Brain Cross Training
Computerized Cognitive Training
Dual N-Back

Mark Ashton Smith Ph.D.

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CONTENTS

Foreword

In this series of 16 eBooks delivered to you weekly, I present you with the most effective, evidence-based cognitive interventions within a brain cross training paradigm. Adopting a brain cross training framework is unique in a brain training industry that focuses exclusively on computer based applications and biometrics. It's my hope that IQ Mindware apps and resources can help set out an easily accessible set of strategies enabling you to tap into the evidence-based potential for improving your cognitive resilience, health and performance.

Enjoy your training!

Mark Ashton Smith, Ph.D.
Personal Website
LinkedIn

Generally what we understand by 'brain training is **computerized cognitive training (CCT)** – apps usually designed to improve your attention, processing speed, memory, reasoning and so on. In this eBook I shall be reviewing what is known about the effectiveness of this kind of training for cognitive performance.

Cognitive Performance

Cognitive performance is defined relative to some demand or challenge, and can be defined as competence and effectiveness in meeting that challenge. Examples include doing well in an entrance exam or job test, solving a problem at work, making a sound decision that has wide impact, devising an effective career strategy, learning a new skill efficiently or retaining self-control under pressure. The current economy is based in large part on cognitive performance - what has been called 'cognitive capital' or 'mental capital'.

> "...One element of human capital is cognitive ability: quickness of mind, the ability to infer and apply patterns drawn from experience, and the ability to deal with mental complexity. Another is character and social skills: self-discipline, persistence, responsibility. And a third is actual knowledge. All of these are becoming increasingly crucial for success in the post-industrial marketplace." (Professor Jerry Muller, March 2013, **Foreign Affairs**)

General Intelligence (G)

The most general idea of cognitive performance is that of **general intelligence**, sometimes simply called 'G'. General intelligence has been defined in different ways by different scientists. [An excellent compilation of definitions of general intelligence can be found here](). Here are some of the better definitions:

> "Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience." L. S. Gottfredson

> "...the capacity to reorganize one's behavior patterns so as to act more effectively and more appropriately in novel situations ...the ability to learn ...the extent to which a person is educable ...the ability to carry on

abstract thinking …the effective use of concepts and symbols in dealing with a problem to be solved …" W. Freeman

"Intelligence is the ability to solve problems, or to create products, that are valued within one or more cultural settings." H. Gardner

IQ Tests

The most well-known measure of general intelligence is a standardized **IQ test**. 'IQ' stands for 'intelligence quotient'. Standardized means that scores can be compared in the general population and you know what score is needed to be in a certain percentile – for instance above average, or in the top 2% (Mensa standard). Examples of IQ tests include the Wechsler Adult Intelligence Scale, the Stanford-Binet, and the Cattell Culture Fair test, and Raven's Progressive Matrices.

There are many bogus IQ tests on the web that either don't accurately or reliably measure your general intelligence, or which give you an inflated score. Valid, reliable, standardized tests are difficult to locate and are usually professionally administered.

IQ tests certainly aren't designed to measure everything important about cognitive performance. They do not measure decision-making ability, attention control or self-control for instance. But IQ tests are the best tests for cognitive performance that scientists have devised. IQ test scores can be used to predict achievements in a wide range of abilities, including creativity, educational attainment, health, leadership, lifespan, professional achievement and income. IQ tests are widely used in our institutions and organisations because of their consistency and validity. Schools and universities use IQ tests (or 'aptitude tests') to select and stream students, companies use IQ tests to screen applicants, with estimates of 80% of Fortune 500 companies' HR departments using these kinds of tests for recruitment.

IQ tests are designed so that the **average IQ score for test takers is 100**. IQ test scores have a distribution in the general population that looks like a symmetrical bell – which is why the IQ distribution is often called a 'bell curve'. You can see this 'bell' in the figure below:
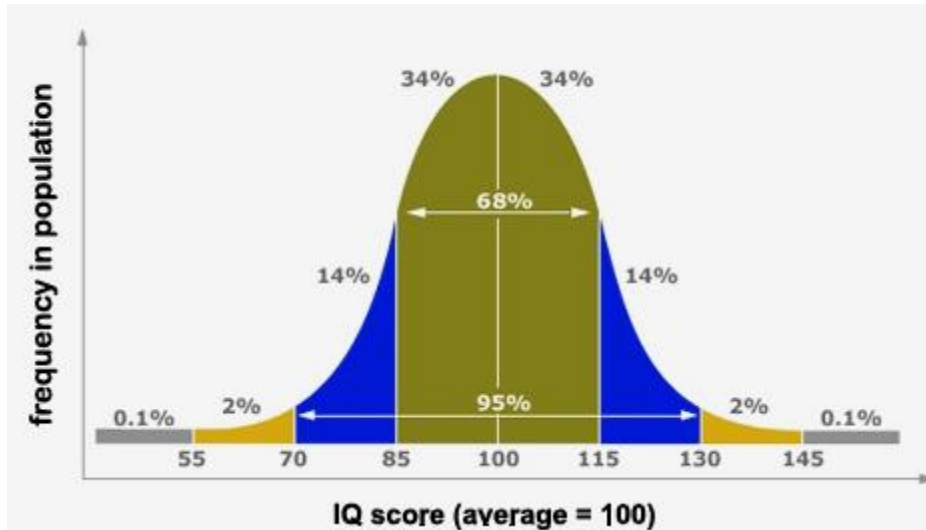
By looking at areas of this curve, you can see that the majority of people (68%) have an IQ score between 85 and 115. Only around 2% have an IQ greater than 130 which is often called 'gifted' intelligence. This is the IQ score needed to join Mensa.

Here is a table that helps us interpret what IQ scores within certain ranges mean:

Classification	IQ Range	%
highly gifted	140+	0.4%
Mensa membership	130+	2%
gifted	130+	2%
International High IQ Society membership	124	5%
high	115-129	15%
high average	110-115	25%
average	90-109	50%
low average	80-89	23%
borderline	70-79	8%

For a rough guide, an IQ of 115 or higher can be considered a 'high IQ'. This equips someone to take on a university degree. An IQ of 130 or higher puts a person into the 'IQ elite' – the sphere of Harvard undergraduates and grad students.

Is Intelligence Fixed In Stone?

General intelligence – based on IQ test scores - has been estimated to be 50-80% heritable – due to genetics. Genetics is what is meant by 'fixed in stone'! Identical twins separated at birth and raised in different family, educational and cultural environments will often have similar IQs due to the shared genetics. The data shown in this graph shows a strong correlation between the IQ's of identical twins reared apart. Unrelated persons reared together did not have a strong correlation of IQ's.
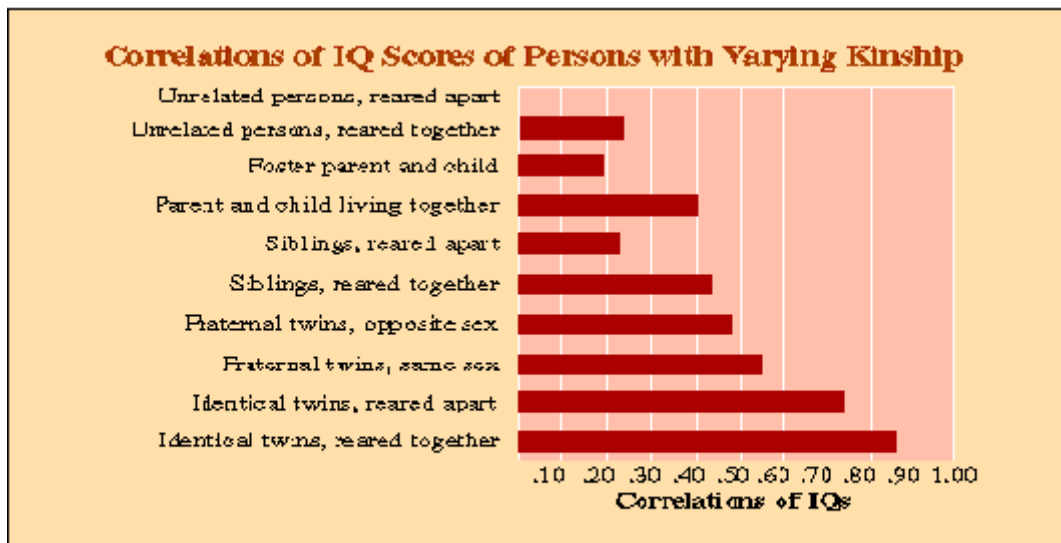
Clearly the 'heritability' estimates depend on how extreme differences in the environment are. Taking into account a broader range of cultural environments over longer time periods, the genetic contribution to IQ may be estimated to be closer to 50%.

The 'Flynn Effect' in developed countries is one demonstration of the impact of non-genetic factors on IQ. Throughout the decades of the last century, IQ test performance rose substantially up to the late 1990s, typically about 3–5 IQ points per decade, as shown in the data here.

The Flynn Effect
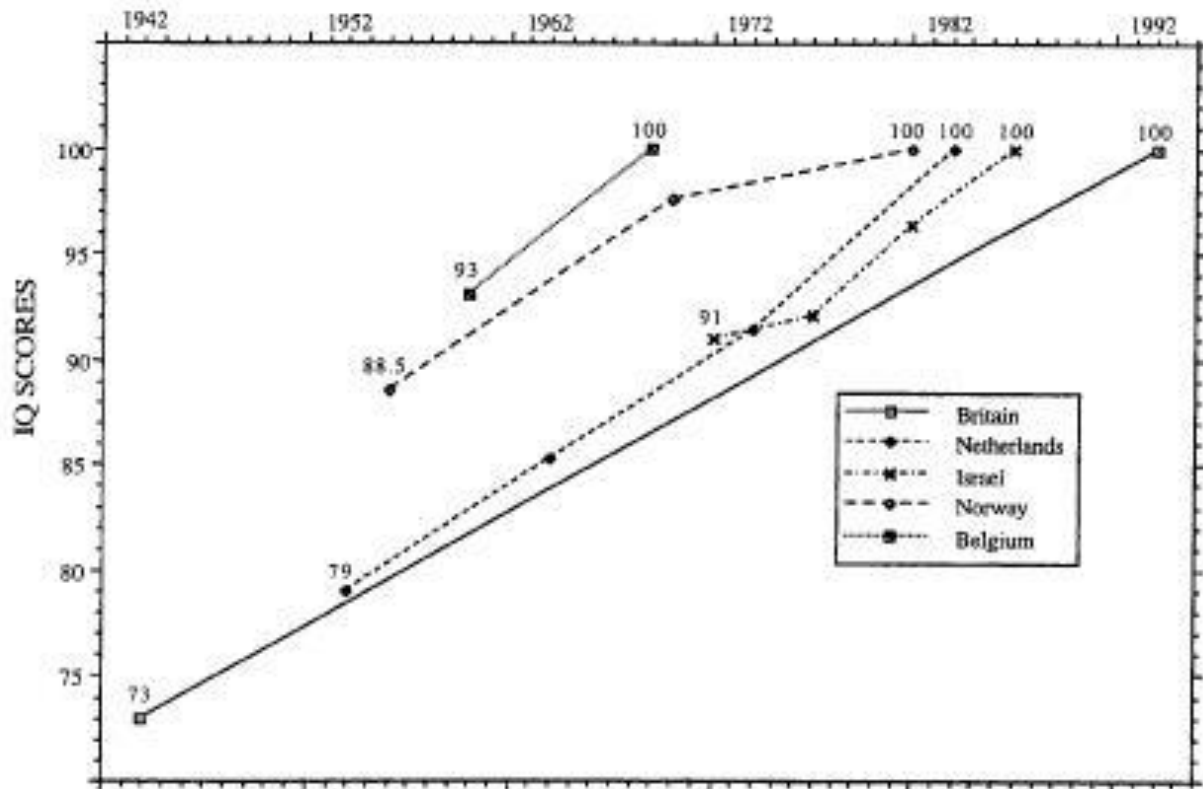
This means that if you gave a modern IQ test to your grandparent's generation their average score would have been around 80, not 100! This steady rise in IQs – called the 'Flynn Effect' – may have peaked in the late 1990s, with [a moderate decline since then](#).

Environmental impact on general intelligence levels include the mother's health during pregnancy, stressors from the physical environment, nutrition, general health and hygiene, education, cultural and social stimulation, and – as we shall see below – dual n-back computerized cognitive training.

Increasing IQ with Computerized Cognitive Training: Working Memory Training

There is accumulating that adopting deliberate IQ increasing strategies can raise IQ, and the most effective and well-researched of these strategies is computerized *working memory training*.

Working memory can be thought of as our 'mental workspace' (imagine a white board that is constantly being written on and erased in a busy meeting).
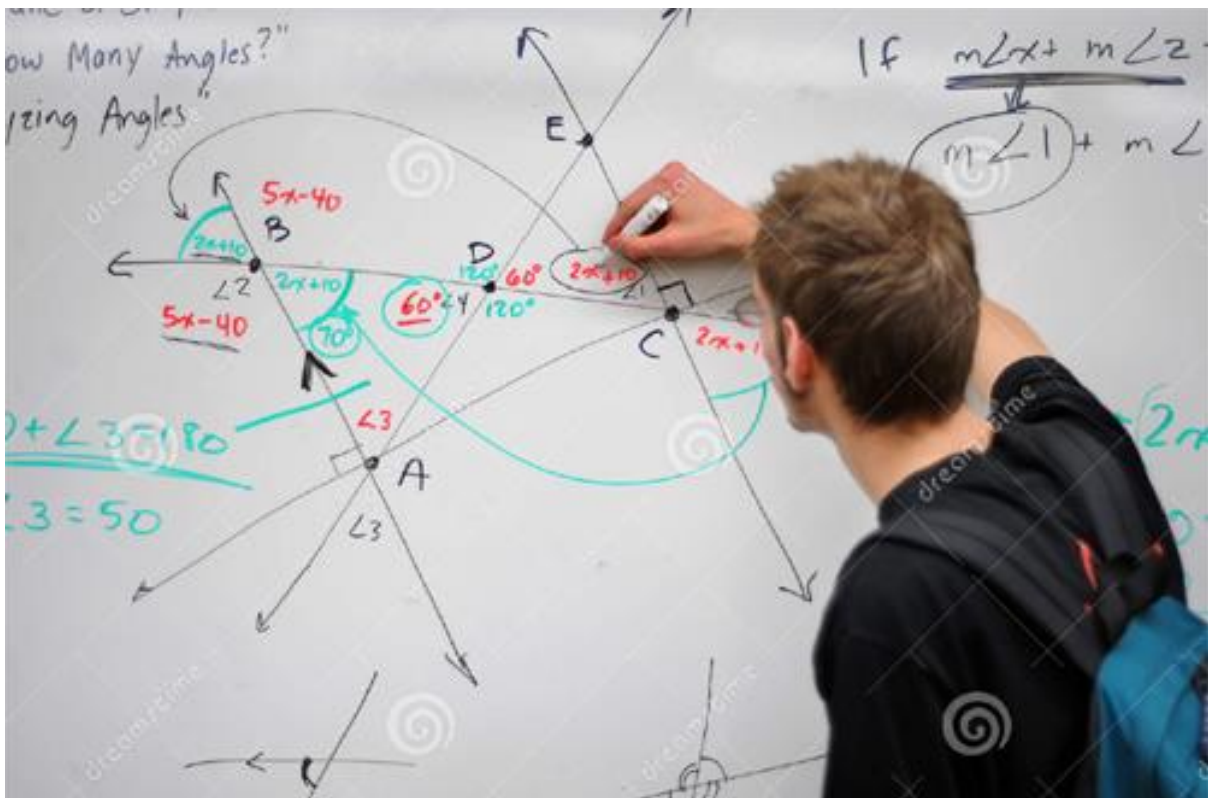
Working memory is a short term memory and management system that

> *"provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning."* (Baddeley, 2003, p. 189)

Individuals differ in their **working memory capacity** – i.e. the quantity of information they can maintain and process – and this capacity correlates with IQ.

This makes sense, as you can imagine that highly intelligent people have a large mental 'workspace' and are able to make relatively more connections and inferences using this workspace.

Dual N-Back Training

In 2008 Susanne M. Jaeggi and colleagues published a seminal paper showing the **wide transfer** of 20 days of computerized working memory training to intelligence. 'Wide transfer' means that training does not simply result in improvements on the game itself but improves performance on general cognitive ability and IQ tests. This paper generated a tremendous amount of interest in the potential of brain training to improve intelligence.

The working memory exercise Jaeggi used was the **dual n-back** – which is now the most widely studied computerized cognitive training exercise. It involves viewing a continuous stream of items such as moving squares and deciding whether each square location matches the location 'n' stimuli back in time. The memory 'gap' is the 'n-back level'. If you need to keep track of the location 2 moves back, then you are at the 2-back level. If you are tracking the location 3 moves back – then you are at the 3-back level. Here you can see
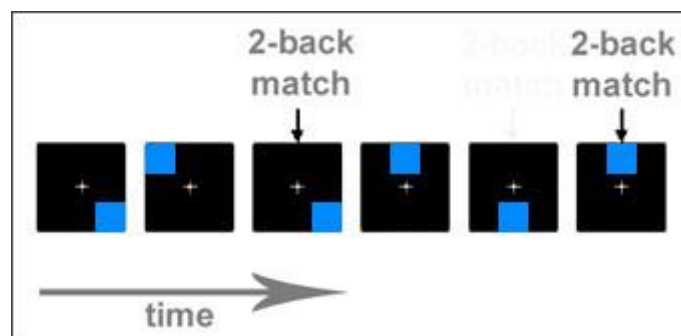
In **dual n-back training**, a verbal and a visual stream of items is presented **simultaneously** and 'n-back' item matches at have to be detected for both, as shown below for n=2.
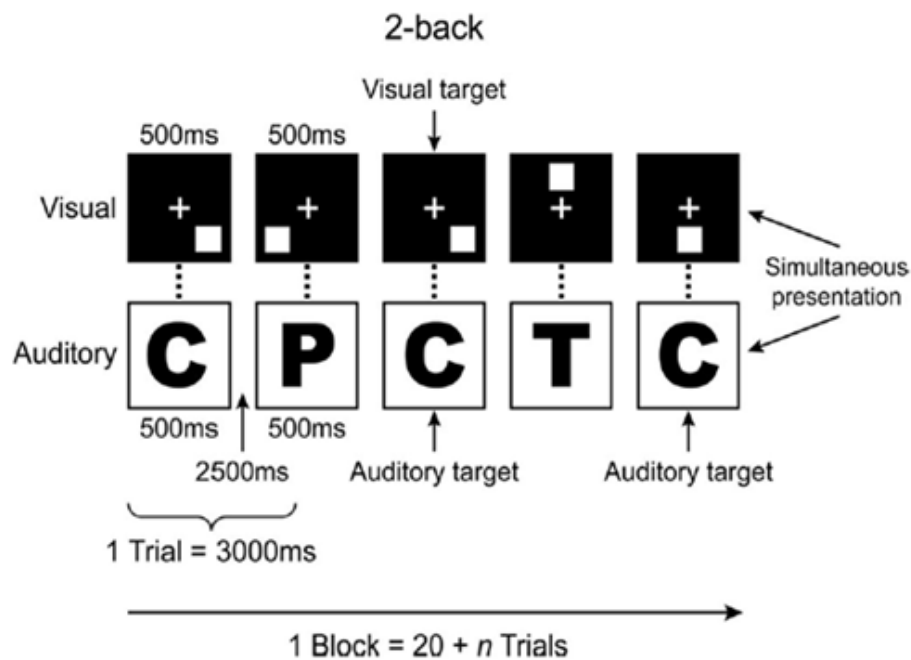
Figure 6. The Dual N-back Task

How To Evaluate The Conflicting Evidence For Dual N-Back Cognitive Training

Jaeggi and her colleagues published their dual n-back study back in 2008. Since then numerous studies investigating the effects of working memory training on cognitive performance have been published, and there has been a heated controversy among both cognitive scientists and the popular media surrounding the idea that cognitive training can increase IQ. Some studies have failed to replicate the IQ-boosting training effect – such as this study by a team led by Todd Thompson in MIT's Department of Brain and Cognitive Sciences which concluded:

> "[our] findings fail to support the idea that adaptive working memory training in healthy young adults enhances working memory capacity in non-trained tasks, fluid intelligence, or other measures of cognitive abilities."

But other studies continue to find IQ increasing training effects, such as this one by Sarah Rudebeck in Oxford University's Department of Experimental Psychology which concludes:

> "*we found that the trainers, compared to non-trainers, exhibited a significant improvement in fluid intelligence after 20 days…. Our findings demonstrate that practice on a …working memory task can potentially improve aspects of both ….memory and fluid intelligence.*"

So how are we to evaluate the conflicting evidence? Does dual n-back training work or not?

There is an issue of **opportunity costs** here. Is it worth investing time and effort in dual n-back training when the alternatives such as learning a musical instrument or going for a run might be more beneficial for cognition?

In answering this question, we need to distinguish between different grades of 'evidence' in order of merit. In this list below, grade 1 is the least trustworthy and grade 4 is the most trustworthy.

1. **'In house' research** c**onference talks, papers 'under review' and other non-published material.** (e.g. *Lumos Labs* unpublished papers.)
2. **Single peer-reviewed journal articles that have not been replicated.**
3. **Several peer-reviewed journal articles from different labs with replications.**
4. **Meta-reviews of multiple peer-reviewed journal articles with replications.**

I always look specifically for **meta-reviews** (Level 4) to reach conclusions about the most reliable and effective types of brain training – whether for computerized cognitive training, or for other brain cross training methods such as nootropics, intermittent fasting or meditation.

The two latest meta-reviews of dual n-back training – one published this year and the other to be published next year - both conclude **dual n-back training is effective in improving general cognitive performance and IQ test scores**.

This 2014 paper by Jacky Au and colleagues at the University of California, Irving, summarizes all the 'effect sizes' of the studies of intelligence gains from dual n-back training, measured by Raven's Progressive Matrices type tests:
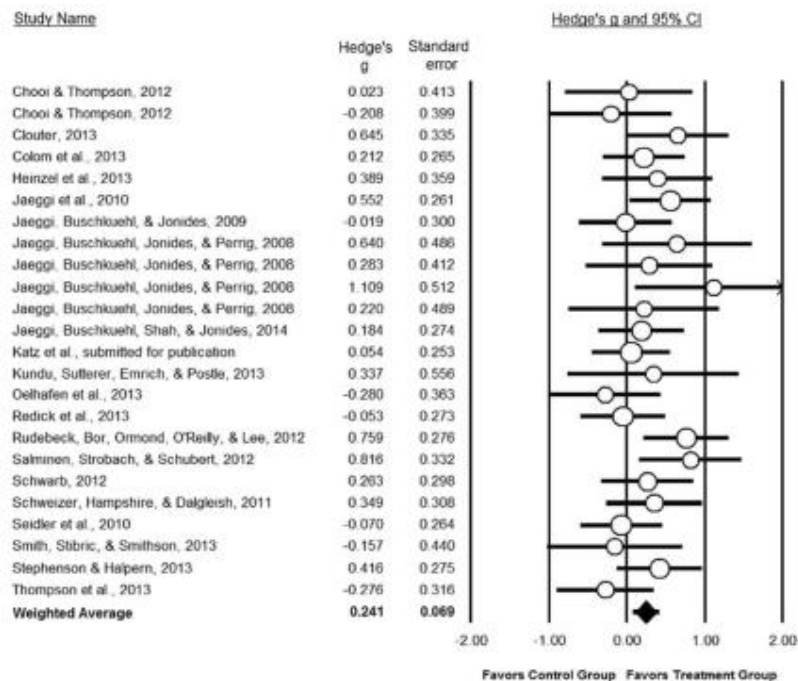
Study Name	Hedge's g	Standard error	Hedge's g and 95% CI
Chooi & Thompson, 2012	0.023	0.413	
Chooi & Thompson, 2012	-0.208	0.399	
Clouter, 2013	0.645	0.335	
Colom et al., 2013	0.212	0.265	
Heinzel et al., 2013	0.389	0.359	
Jaeggi et al., 2010	0.552	0.261	
Jaeggi, Buschkuehl, & Jonides, 2009	-0.019	0.300	
Jaeggi, Buschkuehl, Jonides, & Perrig, 2008	0.640	0.486	
Jaeggi, Buschkuehl, Jonides, & Perrig, 2008	0.283	0.412	
Jaeggi, Buschkuehl, Jonides, & Perrig, 2008	1.109	0.512	
Jaeggi, Buschkuehl, Jonides, & Perrig, 2008	0.220	0.489	
Jaeggi, Buschkuehl, Shah, & Jonides, 2014	0.184	0.274	
Katz et al., submitted for publication	0.054	0.253	
Kundu, Sutterer, Emrich, & Postle, 2013	0.337	0.556	
Oelhafen et al., 2013	-0.280	0.363	
Redick et al., 2013	-0.053	0.273	
Rudebeck, Bor, Ormond, O'Reilly, & Lee, 2012	0.759	0.276	
Salminen, Strobach, & Schubert, 2012	0.816	0.332	
Schwarb, 2012	0.263	0.298	
Schweizer, Hampshire, & Dalgleish, 2011	0.349	0.308	
Seidler et al., 2010	-0.070	0.264	
Smith, Stibric, & Smithson, 2013	-0.157	0.440	
Stephenson & Halpern, 2013	0.416	0.275	
Thompson et al., 2013	-0.276	0.316	
Weighted Average	**0.241**	**0.069**	

-2.00   -1.00   0.00   1.00   2.00

Favors Control Group   Favors Treatment Group

Fig. 3 Overall effect size across studies. Forest plot showing Post ES (Hedges *g*) and 95% confidence intervals from each individual study. Overall weighted ES is displayed at bottom

Looking at the circles in this graph, an effect size of 0.00 means the training in that study was ineffective. An effect size of 1.00 is around a 15 point gain on a standardized IQ test. Several studies found an IQ gain of greater than 10 points, which substantial. ***Averaging over all working memory training studies in this meta-review a significant IQ-boosting effect is found –*** with an average effect size of about 4 IQ points.

The meta-study concludes:

> "Our work demonstrates the efficacy of several weeks of n-back training in improving performance on measures of Gf [fluid intelligence]. We urge that future studies move beyond attempts to answer the simple question of whether or not there is transfer and, instead, seek to explore the nature and extent of how these improved test scores may reflect "true" improvements in Gf that can translate into practical, real-world settings."

My grad school colleague Jason Chein – Principle Investigator at the Temple University Neurocognition Lab reached a similar conclusion in his meta-analysis of working memory training, concluding that training "does indeed

show positive transfer, even to far transfer measures" (personal correspondence).

Based on this meta-review evidence – the highest grade scientific evidence we have - we can conclude that dual n-back training is worth investing your time and effort into if you want to achieve gains in general cognitive performance. No equivalent gains result from learning musical instruments, playing video games, or doing regular aerobic exercise.

Increasing IQ Gains: Dual N-Back Optimization

Jacky Au and colleagues argue in their meta-review that the average increase in IQ from training they found is an **under-estimate** due to the samples and testing criteria. Moreover, they believe that the effect size they reported could be increased by **optimizing** certain game parameters including:

- Program completion
- Increasing intrinsic motivation (rather than monetary rewards) for program completion
- Reducing training session length to e.g. 15-20 minutes per session.

For these reasons the authors argue:

> "*the results reported in this meta-analysis represent a low-end estimate of the true extent of improvement that n-back training can have on measures of [intelligence]*".

The game is now is determining exactly what variations of the dual n-back – what *parameters* - can optimized wide transfer to cognitive performance.

It's like growing tomatoes. If you know you can grow them, your next concern is to figure out how to make them bigger and better – by e.g. different watering schedules or adding fertilizer or varying the growing temperature.

Interference Control & 'Second Generation' Dual N-Back Training

One candidate parameter for optimizing dual n-back training that I have been particularly interested in is *interference control*.

Interference is a technical term for *distracting information* that is similar to the information you need to perform well in a game or cognitive challenge. If you are playing the n-back game, and you are at an N=3 level, a matching stimulus for N=2 would qualify as interference, particularly if you have just being playing at the N=2 level. This is shown in the diagram.
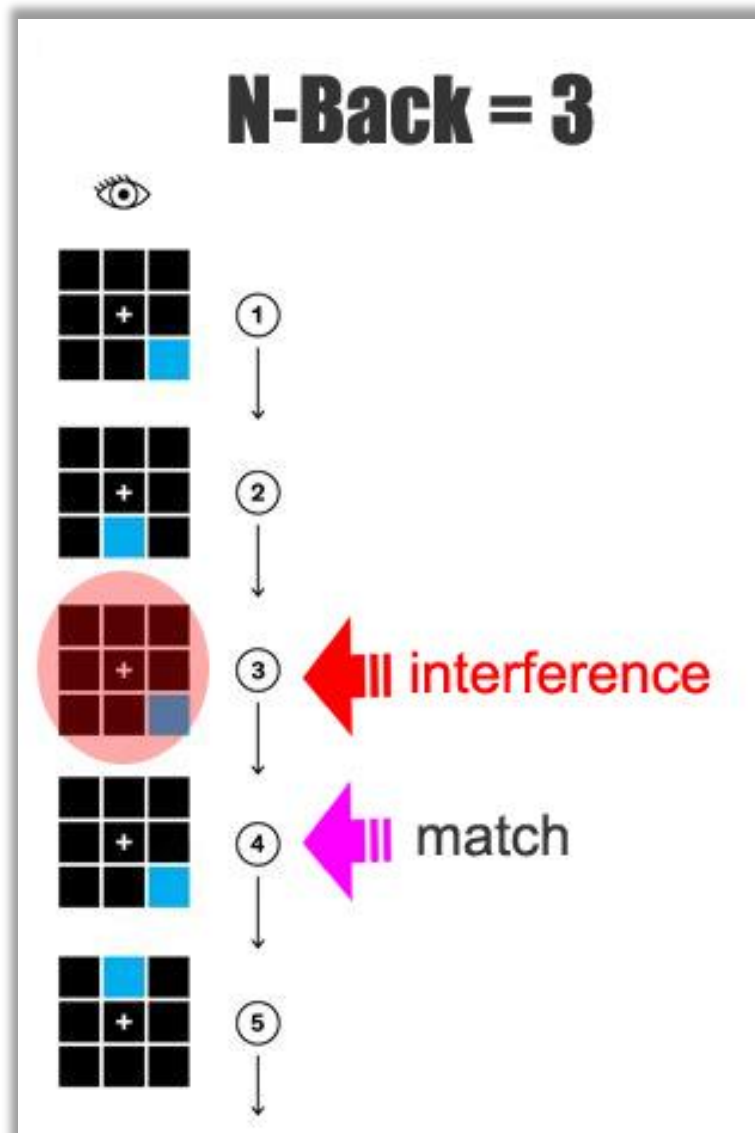
Another type of interference (one that is easier to get a feel for) is found in the 'Stroop task'. You can try the task for yourself now – going from left to right, as quickly as you can say aloud the **ink color** of the words here – ignoring the word meaning (the answer for the first one is 'red').

BLUE   GREEN   YELLOW

PINK   RED   ORANGE

GREY   BLACK   PURPLE

TAN   WHITE   BROWN

Because reading words is so well-practiced and automatic, there is a strong interference effect in this task - as you'll have noticed! The meaning of the word captures your attention, and interferes with your ability to perform the task. It takes concentration to control this interference.

There is good scientific evidence that **interference control** – the ability to filter out distracting information of this sort – **underlies the link between working memory and intelligence**.

- First, brain imaging studies reveal that neural mechanisms of interference control underlie the relationship between fluid intelligence and working memory span.

- Second, Claudia von Bastiana and Klaus Oberauera at the Department of Psychology, University of Zurich, have found that a game based on 'supervision' working memory training alone resulted in IQ gains. Supervision is terminology for **that aspect of working memory used for interference control** - defined as "selective activation of relevant and inhibition of irrelevant information".

Based on this evidence, I have built interference control into the dual n-back game with my IQ Mindware apps as one way of optimizing IQ gains from dual

n-back training. Building interference control into the dual n-back game is something new, and for this reason I have called it 'second generation' (2G) dual n-back training.

Based on the data I have collected so far from the PsiProfiler plugin for i3 Mindware I have found an average pretest IQ score of 110.9, and a post-test average is 120.6. This is a statistically significant effect of approximately 10 IQ points. (It is for this reason I guarantee a 10+ IQ point gain.

With HighIQPro I have also developed an entirely new *Stroop Dual N-Back*. In this game you have to keep track of n-back matches for e.g. the direction of the arrows ignoring their location, and the color of the words, ignoring their meaning. The picture here shows an example of this, with n-back = 2.

Feedback from users' experience of cognitive gains from the Stroop Dual N-Back has so far been positive. This dual n-back variation has a great potential for optimizing IQ gains, and should be seen in controlled, laboratory studies soon. HighIQPro also offers standard dual n-back training with interference.