystallised intelligence is acquired while fluid intelligence is determined biologically (Jensen, 1981). It has however been asserted that practice effects and enhancement of test-specific skills are responsible for the improvement in intelligence test scores. (Jensen, 1998).

Fluid intelligence as well as working memory have recently been reported to increase following visuo-spatial *n*-back cognitive training (Jaeggi, Buschkuehl, Jonides & Perrig, 2008; Jaeggi, Buschkuehl, Jonides & Shah, 2011; Jaeggi, Studer-Leuthi et al., 2010). When skills transferred between tasks are very different, far transfer has occurred and when skills are similar, then the effect is known as near transfer (Perkins & Salomon, 1992). To explore whether skills trained on a working memory task would transfer to a test of fluid intelligence Jaeggi et al. (2008) designed an experiment using two tasks different enough so that practice effects could be avoided. The experiment was based on a hypothesis developed by Halford, Cowan and Andrews (2007) that proposed that working memory and intelligence have similar restrictions on capacity. This common constraint was expressed in the number of items that could be held in working memory and the number of connections between items in a reasoning task. It was theorised that this relationship is based on the common demand for attentional control during working memory tasks and reasoning tasks (Halford et al., 2007).

Strong visuo-spatial elements are a common feature between the two tasks compared by Jaeggi et al. (2008), Jaeggi et al. (2011) and Jaeggi, Studer-Leuthi et al. (2010). It is not known to what extent these elements influenced the far transfer of skills recorded in those studies. Further investigation of the near transfer process of visual skills might explain the far transfer effects reported by Jaeggi et al. (2008), Jaeggi et al. (2011) and Jaeggi, Studer-Leuthi et al. (2010).

There is strong support for the theory that working memory and fluid intelligence are interconnected (Chein & Morrison, 2010; Gray, Chabris & Braver, 2003; Kane et al., 2004) and many studies have found that working memory training transfers to tests of working memory capacity (Jaeggi et al., 2008; Klingberg et al., 2005; Verhaeghn, 2004). It is also known that working memory has an influential relationship with higher cognitive processes; therefore, it is anticipated that any increase in working memory performance through the effects of near transfer will affect other aspects of intelligence (Unsworth, Brewer & Spillers, 2009).

Working Memory and Fluid Intelligence

The relationship between working memory and fluid intelligence is fundamental to the explanation of how far transfer occurred in the Jaeggi et al. (2008), Jaeggi et al. (2011) and Jaeggi, Studer-Leuthi et al. (2010) experiments. The manner in which working memory and fluid intelligence overlap is complex and there are different theories. A generally accepted theory of intelligence is Cattell-Horn-Carroll (CHC) theory, which describes a three-stratum model in which all cognitive mechanisms are linked to *g*. One element of intelligence, visual memory, is defined as a narrow ability associated with the broad ability of visual processing (*Gv)* (McGrew, 2008). Visual memory involves the processing of visual information through storage and retrieval and the ability to manipulate those visual images.

Visual memory is also the component of working memory that includes the ability to maintain the position of objects in memory.

Working memory has been described as a short-term mental storage space that regulates overall thinking systems through the control of attention. This system has been defined as two separate storage spaces, one for short-term storage of aural information (the phonological loop), and one for the short-term storage of visual and spatial information (the visuo-spatial sketch pad) (Baddeley & Hitch, 1974). Both storage spaces are controlled by the central executive, which is responsible for focus of attention.

Working memory capacity is a measure of the ability to maintain information while simultaneously searching and retrieving recently stored information (Unsworth & Engle, 2007). Individual differences in working memory are due to varying abilities in working memory capacity. Tests that assess working memory capacity are considered a good measure of overall working memory ability; however, this predictability is comprised of many different processes that together make up working memory (Unsworth, Brewer & Spillers, 2009).

Working memory is closely related to fluid intelligence with correlations of .70 or higher being reported between intelligence and working memory (Ackerman, Beier & Boyle, 2002; Colom, Francisco, Abad, Rebollo & Shih, 2005; Colom, Rebollo, Palacios, Juan-Espinosa & Kyllonen, 2003). Working memory capacity and fluid intelligence shared 50% of their variance in the data from ten published studies (Kane, Hambrick & Conway, 2005). Glascher et al. (2010) investigated the relationship between areas of the brain that are activated by intelligence tests and found a network of interconnected areas was activated during verbal, visuo-spatial, working memory and executive processes, which suggested an overlap of brain processes.

Complex and Simple Working Memory

Measures of working memory are either simple or complex span tasks. Simple span tasks can be described as a measure of short-term memory, while complex span tasks are a measure of working memory capacity. Simple span tasks involve the storage and retrieval of information. Complex working memory tasks are theorised to use higher levels of cognition, where information is stored, monitored and managed (Siegert, Weatherall, Taylor & Abernethy, 2008).

Performance on the *n*-back task has been found to be associated with performance on simple working memory measures and not on complex working memory measures. It was reported by Jaeggi, Studer-Leuthi et al. (2010) that the *n*-back task correlated even more closely with the forward Digit Span Test than with the backward Digit Span Test. This result was considered to be due to the nature of storage processes associated with these two tasks.

An explanation using this dual component framework of working memory has been proposed by Unsworth and Engle (2007). They describe working memory as consisting of primary and secondary memories. Primary memory is described as the first layer of working memory, where focus of attention is needed to maintain representations in memory. It is proposed that the upper limit to this mental capacity is four items (Cowan, 2001; Shiffrin, 1970; Unsworth & Engle, 2007). When the number of items exceeds four, the items are moved to the secondary storage system and therefore must be retrieved from secondary memory when required (Unsworth & Engle, 2007). Complex span tasks are associated with those tasks that require items to be retrieved from secondary memory. Simple span tasks are associated with tasks that require items to be stored in primary memory. However, simple span tasks may also involve retrieval from secondary memory, but only after primary memory has become filled to capacity (Unsworth & Engle, 2006). Both primary and secondary memory are related to fluid intelligence (Shelton, Elliott, Matthews, Hill & Gouvier, 2010) regardless of whether the stimuli is auditory or visual.

Visual Memory

Visual memory can be described as a component of working memory and is often referred to as visual working memory. This is consistent with Baddeley and Hitch's (1974) theory of the visuo-spatial sketchpad, or a temporary store of visual information. Cattell-Horn-Carroll theory describes visual processing (Gv) as a broad stratum ability that is defined as 'the ability to generate, store, retrieve, and transform visual images and sensations' (MGrew, 2008, p. 5). Further, neural lesion mapping studies have shown that visual-spatial ability and working memory both activated regions of the brain associated with *g* (Glascher et al., 2010). Thus, visual memory is related to working memory and is defined in this thesis as the cognitive manipulation of visual information held in short-term memory, as detailed in the Woodcock-Johnson III Tests of Cognitive Abilities (WJ III) (Woodcock, McGrew & Mather, 2001).Visual memory is measured in the WJ III through a test of recognition.

Recognition is a process closely associated with visual memory (Unsworth & Engle, 2007). Recognition processes aid in the identification of previously seen items from a presented group of items. The exemplar-similarity model describes the recognition process as a cognitive calculation where a comparison is made between items held in memory and presented items (Bledowski, Kaiser, Wibral, Yildiz-Erzberger & Rahm, 2011). During this process, similar brain areas are activated to those used during working memory tasks (Feredoes, Heinen, Weiskopg, Ruff & Driver, 2011) which is evidence of the overlap in physical processes between recognition and working memory.

The capacity of visual memory has been found to be three to four objects (Vogel, Woodman & Luck, 2001), however those objects are held in visual working memory as integrated objects. That is, the colour and features of the object are remembered. Some researchers have questioned the four item limit to visual working memory capacity and found that visual working memory capacity is determined by both the amount of objects and the complexity of the objects (Alvarez & Cavanagh, 2004; Eng, Chen & Jiang, 2005).

When contralateral delay activity in the lateral occipital and posterior parietal electrode sites of the brain associated with maintenance of visual working memory is measured, it is found that participants with low working memory capacity maintain irrelevant information in visual working memory (Vogel, McCollough & Machizawa, 2005). However, participants with high working memory capacity are able to differentiate between relevant and irrelevant visual information in visual working memory. In this way some participants with low working memory capacity are able to hold more information (though it is irrelevant) than those with high working memory capacity. To have a high visual working memory capacity, participants must regulate their visual working memory processes so that maintenance of information is more efficient (Vogel, McCollough & Machizawa, 2005).

Individual differences in visual memory can also be explained by the various techniques used by individuals to store and retrieve visual information. Participants in visual memory studies have described how they have used strategies involving mental images to complete tasks (Berger & Gaunitz, 1979). For example, the use of mnemonic mental imagery devices by participants during a study was explored by Keogh and Pearson (2011). Those participants who rated highly for imagery also performed better on a visual working memory task. This supports a view of visual memory as a construct of working memory where individual differences can be demonstrated through the impact of other cognitive factors.

Memory Training

Many studies have found that working memory is able to be increased through training (Morrison & Chein, 2011); however, based on Jensen's (1981) views, it is questionable whether these effects are transferable to other cognitive tasks such as measures of fluid intelligence. Such transference would be considered far transfer, whereas a change in working memory scores resulting from working memory training would be considered near transfer (Barnett & Ceci, 2002).

In a study conducted by Chein and Morrison (2010), participants were trained with four weeks of working memory training, which consisted of memorising a list of items. Participants' scores on measures of temporary memory, Stroop test scores and reading comprehension test scores increased, leading the researchers to conclude that training had generalised to these two tasks. In a study conducted by Klingberg, Forssberg and Westerberg (2002), children who had been diagnosed with attention deficit hyperactivity disorder (ADHD) were trained on a computerised working memory training program, and improvement was found on working memory tasks. Research in this area was continued by Klingberg et al. (2005) when 44 children diagnosed with ADHD were trained with a computerised working memory task and increased their scores on a verbal working memory task. Further, Klingberg (2010) explored the neuropsychological effects of working memory training and found that training effects are expressed in activity changes in the frontal and parietal cortex and basal ganglia areas of the brain, suggesting that working memory training influenced cognitions associated with the same brain regions.

Despite research supporting the effects of working memory improvement due to training, whether improvement is task specific, and whether training effects are transferable to other cognitive tasks is not fully established. A large study was conducted by Owen et al. (2010) with 11,430 participants who completed online brain training tasks for a period of six weeks. No transfer to untrained cognitive tasks was reported. An explanation for the conflicting results associated with working memory training may be that different working memory subcomponents are measured by different working memory tests, or that or that the modality of training may be important given that the stimuli were auditory or visual. In tests of recognition memory, visual stimuli are more easily remembered than auditory suggesting that the two stimuli are processed differently (Cohen, Horowitz and Wolfe, 2009).

Visual Memory Training

As stated earlier, the capacity of visual memory has been theorised to be limited to four items (Alvarez & Cavanagh, 2004; Cowan, 2001). However, the four items can be varied in their complexity or can be stored in relation to grouping effects (Woodman, Vecera & Luck, 2003). Therefore, it has been suggested that core visual memory capacity cannot be increased through training when the objective is to increase the number of items alone. This is because capacity does not rely simply on the number of items stored, but on how the items are stored. This is supported by Olsen and Jiang (2005), who found no significant training effect in their experiments to increase the number of items held in visual memory through practice.

Nevertheless, training has been found to result in an improvement in some aspects of visual memory. Schneiders, Optitz, Krick and Mecklinger (2011) investigated visual *n*-back working memory training to explore whether visual training effects could be observed in fMRI imaging. Increases in *n*-back proficiency were detected in decreases in the right middle frontal gyrus that were associated with training (Schneiders, Opitz, Krick & Mecklinger, 2011). This experiment showed that visual memory could be trained separately from auditory memory and other more general mechanisms associated with working memory. It should be noted that the passive control group in this study who were tested using the *n*-back task in the initial testing session, also showed a reliable improvement in *n*-back results in the follow up, suggesting that a test-retest effect could also have caused scores to increase. Test-retest effects have been an issue in working memory training experiments where it has been found that a small amount of practice can produce an increase in post-test scores (Jolles, Grol, Buchem, Rombouts & Crone, 2010; Owen et al., 2010).

The *n*-back Task

The *n*-back task was first devised and used by Kirchner (1958) to examine short-term memory in older participants. This working memory task has since been used extensively in neuroimaging studies investigating the neural mechanisms of working memory (Wager & Smith, 2003). The *n*-back task was referred to as the 'gold standard' in working memory tasks by Kane and Engle (2002) since it activated both storage and manipulation components.

The *n*-back task involves remembering where an object is spatially *n* times back in a visual sequence (Jaeggi et al., 2008). For example, in the two-back condition, a square will flash on and off in a matrix pattern on a screen and a participant must keep track of where the square appeared two flashes back. As the square continues to flash in different areas of the matrix, the participant is required to keep a continuous stream in immediate memory to track where the square was *n*-times back (Jaeggi et al., 2008).

There are either visual or auditory versions of the *n*-back task referred to as 'single' versions of the *n*-back task where participants are required to remember either an auditory or visual stimulus *n*-times back in a sequence (McElree, 2001). The *n*-back task can also be presented in the 'dual' version where both visual and auditory stimuli are presented simultaneously. In this version participants are required to keep track of both auditory and visual stimuli (Jaeggi et al., 2008).

The *n*-back task can also take the form of a recall or recognition task (Shelton, Metzger & Elliot, 2007). In the recall version, information is freely recalled from immediate memory. For example, in a version of the *n*-back task developed by Dobbs and Rule (1989), participants were read a list of words and then asked to recall which word was *n*-times back in the spoken sequence. Similarly, Shelton, Metzger and Elliot (2007) used a recall version of the *n*-back task to evaluate the differences between performance when administered in a group or individual setting. In the recognition version of the *n*-back task, items must be identified *n*-times back from among presented cues or lures. The recognition version of the *n*-back task was used by Jaeggi et al. (2008), Jaeggi, Bushkuehl, Perrig and Meier (2010), and Jaeggi et al. (2011) to explore working memory transfer effects on fluid intelligence.

The Jaeggi Studies

When investigating the effectiveness of the *n*-back task as a cognitive training tool, Jaeggi, Buschkuehl et al. (2010) concluded that both the dual *n*-back task and single *n*-back task were as effective as each other. In earlier research, Jaeggi et al. (2003) had theorised that this was due to both versions of the *n*-back task using the same neural networks. Although Jaeggi, Buschkuehl et al. (2010) and Jaeggi et al. (2008) found that increases had been found on a test of fluid intelligence due to *n*-back training, no improvement on complex working memory span tasks were found (Operational Span Task). Further, a decrease in performance on complex working memory span tasks has been observed due to *n*-back training in older adults (Li et al., 2008).

N-back reaction time means have been correlated with a digit span task over a range from r = –.20 to r = .42. This result was larger than an overall measure of working memory capacity (reading span task), which recorded no statistical correlation over a range from r = .26 to r = –.17 (Jaeggi, Buschkuehl et al., 2010). This has led to the suggestion that the *n*-

back task involves functions associated with simple measures of working memory, rather than measures of overall working memory capacity (Jaeggi, Buschkuehl et al., 2010).

The process of transfer observed during training on the *n*-back task is complicated by the discovery that transfer to fluid intelligence was found to be dependent on the amount of improvement on the *n*-back task. When participants' scores were split at the median, only those who performed above the median for *n*-back performance showed transfer to tests of fluid intelligence (Jaeggi et al., 2011). The amount of *n*-back training has also been implicated as a condition for fluid intelligence transfer (Jaeggi et al., 2008).

The validity of the *n*-back task as a measure of working memory has however, been questioned (Kane, Conway, Miura & Colflesh, 2007; Miller, Price, Okun, Montijo & Bowers, 2009) and criticism has been made of the methodology of the Jaeggi et al. (2008) and Jaeggi Studer-Leuthi et al. (2010) studies. Firstly, Jaeggi et al. (2008) used matrix reasoning tests to measure fluid intelligence gains, and did not use other measures of fluid intelligence. Secondly, the Jaeggi et al. (2008) study made use of a shortened version of the Bochumer Matrizen-Test and Raven's Standard Progressive Matrices. It has also been suggested that the *n*-back task is not different enough from the matrix reasoning tests to conclude that far transfer has taken place; the alternative view being that test taking skills have been trained (Moody, 2009) and not fluid intelligence. Jaeggi et al. (2008) and Jaeggi, Studer-Leuthi et al. (2010) have also been criticised for the lack of an active control group (Moody, 2009). Without the experience of training, the Hawthorne effect cannot be discounted from these experiments.

It is not understood how the working memory processes of the *n*-back task influences the increase in fluid intelligence reported in the Jaeggi et al. (2008), Jaeggi, Studer-Leuthi et al. (2010) and Jaeggi et al. (2011) experiments. For example, an increase in performance due to *n*-back training on a simple measure of working memory (Digit Span test) had been noted, but performance on a working memory capacity test (Reading Span test and Operation Span Task) was not (Jaeggi et al., 2008; Jaeggi, Studer-Leuthi et al., 2010). One possible explanation is that there are other mechanisms related to simple measures of working memory that may be associated with fluid intelligence training (Jaeggi et al., 2008).

The purpose of the present study was to investigate whether *n*-back training can increase visual memory. The study was designed to build on research conducted by Jaeggi et al. (2008) and Jaeggi, Studer-Leuthi et al. (2010) and Jaeggi et al. (2011) which demonstrated that fluid intelligence could be improved through training visual memory using an *n*-back working memory training task. An active control group was employed to mediate for the Hawthorne effect.

This experiment investigated whether skills trained by the visual recognition version of the *n*-back task transfer to a test of visual memory. The visual memory measure was Picture Recognition (subtest 13), defined in the WJ III as a test of the broad primary CHC factor, Visual-Spatial Thinking—narrow CHC ability, Visual Memory (Woodcock, McGrew & Mather, 2001). Visual-Spatial thinking involves the ability to cognitively manipulate visual patterns, and store and retrieve visual images from memory. The Picture Recognition subtest can be categorised as simple working memory measure.

Since *n*-back training has been known to produce increases in working memory test scores, it was predicted that training using the *n*-back task might produce significant differences on a test of visual memory. Therefore, it was hypothesised that after training using the single *n*-back task, participants' scores on a Picture Recognition would be significantly higher in comparison to participants who trained in general knowledge and vocabulary. In addition, since performance on *n*-back training is indicative of successful training transfer, it was further hypothesised that those participants who have high gain in *n*-back scores would have significantly higher Picture Recognition scores than those participants who have low gain in *n*-back scores.

Method

Design

The study utilised a mixed factorial design. The between-subjects training factor had two levels: the single *n*-back task and combined general knowledge and vocabulary tasks. The within-subjects factor of time criterion test had two levels consisting of pre-training and post-training phases. The dependent variable was measured by the raw test scores of the Picture Recognition Test, (Subtest 13) of the Woodcock-Johnson III Test of Cognitive Abilities (2001) (WJ III). The experiment therefore consisted of an initial testing phase where participants underwent Picture Recognition, (WJ III) testing, followed by a 30 day period of training with either the single *n*-back task, or general knowledge and vocabulary task training. Training was followed by a final testing phase where participants were retested on Picture Recognition (WJ III).

Participants

Initially 74 participants consisting of students from the Psychology course at Edith Cowan University, and family and friends of the researchers were recruited. Participants were randomly assigned to the *n*-back (experimental) group or the general knowledge and vocabulary (active control) group. Of the initial participants, 27 withdrew from the study before the final testing phase (16 from the experimental group and 11 from the active control group). One participant in the experimental group was not included because the reported results were not consistent with *n*-back scoring. This left 47 participants (21 in the active control group and 26 in the experimental group) who completed training ranging from the ages of 18 to 68 (M = 35.91) in the *n*-back group, and (M = 40.44) in the active control group. Of the final group of participants, 32 were university students, 22 had attained a minimum education level of Year 12, 15 had completed a University Degree, six had gained an educational qualification other than a university degree and five had an education level lower than Year 12.

Power Analysis

Jaeggi, Buschkuehl et al. (2010) reported an effect size of d = .65 related to an improvement in fluid intelligence following 20 days of *n*-back training. Since working memory and visual memory has been found to be related to fluid intelligence, this calculation was considered appropriate for this experiment. Therefore, to achieve a statistical power of 0.8 (Field, 2009), 25 participants in both the experimental and active control groups were required.

Materials and Procedure

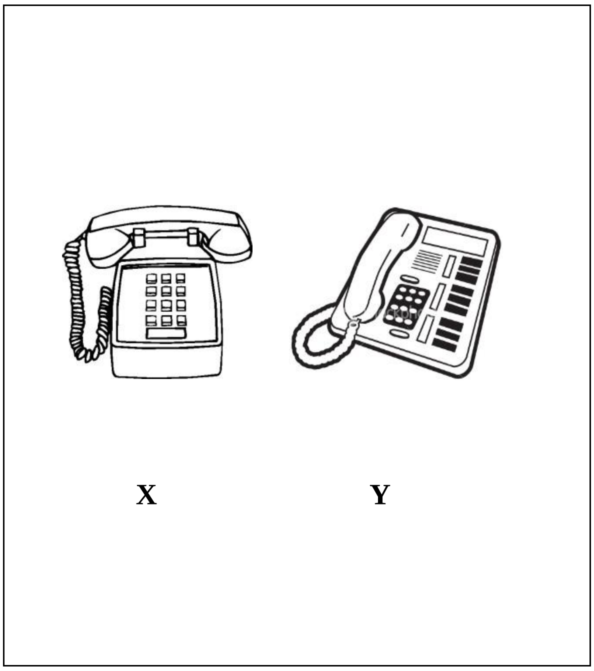
Initial testing phase. Following ethics approval from the Edith Cowan University Human Research Ethics Committee participants received an information letter (see Appendix A) outlining the objective of the study. Participants were assigned randomly to either the n-back task (experimental group) or the combined general knowledge/vocabulary task (active control group). Before initial testing began, participants were asked to sign a consent form (see Appendix B) which reiterated the expectations of participants and explained that participants may leave the study at any time.

Picture Recognition. Testing took place either in a room at the Edith Cowan University Joondalup campus or in a quiet room in the participant’s home or work place.

Picture Recognition (Subtest 13) was administered in accordance with the procedures specified in the WJ III testing manual (Woodcock et al., 2001).

Picture Recognition (WJ III) is a test of visual memory comprising of 24 test items and three items used for demonstration. Each item is composed of a stimulus and a response page. The stimulus page contains pictures that are to be identified on the response page. The stimulus page is viewed by the participant for five seconds, and then the response page is presented. The response page contains the item(s) on the stimulus page and contains items that are not presented on the stimulus page. Each item on the response page has an allocated letter. The participant is to identify which items on the response page were present on the stimulus page. Each item on the response page is identified by either pointing to the items recognised from the stimulus page or by naming its allocated letter (see Figure 1).

Stimulus page



Response page

Figure 1. An illustration of a stimulus and response page similar to those in Picture Recognition (Subtest 13), WJ III.

The test increases in difficulty with the first stimulus page containing one item and this one item plus a distracter item on the response page. The number of stimulus items increases and the number of distracter items on the response page increases until the stimulus page contains seven items and the response page contains seven items. The maximum number of items to be identified on the response page is four items with a maximum of three distractor items.

Picture Recognition, WJ III has a median reliability of .79 in the adult range (Woodcock et al., 2001). The object of the Picture Recognition test is to recognise a(n) item(s) that have been seen previously from a group of distractor items. The skills required for the Picture Recognition test, according to the WJ III manual are based on abilities that are not influenced by education and learning and there is only slight change due to age. Therefore, age is not considered influential in Picture Recognition scores.

Participants were also administered Subtests 7 and 9 of the WJ III due to this experiment being part of a companion study conducted by Paul Beavon, another Psychology Honours student researching short-term and auditory working memory. Subtests 7, 9 and 13 of the WJ III were administered consecutively. The order in which the three tests were conducted was counterbalanced across all participants. Together, all three tests took participants approximately 45 minutes to one hour to complete.

Cognitive training phase. On completion of initial testing, participants were instructed in their particular training task, either the n-back task or the combined general knowledge and vocabulary task.

N-back training task. Experimental group. A single *n*-back program, emulating the training program used by Jaeggi, Studer-Leuthi et al. (2010) was used as the experimental training task. The Microsoft Windows downloadable *n*-back training software was sourced from the Brainworkshop web page (Brainworkshop, n.d.). The software was altered so the task displayed all the characteristics of the task used by Jaeggi, Studer-Leuthi et al. (2010) (see Supplementary Materials). The software was downloaded onto the participants' laptop or desktop computer by the researcher. The researcher explained and demonstrated the task to the participant. The researcher also explained the scoring process to the participant. The participant was encouraged to complete a practice round of the task with the researcher's guidance. The participant was given an information sheet with instructions and contact details of the researcher and a scoring sheet to record their highest score and average score on a daily basis (see Appendices C and D).

Fifteen blocks of 20 trials of visuo-spatial stimuli were presented. A trial consisted of a visuo-spatial stimuli presentation every 2500ms for a duration of 500ms. The visuo-spatial stimuli was a blue square that appeared in one of eight outside positions in a 3 x 3 square grid. When the blue square reappeared in the position it was *n* moves ago a response was required. This is considered a match (see Figure 2.). A match was registered by the participant using their computer keyboard.

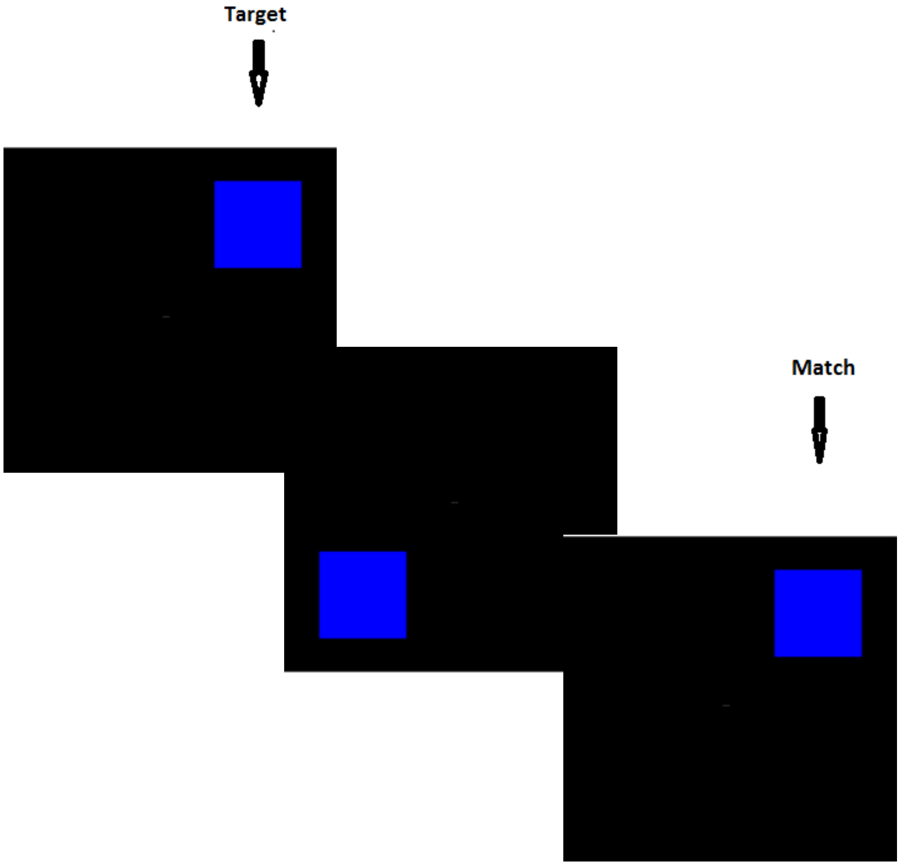


Figure 2. Illustration of the *n*-back task in the two-back phase.

During a block of 20 trials, there were six square position matches, 10% of the remaining trials consisted of lures, where the blue square appeared in an n-back position that is n + 1 or n – 1 positions ago, and was therefore not a match.

If after a block of 20 trials the participant had identified 90% of the position matches, the *n*-back level increased by one for the next block of trials. If the participant identified less than 70% of the position matches, then the *n*-back level was decreased by one for the next block of trials. If performance was maintained between 70% and 90%, the *n*-back level remained the same for the next block of trials. This adaptive responding was consistent with

Jaeggi, Studer-Leuthi et al. (2010). At the completion of each block, the participant received feedback on the screen regarding their percentage of correct responses. The daily training consisted of 15 blocks. Training began daily at the two-back level with no record of previous performance.

Training commenced the day after testing had taken place. Participants were encouraged to train for five consecutive days followed by two days of no training. This is in accordance with Jaeggi, Studer-Leuthi et al. (2010) who theorised that the brain would need a rest phase during the training schedule. Training took place in the participant’s home on the participant’s home computer or laptop.

Vocabulary and general knowledge tasks: Active control group. The active control group was trained using the vocabulary tasks used by Preece (2011) and Palmer (2011) in their investigations. These Honours studies investigated transfer effects on fluid intelligence, and the control tasks were chosen for that study because they required skills associated with crystallised intelligence.

Participants in the active control group completed two training tasks for 20 minutes per day. Participants spent ten minutes per day on each task alternating between the two tasks on successive days. The general knowledge task was a computer game based on the television show Who Wants to Be a Millionaire ('Millionaire'; Real Player Games Directory, n.d.) and the vocabulary task was a word definition computer game Definetime (East of the Web, n.d.).

On completion of testing, participants were given the website addresses of the two control tasks to access from their home computer. The games Definetime and Millionaire were demonstrated by the researcher. The participant then played the games for five minutes to demonstrate the tasks. The participant was given a scoresheet to complete daily, recording the highest level attained daily in Millionaire and the highest score attained daily in Definetime (see Appendices E and F).

Definetime. In Definetime (East of the Web, n.d.) participants scored ten points for correctly identifying a definition of a word from four presented definitions. Participants chose from three letter word definitions or words from short stories. A word was then presented at the top of the screen and four possible definitions were presented below identified by a letter of the alphabet. The participant used the computer mouse to select their chosen definition by clicking on that definition. After a word was chosen, if the definition was correct a new word was then presented with four new definitions. If the definition chosen was not the correct, the definition disappeared from the list and another choice was made. Each incorrect choice resulted in a five-point deduction from the score.

Definitions were presented for a two minute round. At the end of the round, the score for the round was presented, and another round began. Once Definetime had been demonstrated by the researcher, the participant was instructed to complete one round under the observation of the researcher and was asked if they had any questions concerning the task. The participant was then given the scoresheet to record their highest daily score and asked to play Definetime for duration of ten minutes daily.

Who Wants to Be a Millionaire. The knowledge task was based on the television show Who Wants to Be a Millionaire. This game was accompanied by theme music similar to that used on the television show of the same name, and by a countdown clock on the screen. Participants answered a series of 15 questions ranging from easy to difficult. Each question had a monetary value attached to it ranging from $100 to $1,000,000. Each question was presented with four possible answers to choose from. The answer was chosen by clicking on that answer. If a participant was unsure of which answer to choose, three ‘lifelines’ were offered, which gave clues to the answers. The ‘lifelines’ were: audience assistance, where the program offered a survey of the answers from a virtual audience poll; call-a-buddy, where a list of virtual friends and their occupations were presented (when one is chosen, their answer and how confident they were in percentage is shown); and lastly ‘half and half’ where the computer removes two of the incorrect choices. The participant was to answer the questions until they got one wrong, at this point the round was over. At the end of the round, the participant was instructed to keep track of their score.

The researcher demonstrated one round of the Millionaire task to the participant and explained and demonstrated the three lifelines. The participant underwent a practice round while supervised by the researcher. The participant was then instructed to record their daily highest score on the same scoresheet as Definetime scores.

Post-training retesting phase. Participants underwent retesting in WJ III Subtests 7 Numbers Reversed, 9 Auditory Working Memory and 13 Picture Recognition in the same order that they were administered in the pre-testing phase. Retesting was conducted within three to five days of training completion. Post-testing took place in the same location as the pre-test. Participants were informed of their final test scores by email (see Appendix G).

Data Analysis and Screening

Analysis of all data was conducted using IBM SPSS 20 Statistics software. Examination of box plots of participant’s pre-Picture Recognition test and post-Picture Recognition test scores and improvement between pre and post-Picture Recognition test scores revealed two outliers. One participant scored lower than 1.5 box lengths below the 25th percentile in post-test 13, and one participant scored higher than 1.5 box lengths above the 75th percentile in improvement between pre and post-Picture Recognition test scores. Both outliers were in the experimental group and were not included in further analysis unless otherwise stipulated. This left 21 participants in the control group and 24 participants in the experimental group.

Results

Picture Recognition Test Performance

Effects of training on Picture Recognition performance. To evaluate whether participant performance improved on the Picture Recognition test from pre-test to post-test due to the influence of training, a split plot analysis of variance (SPANOVA) was used. Exploration of data revealed a further outlier in the experimental group in post-Picture Recognition test gain with a score lower than 1.5 box lengths below the 25th percentile. This outlier was removed from the analysis. Assumptions of normality and homogeneity of variance were analysed by the Shapiro-Wilk test of normality indicating neither was violated for both the control and experimental groups in pre-Picture Recognition test scores and Picture Recognition test gain ($p > .05$), but indicated that post-Picture Recognition test scores were not normally distributed. However, inspection of the histogram indicated that the results were normal and skewness and kurtosis were within ± 1.96. Further, both Levene's test for homogeneity of variance ($p > .05$) and Box's M statistic ($p > .001$) were both not significant indicating assumptions of homogeneity of variance were met.

The interaction between the training group and pre- post-Picture Recognition testing was non-significant indicating that participants' raw scores on post-Picture Recognition did not significantly increase due to training (See Table 1 for descriptive statistics). This indicated that type of training did not have an influence over improvement in visual memory scores, SPANOVA $F(1,42) = 0.179$, $p = .675$, partial $\eta^2 = .004$. Overall both groups significantly improved in their Picture Recognition test scores from pre-test to post-test

SPANOVA F(1,42) = 16.538, $p < .001$, partial $\eta^2 = .283$. The analysis was re-conducted with all outliers included and the significance of the results were unaffected.

Table 1.

Means and Standard Deviations of Raw Pre- and Post-Picture Recognition Test Scores for N-back and Active Control Groups.

	Pre-training		Post-training	
Training group	*M*	*SD*	*M*	*SD*
Control	50.95	2.66	52.24	1.97
N-back	51.26	2.47	52.30	1.64
Total	51.11	2.54	52.27	1.79

After outliers were removed, a one-way repeated measures analysis of variance (ANOVA) found that both groups significantly increased their Picture Recognition test scores between pre- and post-Picture Recognition test sessions. When outliers were included, the results remained significant. *N*-back group ANOVA $F(1,23) = 4.577$, $p = .043$, partial $\eta^2 = .166$, control (general knowledge/vocabulary) group, ANOVA $F(1,19) = 9.615$, $p = .006$, partial $\eta^2 = .336$.

High and Low Gain Groups

Jaeggi et al. (2011) and Jaeggi et al. (2008) investigated the improvement in results through comparison of the high gain group and the low gain group based on training scores. This was accomplished by splitting the training groups at the median into high and low gain groups. Therefore, a comparison was made by splitting both the *n*-back and control groups into high and low gain based on the median of improvement on *n*-back score and Millionaire and Definetime scores. Improvement on the *n*-back task was defined by the mean *n*-back level reached based on a participant's first two training sessions subtracted from the mean of their last two training sessions. This was the same method used by Jaeggi et al. (2008) and Jaeggi et al. (2011).

A one-way between groups ANOVA was used to examine the participants' improvement in Picture Recognition test scores in relation to the low *n*-back gain group and the high *n*-back gain group. A one-way between groups ANOVA was then used to analyse participants' gain in Picture Recognition test scores in the high vocabulary gain group and the low vocabulary gain group. The analysis was conducted with the inclusion of the three original outliers due to the small number in each group and large variability. Each analysis was repeated with outliers removed and this did not affect the statistical significance of the results.

***N*-back group.** Results indicated that there was no significant difference in Picture Recognition test scores between participants in the low gain *n*-back group as opposed to those in the high gain *n*-back group. Shapiro-Wilk statistics indicated that the assumption of normality was supported for high and low *n*-back gain groups. Levene's statistic was significant $F(1,18) = 6.504$, $p = .02$ indicating that the assumption of homogeneity of variance was violated. However, ANOVA is robust to violation of homogeneity of variance if group sizes are equal. ANOVA $F(1,23) = .879$, $p = .358$. Cohen's $f = .20$, which suggests a medium effect size. This result suggests that the amount of gain on *n*-back performance had no bearing on gain in Picture Recognition test scores.

Active control group: vocabulary (Definetime). There was statistically significant difference between participants who had high gain and low gain in their Definetime scores and improvement in Picture Recognition test scores were. Those participants in the high Definetime gain group had a statistically higher gain in Picture Recognition test scores .The Shapiro-Wilk statistic indicated that the assumption of normality was supported for high and low Definetime gain groups. Levene's test was also non-significant, therefore equal variances can be assumed, ANOVA $F(1,19) = 6.864$, $p = .017$. Cohen's $f = .61$, which suggests a large effect size.

Active control group: general knowledge (Who Wants to Be a Millionaire). The results were not statistically significant indicating that gain in Picture Recognition test scores were not influenced by whether a participant had a high gain in their Millionaire scores or a low gain in their Millionaire scores. The Shapiro-Wilk statistic indicated that the assumption of normality was met. Levene's statistic was non-significant and therefore the assumption of homogeneity was not violated, ANOVA. $F(1,19) = .811$, $p = .379$, Cohen's $f = .20$, suggesting a medium effect size.

Table 2.

Means and Standard Deviations of Picture Recognition Gain in Low and High Performing Groups.

	Low		High		
Training group	*M*	*SD*	*M*	*SD*	η^2
Definetime	0.40	1.71	2.18	1.40	.27
Millionaire	1.70	2.11	1.00	1.41	.04
N-back	0.46	2.47	1.25	1.60	.04

Training Task Performance

N-back group. Analysis revealed that participants' mean final n-back score (M = 4.73, SD = 1.36) was significantly higher than their mean initial *n*-back score (M = 3.20, SD = 0.70), ANOVA $F(1,24) = 59.914$, $p < .001$, partial $\eta^2 = .714$ (sphericity assumed). These results indicated that participants' performance on the n-back task increased over the training period (see Figure 1.) A one-way repeated measures ANOVA was used to compare initial *n*-back performance with final *n*-back performance. The mean of the first two *n*-back sessions was used as the initial performance measure and the mean of the final two *n*-back sessions was used as the final performance measure.

The analysis was conducted with the exclusion of one outlier that indicated an improvement between pre and post-Picture Recognition test scores higher than 1.5 box lengths above the 75th percentile. Histograms of first two *n*-back session means and last two *n*-back session means and Shapiro-Wilk statistics indicated that the assumption of normality was supported ($p > .05$). The F_{max} value was less than ten (3.772) indicating that homogeneity of variance was not violated. No outliers were found in the two groups.

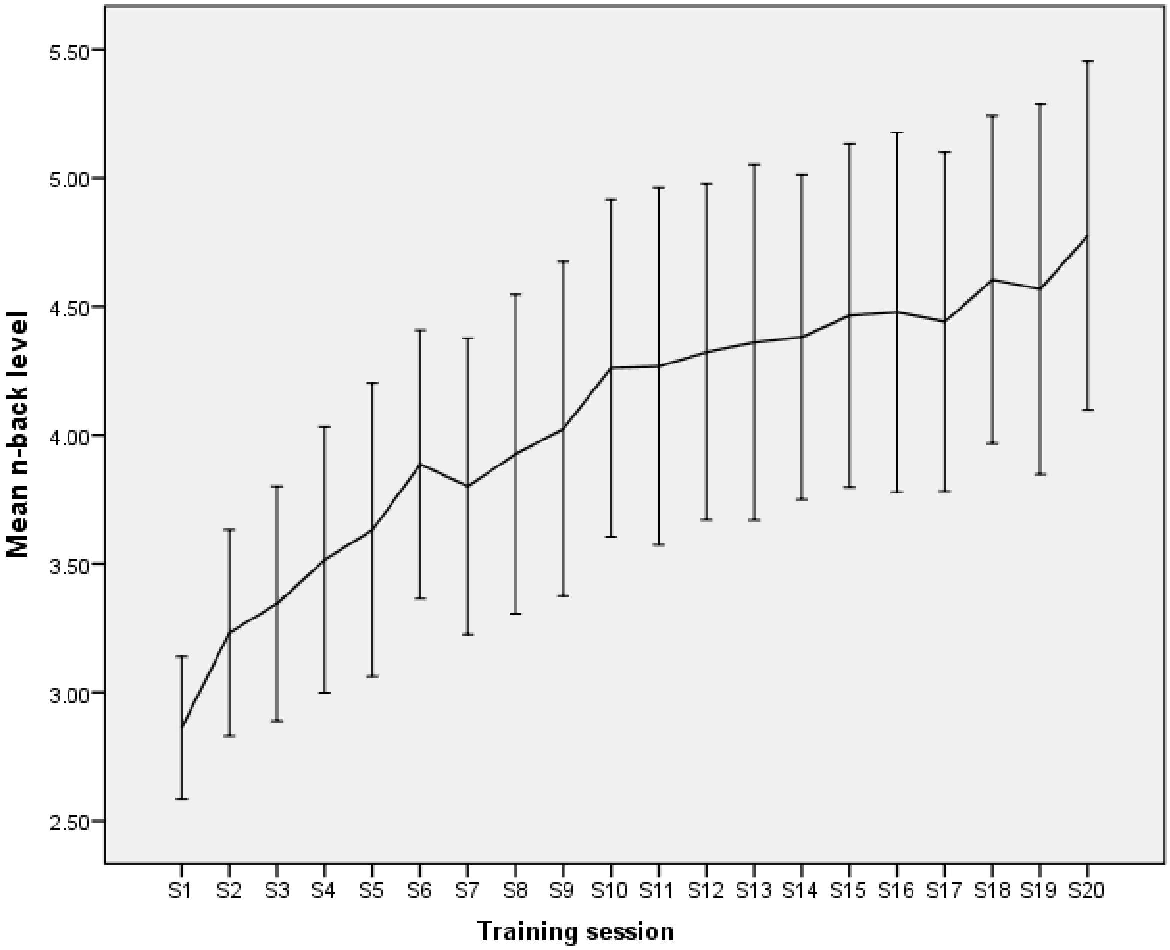


Figure 3. Average n-back level performance per session (95% confidence interval).

Active control group. Participants' mean final Definetime score (M = 447.08, SD = 198.82) was significantly higher than their initial score (M = 205.00, SD = 69.47), ANOVA $F(1,17) = 39.46$, $p < .001$, partial $\eta^2 = .699$ (sphericity assumed). These results indicated that participants' performance on Definetime increased over the training period (see Figure 2.). A one-way repeated measures ANOVA was used to compare average of participants' initial two vocabulary (Definetime) scores and the average of the last two vocabulary scores. Boxplots of the first two Definetime session means and last two Definetime vocabulary session means, along with Shapiro-Wilk statistics indicated that the assumption of normality was supported ($p > .05$); however, two outliers were found to be higher than 1.5 box lengths above the 75th percentile in the average first two sessions score. Both outliers were not included in the ANOVA analysis. The F_{max} value was less than ten (8.192) indicating that homogeneity of variance was not violated.

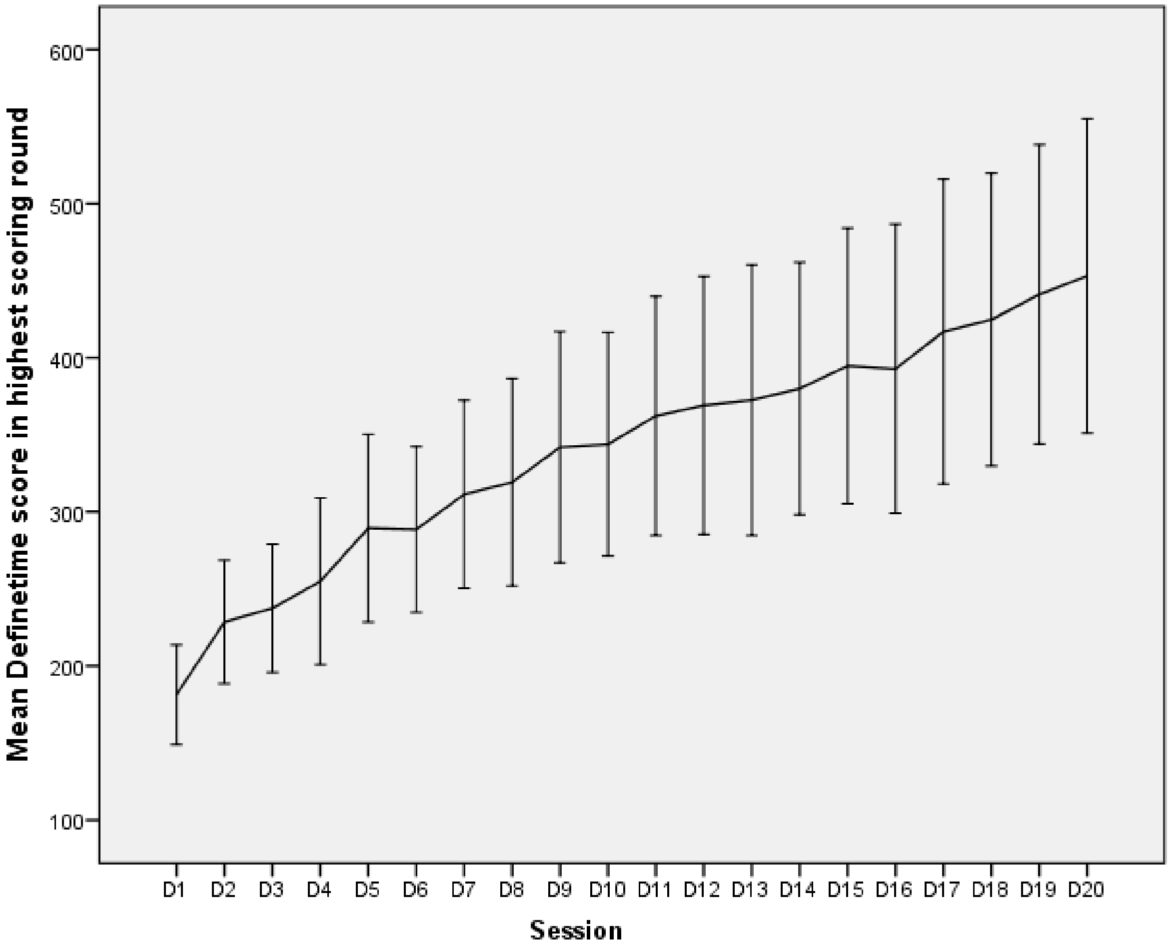


Figure 4. Highest Definetime score per session (95% confidence interval).

Participants' performance increased over the training period for the Millionaire task (see Figure 3). Participants' mean final Millionaire score (*M* = 8.89, *SD* = 1.44) was significantly higher than their mean initial Millionaire score (*M* = 7.37, *SD* = 1.56), ANOVA $F(1,18) = 10.732$, p =.004, partial η^2 =.374 (sphericity assumed). Initial analysis detected one outlier that scored higher than 1.5 box lengths above the 75th percentile in the average first two session score and was not included in further analysis. Boxplots of the first two Millionaire session means and last two Millionaire general knowledge session means, along with Shapiro-Wilk statistics indicated that the assumption of normality was supported ($p > .05$) for the last two average scores, but not for the first two average scores. However, skewness (0.501) and kurtosis (–0.133) indicated that the distribution of final average Millionaire scores were approximately normally distributed. The F_{max} value was less than ten (1.175) indicating that homogeneity of variance was not violated.

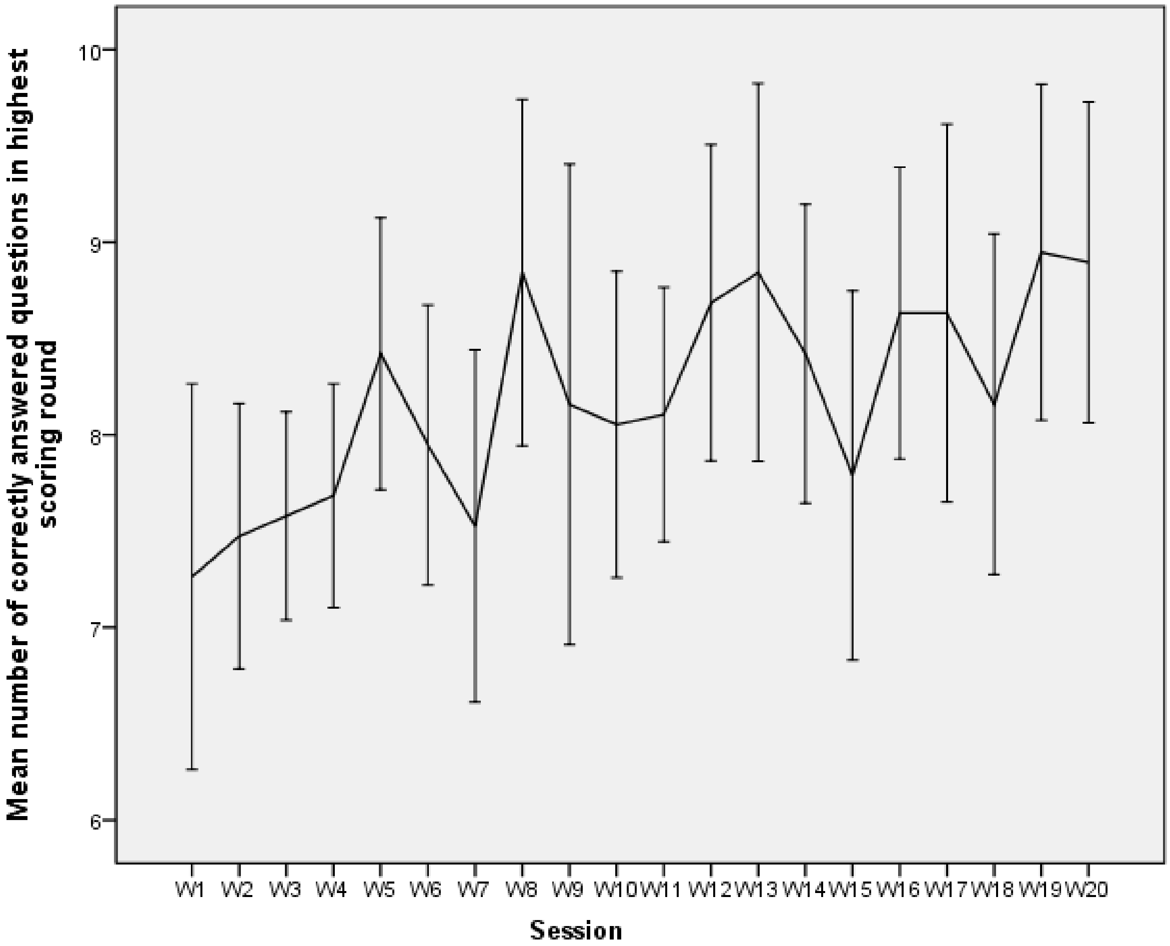


Figure 5. Highest Millionaire score per session (95% confidence interval).

Post-Training Interviews

Participants were questioned about their experiences with the training tasks. Participants who completed the *n*-back task reported low motivation levels to continue the training. Participants who completed the general knowledge and vocabulary training tasks reported that they were motivated to continue the task. In particular, those who showed high gain in their Definetime training scores reported striving to get their personal highest score on the Definetime High Scoring Board. When explaining their strategies for performance on the Definetime task, participants described how they no longer read the word to be defined or the questions. They instead identified the answer by remembering the silhouette formed by all the words in the answer. These strategies were used without regard for the individual words or their meanings. Since the Definetime questions repeated often, participants were able to *recognise* the correct answer without reading it, even though the answers were always presented in a different order.

Discussion

Both training groups significantly improved their performance on their post-training Picture Recognition test scores in comparison to their pre-training test scores. Despite this, the experimental hypothesis that single *n*-back training leads to greater improvement in visual memory compared with the active control training group was not supported. There was no significant interaction which is consistent with the conclusion that *n*-back training is no better than general knowledge and vocabulary training in improving performance on a test of visual memory.

Further, when participants were grouped into high and low training score gain, the second hypothesis that those in the high gain *n*-back group would have more improvement in Picture Recognition test scores than those in the low gain *n*-back group was not supported. This indicates that how proficient a participant became on the *n*-back task had no bearing on Picture Recognition performance. In comparison, however, when the scores of the control group were split into high and low gain, there was a significant effect of gain within the Definetime group on Picture Recognition scores.

One explanation for this result is that both the experimental and control tasks trained participants in skills that transferred to the Picture Recognition test, and those participants who improved most in their Definetime performance demonstrated the highest amount of transfer to the Picture Recognition test. This explanation suggests that the Definetime task was training elements of recognition that were measured in the Picture Recognition test. It could therefore be argued that inclusion of Definetine task confounded the experimental results by producing a similar training effect to that expected from the *n*-back task.

Definetime was chosen because it had been used as a control task in previous Honours research exploring *n*-back training (Palmer, 2011; Preece, 2011) and used verbal skills drawing on crystallised intelligence. It was not expected that this task would train visual memory. Post-test interviews showed that participants were not completing the Definetime task in the way that it was designed, and instead, participants were using shape recognition strategies.

The results of this study were unexpected, but may be explained by the strategies used by the participants. Of those participants in the high gain Definetime group, all 11 of the participants reported using the shape formed by the silhouette of the definition answer to recognise the correct response (see Figure 3). Of those participants in the low gain Definetime group, only four of the ten participants reported using shape recognition strategies to identify the correct answer. The majority of the participants in the low gain group were completing the task in the way in which it was intended, using vocabulary skills. In contrast, the high scorers were describing the use of recognition strategies.

This demonstrates that the participants in the high gain Definetime group were using similar strategies and these strategies impacted on their proficiency in the Definetime task. Further, those strategies were based on visual recognition skills. This analysis is provisional, and further experiments specifically designed to test for shape recognition strategies using the Definetime task are required before a firm conclusion may be reached.

Figure 3. A depiction of shapes strategies used by participants for recognition in the Definetime task.

Visual Recognition

In the Picture Recognition test the amount of items to be recognised increases from one to seven. During the early stages, it could be argued that this test uses the process of familiarity in primary memory but as the amount of items required to be remembered increases, use is made of secondary memory. It has been found that both primary and secondary memory are significantly correlated with fluid intelligence (Shelton et al. 2010). There was not a large variance between Picture Recognition scores of all participants, with scores reflecting test levels where more than four objects are presented to be remembered. Therefore, it can be argued that all participants used both primary and secondary memory storage processes. This suggests that Picture Recognition may not be a simple span measure, but may involve more complex elements. Further if is accepted that both training groups improved recognition as measured by the Picture Recognition test, then this would be contrary to the case made by Jaeggi et al. (2008) and Jaeggi, Studer-Leuthi et al. (2010) who suggest that *n*-back loads only on simple span tasks.

The definition and terms used to describe recognition vary among researchers. For example, Oberauer (2005) described recognition as having two modes: ‘familiarity’, which described short-term recognition; and ‘recall’, which describe the processes that use bindings to generate comparisons between items and representations of items. Recall was defined as a longer strategic search through memory to identify a target previously stored in memory, and familiarity was defined a simpler and faster cognitive process. It has been theorised that recognition involves a search of secondary memory and individual differences in recognition are expressed in the accuracy of a controlled and strategic search (Unsworth & Engle, 2007). Further, it is argued that people with low working memory capacity have a lesser ability to use internal cues to direct their search of secondary memory. This theory is supported by the findings of Conway and Engle (1994) and Bunting, Conway and Heitz (2004), who found that when items that have similar concepts are to be differentiated through recognition, participants are slower to respond. High working memory capacity individuals are also more accurate (Conway & Engle, 1994).

The WJ III manual describes recognition as identifying a memory of a(n) object(s) or picture(s) from a presented group of object(s) or picture(s), some of which are distractor items. This is compatible with the definition of recognition suggested by Bledowski et al. (2011) which involves the comparison of items to memory representations and evaluating whether the number of similarities between the memory representation and the presented item are enough to register a match (Bledowski et al., 2011). This recognition judgment is expressed by the exemplar-similarity model of recognition whereby a calculation is made involving the sum of similar characteristics held in memory and in the item presented (Nosofsky & Kantner, 2006). When the number of similar characteristics exceeds a critical level, then recognition of the object occurs (Yotsumoto, McLaughlin & Sekuler, 2008). This description of recognition also implies that recognition is more than a simple span task.

Although recognition is related to working memory, it does involve retrieval from both long-term and short-term memory. There has been considerable overlap found during fMRI in the areas of the brain used for long-term memory and recognition (Bledowsi, Rahm & Rowe, 2009; Nee & Jonides, 2008), suggesting that recognition interacts with other memory processes. The picture superiority effect is one process that may have had an influence on participants' recognition skills. This effect makes it easier to remember pictures than words in tests of recognition.

It has been theorised that pictures are easier to remember because pictures are stored in memory in both word and visual form (Hockley & Bancroft, 2011; Weldon, Roediger & Challis, 1989) allowing more pathways for retrieval. The semantic meaning of pictured objects are accessed quicker than words alone (Hockley & Bancroft, 2011), giving an advantage to items stored in pre-existing schemas. The picture superiority effect is activated during completion of the Picture Recognition test, which is comprised of items that are iconic, easily identifiable line pictures of objects that are familiar to participants.

To explore the areas of the brain associated with visual working memory, Feredoes, Heinen, Weiskopf, Ruf and Driver (2011) used a visual recognition task. Participants underwent transcranial magnetic stimulation during an fMRI while engaged in the visual recognition task. When participants were in the process of distinguishing between distractor items to identify target items, the dorsolateral prefrontal cortex was activated. This is the same brain area activated during working memory tasks, indicating that visual recognition is closely associated with working memory and has been described as a sub-component of working memory (Unsworth & Engle, 2007).

Individual differences account for the strategies used in correctly identifying items and the ways in which items are stored. For instance, participants have been found to use mental images to help retrieve and store visual information (Berger & Gaunitz, 1979) and as mnemonic devices. Further, those with higher working memory capacity are better able to regulate how they discriminate between items and lures (Vogen, Woodman &B Luck, 2001). Therefore recognition involves more cognitive processes that just a simple short-term memory processes. Recognition involves the use of both primary and secondary memory depending on the characteristics of the recognition task and the strategies used by the participant. This implies that the Picture Recognition test may not be a simple span task. In light of the results of this experiment it may be that both *n*-back and Definetime train memory processes that are complex rather than simple.

Definetime. The results of this experiment suggested that participants who trained on the vocabulary training task improved their performance on a test of visual recognition. Further, those participants who have higher gains on the Definetime task were likely to be training skills that affect their performance on a test of visual recognition more efficiently than those who had lower gains on Definetime. When questioned about techniques and strategies used to gain high scores on the Definetime task, high scoring participants revealed that they were not using vocabulary skills to complete the task.

Since recognition is defined as distinguishing a target item from among distractor items (Bledowski, Kaiser, Wibral, Yildiz-Erzberger & Rahm, 2011) and participants reported that they were using shapes to recognise the correct answer, one explanation for the results of this experiment is that participants were training their visual recognition memory. In the Definetime task, there are a predetermined number of questions to be answered. Therefore, the more questions that are answered, the more likely that questions would be repeated. When questions are repeated, the repeated answers are rearranged randomly. For example, if the correct response was ‘A’, then the next time the question was presented the answer may be ‘B’, ‘C’ or ‘D’. The more a participant played Definetime, the more likely it is that they would be exposed to repeated questions. In Definetime, a round is two minutes long, no matter how many questions are answered. Consequently, the faster the questions are answered, the greater the number of questions that are presented, and the greater the probability that questions would be repeated.

In a previous Honours study Palmer (2011) found a greater improvement in fluid intelligence as measured on the Raven's Advanced Progressive Matrices associated with Definetime and Millionaire training compared with the experimental *n*-back training. In light of the results of this current study, recognition processes associated with Definetime appear to have played some part in the fluid intelligence gains of Palmer's (2011) study and Picture Recognition test gains of this current study. It therefore, might be worth reanalysing Palmer's data in a similar way to that described here.

The *n*-back group. The single *n*-back task is described by Jaeggi, Studer-Leuthi et al. (2010) as a simple working memory task. They maintain that this is the reason that measures of simple working memory show an improvement after *n*-back training. This description of recognition is consistent with Oberauer's (2005) definition of familiarity as a simple measure. When however, visual recognition is expressed as part of a multimodal interpretation of working memory with substantial overlap between subcomponents (Repovs & Baddeley, 2006), this definition of recognition may be too simplistic.

The single *n*-back task is a visual recognition training task. Participants are required to remember where a blue square is *n* times back in a sequence. The decision whether the blue square is in the correct position requires the participant to make a calculation in the style of the exemplar-similarity model of recognition whereby a comparison is made with the position of the square held in memory and the position of the square presented (Nosofsky & Kantner, 2006). The *n*-back task is repetitive. There are only eight positions in which the blue square can be presented. This means that the positions are repeated often, and the more the task is used, the more often presentations will be repeated. The processes are practiced and automated and need relatively little cognitive manipulation, it appears that the recognition processes of the *n*-back task are highly relatable to simple span measures (Kane et al., 2007). However, whether *n*-back is using the process of familiarity or the process of recall, recognition processes are involved and these processes were likely to be the same as those used by the high gain group trained using the Definetine task.

N-back training involves other cognitive processes than those measured by the working memory tests used by Jaeggi et al. (2008) and Jaeggi, Buschkuehl et al. (2010). It has been suggested that *n*-back training influences participants to use mechanisms associated with recognition to complete working memory capacity tests, which require recall processes. These recognition processes are used in preference to the recall processes that are normally required to perform well on a working memory capacity test. This difference in test taking strategy has been proposed by Jaeggi, Buschkuehl et al. (2010) as an explanation for why *n*-back training does not transfer to complex working memory tasks. However, in the current experiment it might be that complex processes associated with recognition have transferred from the *n*-back, task giving an alternative view to Jaeggi, Buschkuehl et al. (2010).

Motivational Factors

A further way in which the results of this experiment may be interpreted is that Definetime trained visual recognition processes in participants who were motivated to achieve high scores. High Definetime scores can only be achieved when recognition strategies are used and not vocabulary strategies for which the task was originally designed because high scores are gained by increasing the speed at which answers are given.

People are more likely to respond to feedback that is immediate rather than delayed, especially when that feedback is in the form of knowledge of correct response (Kleij, Eggen, Timmers & Veldkamp, 2012). This positive feedback strengthens intrinsic motivation in a task (Deci, Ryan & Koestner, 1999). Additionally, having a sense of control over events is associated with intrinsic motivation (Shamloo & Cox, 2010).

In the current study, 27 participants did not continue training for the full training schedule, 16 in the *n*-back group, and 11 in the general knowledge and vocabulary training groups. Participants who did continue the full course of training in the *n*-back group spoke of their low levels of motivation during the training schedule in follow-up interviews. Those *n*-back participants who left the study also expressed difficulty in understanding the *n*-back task and felt it was too difficult, which had an effect on their enthusiasm for the task.

It is important to note that the *n*-back task used in this experiment was altered to be virtually identical to the *n*-back task used by Jaeggi (2008). This version of the *n*-back task offers no feedback on the accuracy on a participant's performance until the end of a round. As participants complete a round, it is not known to them whether they are correct in their choices or not. The feedback is not accessible until the end of the round. The general knowledge and vocabulary tasks in comparison gave the participants immediate feedback on the accuracy of their answers, in the way of increasing or decreasing their scores based on correct responses. Further, the speed at which items were presented in the general knowledge Millionaire and vocabulary Definetime task was controlled by the participant in that the faster they answered, the quicker a new item was offered. In contrast the *n*-back task continued at a designated speed, which the participant has no control over. These elements of immediate feedback and a sense of control contributed to create a higher level of motivation on the control tasks than the experimental task, and may have contributed to the higher gains in scores seen in the Definetime high scoring group. In the Definetime task motivation level and task behaviour had a reciprocal relationship. The more proficient a participant became on the task, the more motivated they were to be more proficient on the task.

Limitations

Test-retest effects. It is possible that the improvement on Picture Recognition could be due to practice effects experienced by retaking the test. No retest statistics are available for Picture Recognition Test 13 of the WJ III. However, the correlation coefficients for Test 17, Memory for Words ranged from .61 and .77 for less than one year, suggesting that retest scores are moderately to highly correlated to the initial test scores. This information only infers retest reliability for Picture Recognition, Test 13. Unfortunately, it is unknown how repetition of the initial test affected the final results. This issue could have been mediated by the inclusion of a non-active control group. A comparison could then be made between this group and the active control group and the experimental group and this should be considered in follow up studies. In this way the effect of practice learning could be discounted.

Unsupervised training. Due to the nature of the experiment, it was impractical to supervise all training sessions. It is therefore not known whether all training tasks were carried out in accordance with the instructions provided. It is possible that participants may not have completed all training sessions and fabricated results on the feedback sheets. Given the large dropout rate among initial participants, and problems with motivation levels reported by participants at follow-up interviews, it can be assumed that some participants did not put much effort into the training regime.

In future studies of this nature, it might be possible to have participants log on to an online version of the training tasks via a webpage. In this way, training could be monitored directly by the researchers. Information such as scores, the time when training takes place and how long and how often training tasks are accessed could be stored automatically. In this way, performance would be closely monitored and results would no longer depend on the reliability of self-reporting.

Analysis. Comparison of the high and low gain experimental and control groups was difficult due to the control task consisting of two training tasks. Using a series of ANOVA to explore high and low gain relationships may have increased the risk of Type I error. Therefore the analysis must be considered provisional and further research should be conducted on the Definetime task to establish the influence of the recognition strategy effects. Replication and extension is recommended especially when the effect size is considered (Cohen's *f* = .61, compared with .2 associated with n-back, and with Millionaire gain).

Future Directions

Visual memory has been found to undergo improvement due to *n*-back task training and this improvement has been observed in fMRI imaging (Burgess et al., 2011). Unsworth and Engle (2007) posit that when items stored in primary memory exceed four, the items are moved to secondary memory. Recognition can take place in primary or secondary memory and both are related to fluid intelligence (Unsworth, Brewer, & Spillers, 2009).

The relationship between the various constructs of working memory and fluid intelligence are complex. There may be many ways in which different aspects of memory interact with each other and separately that might account for individual differences (Unsworth & Spillers 2010). Further, Unsworth and Spillers (2009) suggest that there may be other unexplored relationships between constructs that may account for differing abilities in working memory.

Future research is needed to explore the relationship between visual recognition and fluid intelligence. The *n*-back task is described as a recognition task and it has been argued that the reason that no improvement is demonstrated on a test of working memory capacity might be because participants are using recognition techniques that have been improved due to *n*-back training to complete working memory capacity tests (Jaeggi, Buschkuehl et al., 2010). This has led to speculation that there are skills other than those measured by the working memory tests used by Jaeggi et al. (2008), Jaeggi, Studer-Leuthi et al. (2010) and Jaeggi et al. (2011) that are activated by *n*-back training that may engage fluid intelligence.

In a companion study, Beavon (2012) found no improvement in a test of working memory capacity or short-term memory due to *n*-back training. However, Jaeggi et al. (2008) did observe an improvement in a test of short-term memory due to *n*-back training. Since *n*-back training does not produce an improvement in tests of complex working memory measures, and might produce an improvement in a test of simple working memory, it may be that the *n*-back task is loading on working memory constructs that are not able to be identified by complex working memory tests (Jaeggi, Buschkuehl et al., 2010). Visual recognition is activated by *n*-back training and the reason complex working memory span tasks are not improved with *n*-back training is that they employ working memory constructs other than recognition.

Conclusion

Building on previous research by Jaeggi et al. (2008), this study explored the process of near transfer from a working memory task to a test of visual memory, a component of working memory. Experimental and active control training groups were employed, and both groups significantly improved their performance on their post-training Picture Recognition test scores in comparison to their pre-training test scores. Despite this, the experimental hypothesis that single *n*-back training leads to greater improvement in visual memory compared with the active control training group was not supported. The results were consistent with a confound, in that the active control group training included a task that improved visual memory.

Re-analysis of the results of this experiment suggested that both the *n*-back task and the Definetime task trained visual memory through the construct of recognition. Moreover, it would be appropriate to follow up the recognition improvements found using the Definetime task, and demonstrate that recognition memory strategies are operating to improve visual memory.

Recognition requires an ability to distinguish between lures to make a correct identification, whether visual recognition takes place in primary memory (as familiarity) or takes place in secondary memory. This ability to maintain attention and control for interference in the face of distractors is linked to fluid intelligence (Burgess el al., 2011). In an Honours study, Palmer (2011) found that training using Definetime and Millionaire resulted in a larger gain in fluid intelligence than *n*-back training. These results, in addition to the findings of the current experiment, question the use of the *n*-back task as the most efficient cognitive training tool and suggest that the Definetime task has potentially better outcomes. The *n*-back training task has been suggested as a measure of working memory in clinical situations (Miller et al., 2009) and has made its way into the marketplace as a working memory and fluid intelligence training tool. More research must be applied to this task before its validity as a preferred cognitive training task can be completely supported.

An improvement in fluid intelligence attributable to *n*-back working memory training was found by Jaeggi et al. (2008) and Jaeggi, Studer-Leuthi et al. (2010), Jaeggi et al. (2011). The results of the current study suggest that both *n*-back and Definetime trained visual recognition, which is related to fluid intelligence through familiarity and recall processes. Therefore it might be working memory elements associated with visual recognition that are the underlying constructs that drive improvement in fluid intelligence, through a multimodal working memory structure.

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Appendix A

Information Letter to Participants (On ECU letterhead)

Improving Intelligence through Cognitive Training

Thank you for considering to participate in our research project. This study is a requirement for the Psychology Honours program at Edith Cowan University, which has been given approval by the Faculty of Computing, Health, and Science Ethics Sub-Committee.

The aim of this research is to investigate whether intelligence can be improved through cognitive training. The previous understanding of intelligence was that it was relatively fixed, with hereditary being the major determinant. However, a number of recent studies have indicated that intelligence can be modified through specific cognitive training tasks.

As a participant you will be asked to:

1. Undertake three intelligence tests at a convenient day/time, at a convenient location of your choice. This process will take approximately 60 minutes.

2. Train using a computer based cognitive task, accessed through your own personal computer. The daily requirements of the training schedule are 18-20 minutes per day for 20 days once the initial intelligence testing has been completed.

3. Retake the initial intelligence tests. Again this should take about 60 minutes, and ideally would occur within three days of completing the cognitive training task.

Note: The schedule for the training task is flexible, however learning is maximised when there is some form of routine. The only stipulation is that the 20 days of training occur within a 30 day period. A recommended training schedule is 5 consecutive days, followed by two days break, which is equivalent to weekly training with the weekends off.

Participant benefits: Potential gains include an improvement in intelligence. Further, research has indicated that any gains attained appear to have longevity. Also access to the cognitive training task will remain, if continued practice is of interest.

The intelligence tests used in this research are similar to those which are used in recruitment and education. Therefore exposure to these tests may provide an advantage in future vocational testing or recruitment selection processes.

Potential risks / discomfort to participants: There are no foreseeable risks to participants in this study, apart from the inconvenience of committing to training and testing.

Confidentiality / Use of study data: All data gathered during the course of this study will remain confidential, and will not be disclosed to anyone outside of the research team. Part of the data collation process is the removal of all personal information, with names replaced with an alphanumeric identifier e.g. A23, and therefore no individual will be able to be personally identified with any of the data. There is a likelihood that the results will be published for scientific purposes, however using the above process ensures that individuals will maintain anonymity, and not be personally identifiable.

Choice to participate in the study: There is no mandatory obligation to participate in this study. No punishment, consequences or loss of benefits will occur should you choose not to participate.

Also if you elect to participate in the study, you are free to withdraw at any time without explanation, simply by contacting Paul Beavon, Allison Prandl, Dr Ken Robinson or Dr Ricks Allan at your earliest convenience.

Contacts: If you would like to take part in this project or require further information, please contact Paul Beavon or Allison Prandl via email or phone - contact details can be found below.

Thank you for your consideration,

Yours sincerely,

Paul Beavon Allison Prandl

Contact Details (for further information)

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Appendix B

Participant Informed Consent Form (On ECU letterhead)

Project Title: Improving Intelligence through Cognitive Training

Consent:

The signing of this form indicates that you have read the information letter provided and are interested in participating in the study.

I have been provided with the 'Information Letter to Participants' which I have read and understood. I am aware of the purpose of this study, my requirements as a participant and how the resulting data will be used. In accordance with the information provided:

- *I am volunteering to be a participant in 'Improving Intelligence through Cognitive Training' study.*
- *I understand that I can withdraw from the study at any time without providing a reason*
- *I give permission for the data to be published without any of my personal details thereby maintaining my anonymity.*

Participants Name: ___________________________________

Participant's Signature: ___________________________________ Date: / / 2012

Researcher's Name: ___________________________________

Researcher's Signature: ___________________________________ Date: / / 2012

Appendix C

Improving Intelligence through Cognitive Training: User's Guide

Single n-back game

The position or single *n*-back task is a memory task requiring the player to remember where a visual stimuli or target was presented *n* iterations previously. The scoring system is the ratio of correct responses to total responses. Correct responses are when a target or non target is identified and responded to correctly, and incorrect responses occur when a stimulus is incorrectly identified as a target, or target is incorrectly identified as a non-target.

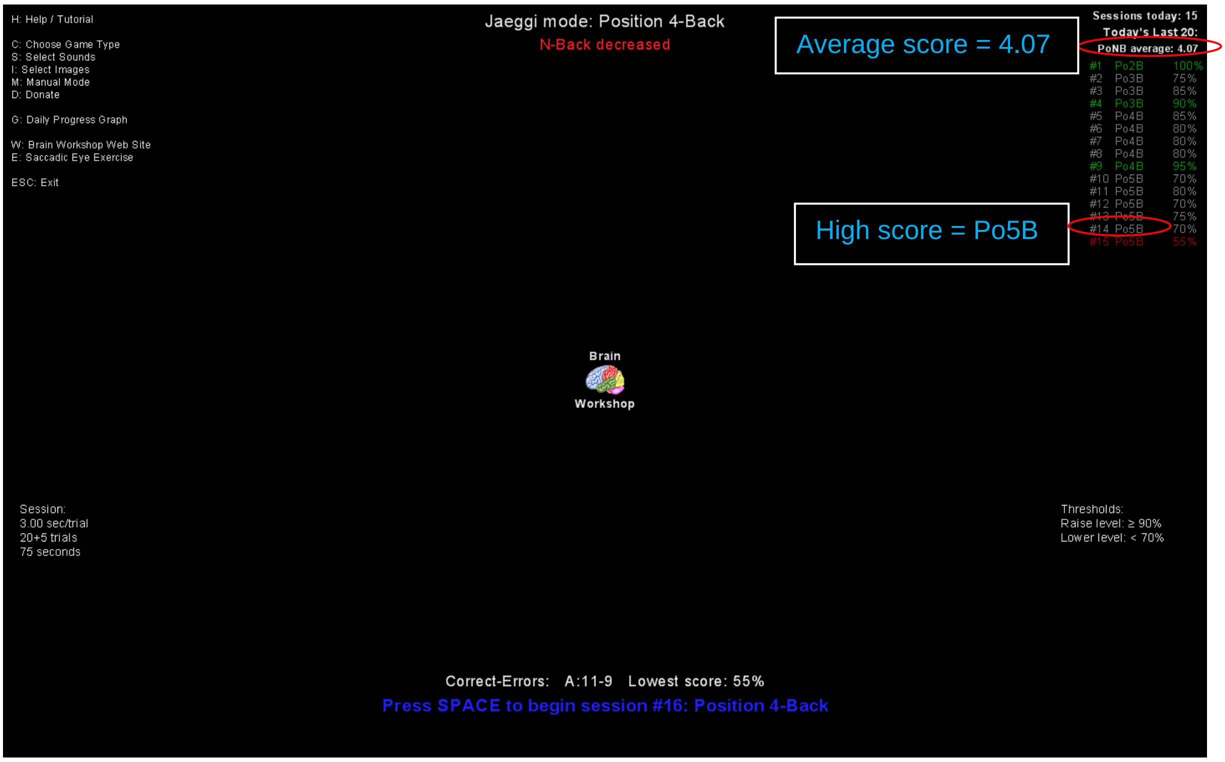
Single n-back task presents a visuospatial stimuli of over a 500ms duration, followed by a 2500ms interstimulus interval. This is defined as a trial. The visuospatial presentation consists of a blue square in one of eight positions on the display monitor. A response is required whenever the visuospatial stimuli match the stimuli n iterations back in the sequence. A target is the presentation of a visual stimulus that is a potential match. A block consists of 20 trials, where there are six visual targets per block. To register a match, the A key is pressed for visuospatial targets. No response is required for non-targets.

The single n-back task automatically manages the level of difficulty based on the score from the previous block by altering n. If the participant made fewer than three mistakes— *n* is increased by one; and decreased by one if five or more mistakes were made. This reflects a performance of GE 90% or LE 70% respectively; otherwise the difficulty level remains unchanged. Performance is measured using the following formula:

$$\text{Performance} = \frac{(\text{True positives} + \text{True Negatives}) \times 100}{\text{True positives} + \text{True negatives} + \text{False positives} + \text{False negatives}}$$

Session. A training session consists of 15 rounds of single *n*-back, which will take between 15 and is 20 minutes.

Scoring. Each participant is required to record their average and highest score attained in each session. This can be found on the primary panel.



Duration. 20 Sessions over a contiguous 30-day period. The preferred training routine is five consecutive days followed by a two-day break.

Appendix D

Task 1: Scoring Sheet

Identifier: Start date: End date:

Duration: 20 sessions over 30 days of practice

Session	Average score	Highest score
Practice		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Appendix E

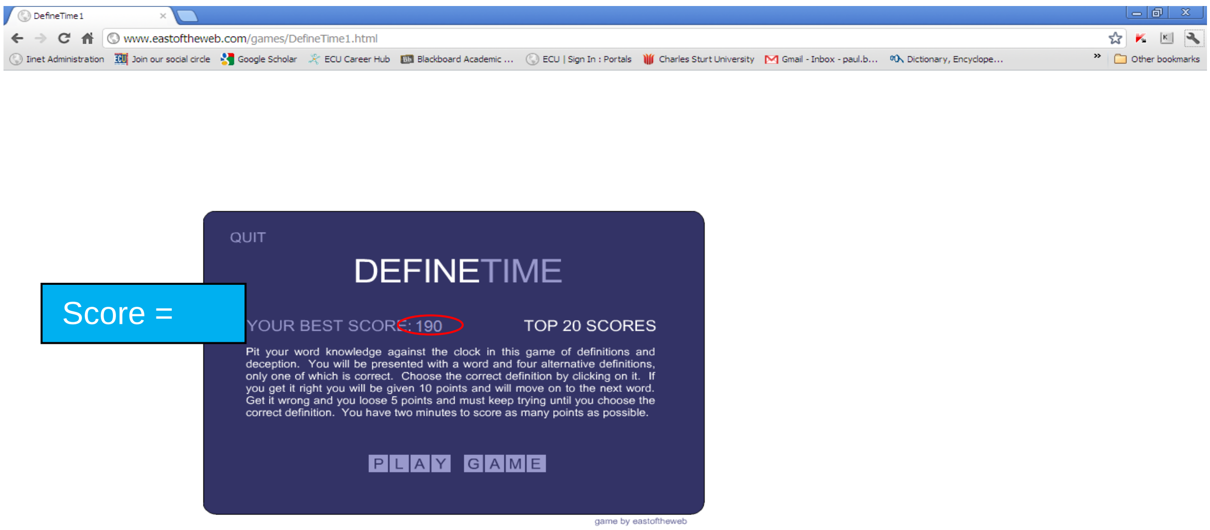
Improving Intelligence through Cognitive Training: User's Guide

Definetime

Definetime is an internet based quiz that requires the participant to select the correct definition of a word from four possible options. A correct response gives the player 10 points, however each incorrect response, reduces the players score by five points. Players must continue to choose a response until they select the correct definition. The object is to score as many points as possible within the two-minute time limit.

Session. A training session is 20 minutes in length alternating between 'Define time' and 'Who wants to be a millionaire'.

Scoring. Define time automatically scores each game. Participant's highest score for the session is required to be recorded on the scoring sheet provided.



Duration. 20 Sessions over a contiguous 30-day period. The preferred training routine is five consecutive days followed by a two-day break.

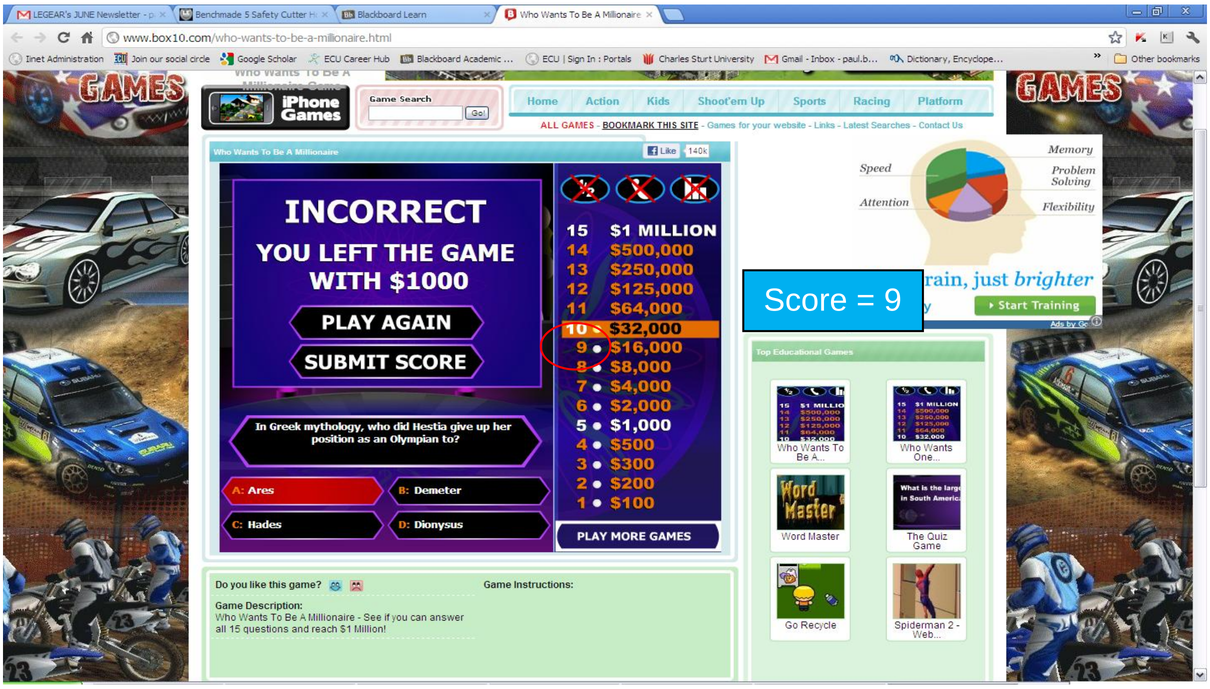
URL: http://www.eastoftheweb.com/cgi-bin/top_scores.pl?game=definetime

Who wants to be a millionaire?

This task is an internet version of Channel 9's game show hosted by Eddy McGuire. The objective is to win one million dollars by answering 15 consecutive questions correctly— with 30 seconds to answer each question. If a participant is unsure of the correct answer, they have three lifelines to improve the probability of answering correctly. The first lifeline is 'call-a-buddy' where the participant can ask another person the question. They can provide a possible answer together with the probability that their answer is correct. The second lifeline is '50% chance', where two of the potential answers are removed. The third lifeline is 'audience assistance' where the participant can ask the audience for help.

Session. A training session is 20 minutes in length alternating between 'Define time' and 'Who wants to be a millionaire'.

Scoring. Every correct answer within a game earns one point. There is a maximum 15 points per game. Participant's highest score for the session is required to be recorded on the scoring sheet provided.



Duration. 20 Sessions over a contiguous 30-day period. The preferred training routine is five consecutive days followed by a two-day break.

URL: http://www.box10.com/who-wants-to-be-a-millionaire.html

Appendix F

Task 2: Scoring Sheet

Identifier: Start date: End date:

Duration: 20 sessions over 20 days

Session	Game	Highest score
1	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
2	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
3	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
4	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
5	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
6	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
7	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
8	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
9	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
10	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
11	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

	Definetime	
12	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
13	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
14	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
15	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
16	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
17	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
18	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
19	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	
20	Who Wants to be a Millionaire	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
	Definetime	

Appendix G

Improving Working Memory through

Cognitive Training (On ECU letterhead)

Dear

Thank you for participating in the '*Improving Intelligence through Cognitive Training'* study. Below is feedback regarding your performance on the tests you completed during the study.

Working Memory Capacity **Woodcock-Johnson III, Tests 7 & 9**	**Level of Performance**
Tests 7 & 9 of the WJIII evaluate short term memory span and auditory working memory. Short term memory refers to how many bits of information you can hold in your immediate memory while manipulating that information. Auditory working memory refers to short term memory stimulated by sound.	Your Working Memory score placed you at the __ percentile, which means that you performed as well as or better than __ of your age related peers.

Visual Memory **Woodcock-Johnson III, Test 13**	**Level of Performance**
Test 13 of the WJIII evaluates visual memory, which refers to short term memory stimulated by vision.	Your Visual Memory score placed you at the __ percentile, which means that you performed as well as or better than __ of your age related peers.

If you have any questions about your scores please contact any of the following by phone or email:

Contact Details (for further information)	
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School	Edith Cowan University (Joondalup)
Faculty	School of Psychology and Social Science

Appendix H

Participant Demographic Information Sheet

Name : ____

Age (years) : __________

Gender : M F

Contact number : ______________________

Email address : ____

Study Identifier : ____________ (provided by researcher)

What is your highest qualification attained?

- < Year 12
- Year 12
- University degree
- Other qualification after Year 12

Are you currently studying at:

- University
- Another institution (TAFE, other colleges)

Supplementary Materials

Brainworkshop (n.d) Modified computer software for *n*-back training task [CD]