PSYCHOMETRIC
IQ AUGMENTATION 1
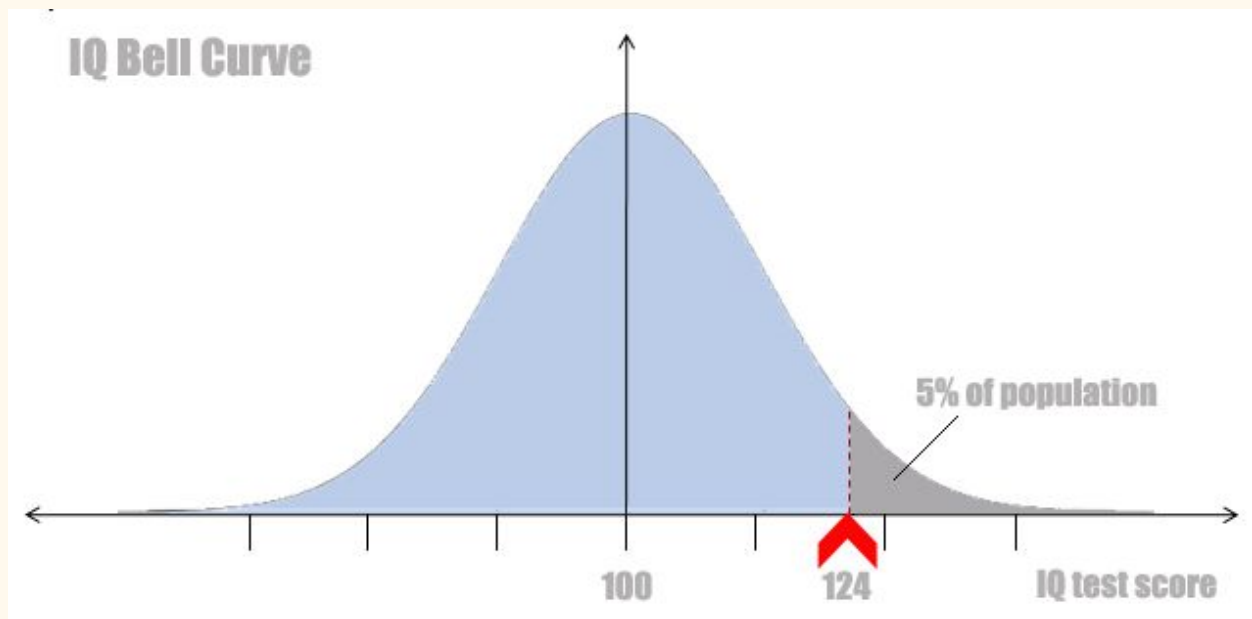
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WHAT IS GENERAL INTELLIGENCE?

Definitions

A good cognitive science definition of general intelligence is:

> *". . . that facet of mind underlying our capacity to think, to solve novel problems, to reason and to have knowledge of the world."* **M. Anderson**

Note that the definition emphasizes ***abstract*** cognitive processes: thinking and reasoning and knowledge as mental models. This op-ed statement signed by fifty-two researchers in the field ([ref](#)) extends this idea to include learning and being 'switched on':

> *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. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings —"catching on," "making sense" of things, or "figuring out" what to do.*

This 20+ year old definition still holds, but over the past 20 years different working definitions have evolved in different fields.

From an **applied IQ** perspective comes and emphasis on productivity, captured by:

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

". . . I prefer to refer to it as 'successful intelligence.' And the reason is that the emphasis is on the use of your intelligence to achieve success in your life. So I define it as your skill in achieving whatever it is you want to attain in your life within your sociocultural context" **R. Sternberg**

From the **artificial intelligence (AI)** movement comes an emphasis on efficient **goal** achievement, captured in these definitions:

"Achieving complex goals in complex environments." **B. Goertzel**

"Intelligence is the ability to use optimally limited resources – including time – to achieve goals." **R. Kurzweil**

However intelligence is defined in real-life settings, from a scientific point of view, it needs to be **measured**, and the science of measuring cognitive abilities is called 'psychometrics'.

It is the psychometric tradition that gives us our much-loved IQ tests such as the WISC-IV, WJ-IV and WAIS-IV, and the host of aptitude and ability tests that play an important selecting and streaming role in educational and professional development.

Psychometric IQ
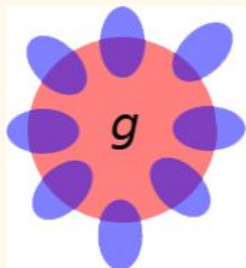
Our numeric IQ level is what psychometric IQ tests measure. While people have different cognitive strengths and weaknesses (e.g. language, math, visuospatial), **correlations** (statistical links) between measures of these abilities show us there is a common component to all of them. This underlying component is called *g* (general intelligence). Standardized **full-scale** IQ tests are designed to measure *g*.

Further statistical analysis shows that test scores on different types of cognitive ability tests tend to cluster or group in certain ways, revealing a number of underlying 'broad ability' factors of intelligence - such as quantitative and general knowledge abilities.

Individuals can differ not just on how they score compared to others on their overall intelligence (*g*) but also on different broad abilities which we'll look at below.

Individual Differences in Test Scores

"Each mind has its own method." Emerson

"Minds differ more than faces." Voltaire

As argued by the Director of the Institute for Applied Psychometrics, Kevin McGrew, a major purpose of psychometric testing: to appreciate *the individual difference terrain or landscape of each individual's personal abilities*. In other words, to understand each person's **unique personal profile** - their cognitive peaks (potentialis, capacities, strengths) and valleys (weaknesses, deficiencies), to design programs to allow them to reach their fullest potential.

This is the primary aim underlying the development of IQ increasing apps such as i3 Mindware.

Another purpose of psychological testing is **selection and streaming** - for example testing for college admissions or job selection.

Broad Ability Domains and the Structure of IQ

The remainder of this eBook outlines 3 closely related theories based on extensive data that give us insights into the nature of general intelligence. They are the theories that we have adopted at *IQ Mindware Ltd* to develop our software apps (such as **i3 Mindware**). The theories help clarify why these apps are effective in increasing *g*.

The CHC Theory of General Intelligence

The CHC theory (ref) is based on the analysis of hundreds of data-sets and is the most widely accepted taxonomy of intelligence.

There are **three strata** or levels. General intelligence (*Spearman's g* or simply *g*) is at the top (Stratum 3), with **9 broad ability domains** below that (Stratum 2), and more than 70 'narrow' abilities (Stratum 1) below that.
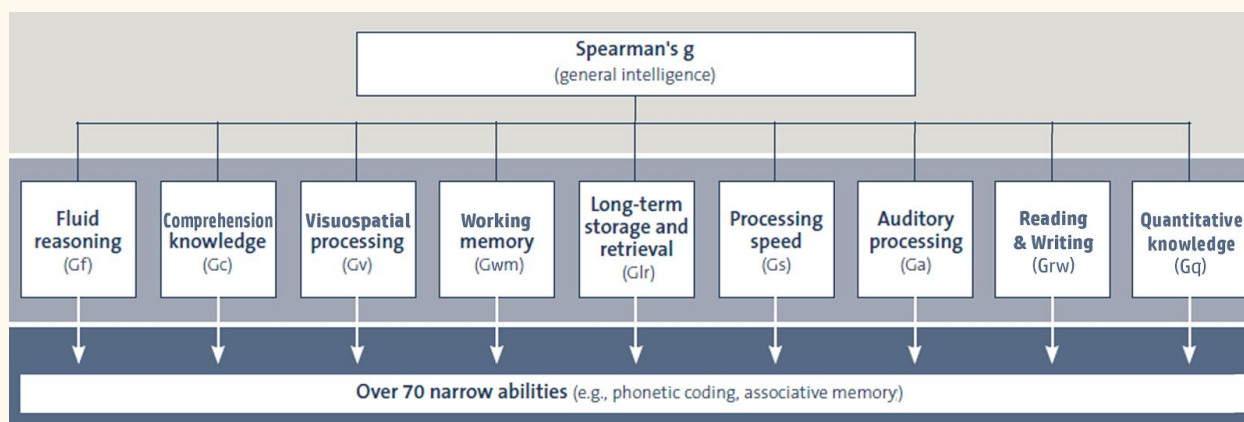
Individual differences in overall intelligence (*g*) as well as broad ability domains are measured by the IQ subtests full-scale, professionally administered IQ tests such as the WISC-V or WJ-IV.
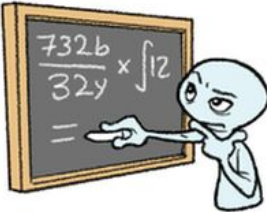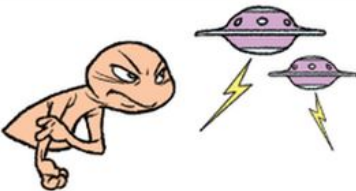
Here is a diagram showing how the broad ability domains of intelligence have been measured by subtests of the WJ-III IQ test (the subtest titles are on the left).
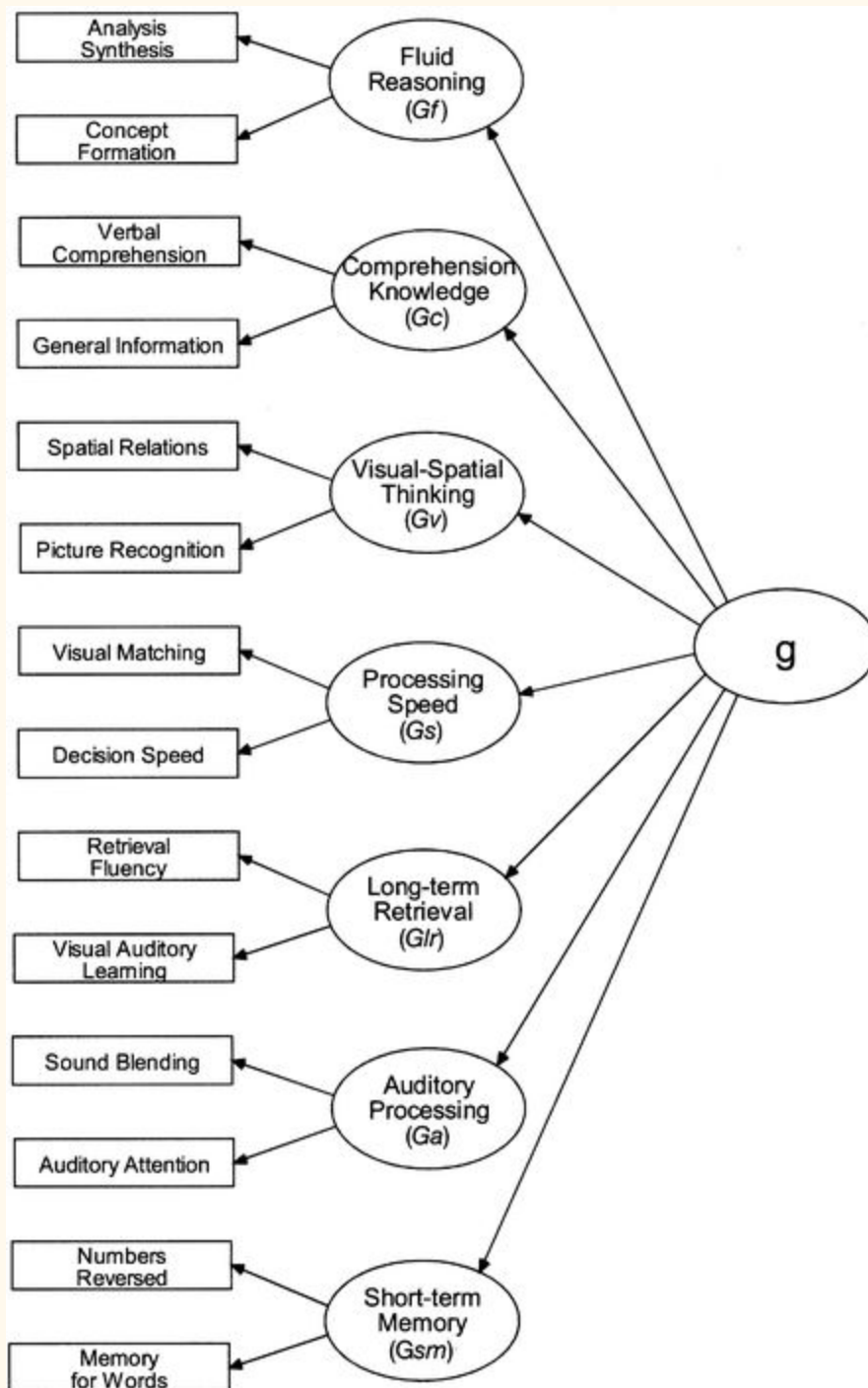
g, broad abilities, and their IQ subtests

So what *are* these broad cognitive abilities underlying our general intelligence?

All 9 are defined in this cartoon, taken from *Ungifted: Intelligence Redefined* by Scott Kaufman. Note that the label 'working memory (*Gwm*)' is now preferred to 'short-term memory' (*Gsm*) (ref).

QUANTITATIVE KNOWLEDGE (GQ): DEPTH AND BREADTH OF KNOWLEDGE RELATED TO MATHEMATICS.

READING + WRITING (GRW): DEPTH AND BREADTH OF KNOWLEDGE AND SKILLS RELATED TO WRITTEN LANGUAGE.

COMPREHENSION - KNOWLEDGE (GC): DEPTH AND BREADTH OF KNOWLEDGE AND SKILLS THAT ARE VALUED BY ONE'S CULTURE.

FLUID REASONING (GF): THE DELIBERATE BUT FLEXIBLE CONTROL OF ATTENTION TO SOLVE NOVEL "ON THE SPOT" PROBLEMS THAT CANNOT BE PERFORMED BY RELYING EXCLUSIVELY ON PREVIOUSLY LEARNED HABITS, SCHEMAS, AND SCRIPTS.

SHORT-TERM MEMORY (GSM): THE ABILITY TO ENCODE, MAINTAIN, AND MANIPULATE INFORMATION IN ONE'S IMMEDIATE AWARENESS.

LONG-TERM STORAGE + RETRIEVAL (GLR): THE ABILITY TO STORE, CONSOLIDATE, AND RETRIEVE INFORMATION OVER PERIODS OF TIME MEASURED IN MINUTES, HOURS, DAYS, AND YEARS.

VISUAL PROCESSING (GV): THE ABILITY TO MAKE USE OF SIMULATED MENTAL IMAGERY (OFTEN IN CONJUNCTION WITH CURRENTLY PERCEIVED IMAGES) TO SOLVE PROBLEMS.

AUDITORY PROCESSING (GA): THE ABILITY TO DETECT AND PROCESS MEANINGFUL NONVERBAL INFORMATION IN SOUND.

PROCESSING SPEED (GS): THE ABILITY TO PERFORM SIMPLE REPETITIVE COGNITIVE TASKS QUICKLY AND FLUENTLY.

Broad Abilities Assessed in IQ Tests

Typically **5-7** of the broad abilities are measured by **sub-tests** in full-scale IQ tests such as the WJ-IV. For instance, the Spatial Relations and Picture Recognition subtests of the WJ-IV are measures of Visuospatial Processing (*Gv*) while the Concept Formation and Analysis-Synthesis subtests are measures of Fluid Reasoning (*Gf*).

The broad abilities of the CHC model often measured by subtests of full scale IQ tests are the following:

Comprehension Knowledge (*Gc*)

Also called 'Crystallized Intelligence'. This is knowledge and skills gained through experience, education and training. It depends on what we learn from our surrounding culture, and may be tested by vocabulary or general knowledge IQ subtests. Crystallized intelligence tends to remain constant over the lifespan and can even increase by acquiring more knowledge and skills.

> **Vocabulary-The examinee is asked to orally define words covering a wide range of difficulty. The test is designed to measure knowledge of words, which correlates with general mental ability.**
> 1. What does *retain* mean?
> 2. What does *robust* mean?
> 3. What does *sojourn* mean?
> 4. What does *harass* mean?
> 5. What does *desultory* mean?
> 6. What does *inclement* mean?

Gc IQ subtest questions

Fluid Reasoning (*Gf*)

Also called fluid intelligence, this is our on-the-spot reasoning and problem solving ability, not dependent on background knowledge, education or any specific expertise. It enables us to see relationships and learn quickly in new situations.

Fluid reasoning overlaps with other broad abilities in this way (ref):
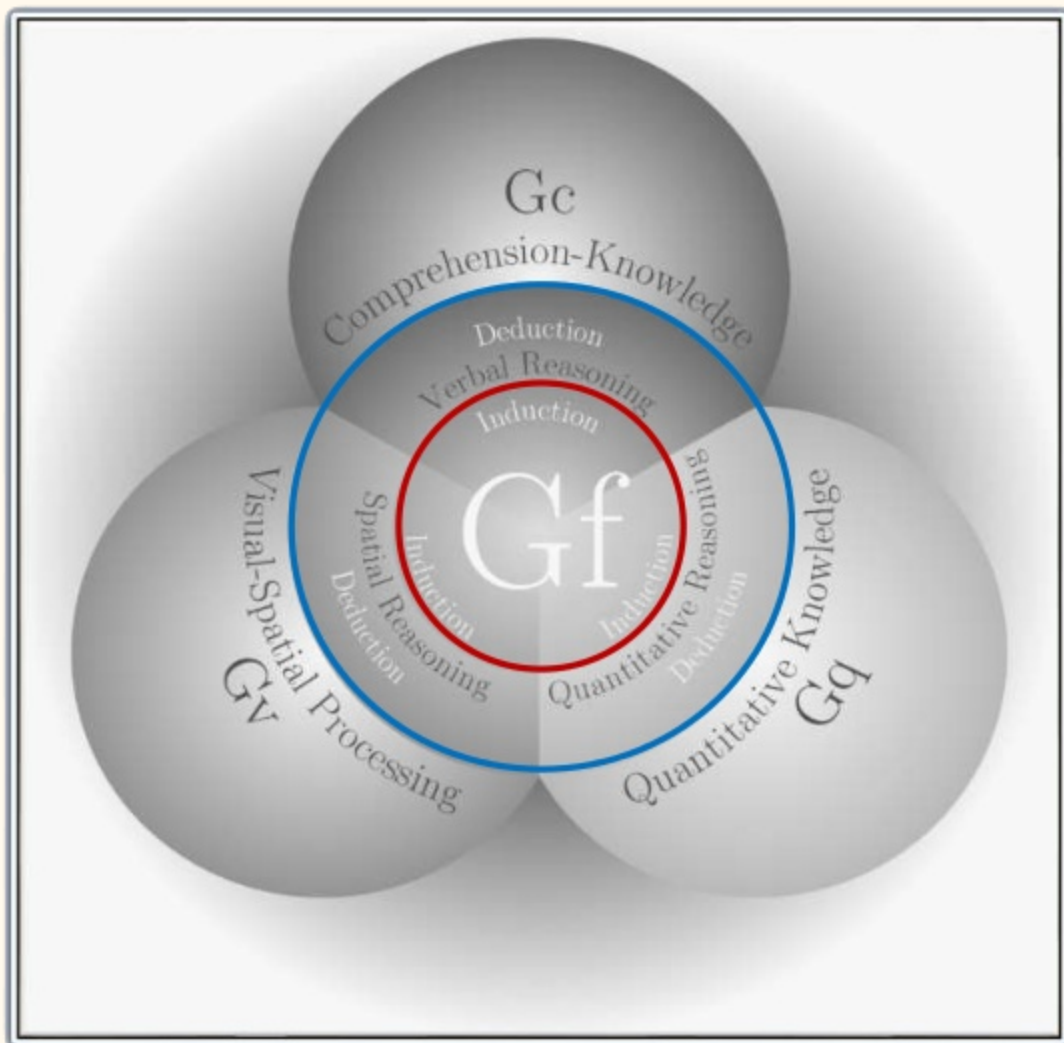
Inductive (e.g. matrices) and deductive reasoning (logic) tests give us measures of *Gf* in IQ. Concept formation and analogical reasoning tests can also be used as measures of *Gf*.

Similarities-Presents two words that represent common objects or concepts. The examinee is asked to state how the objects or concepts are similar. The task is designed to measure logical or abstract thinking and the ability to categorize and generalize.
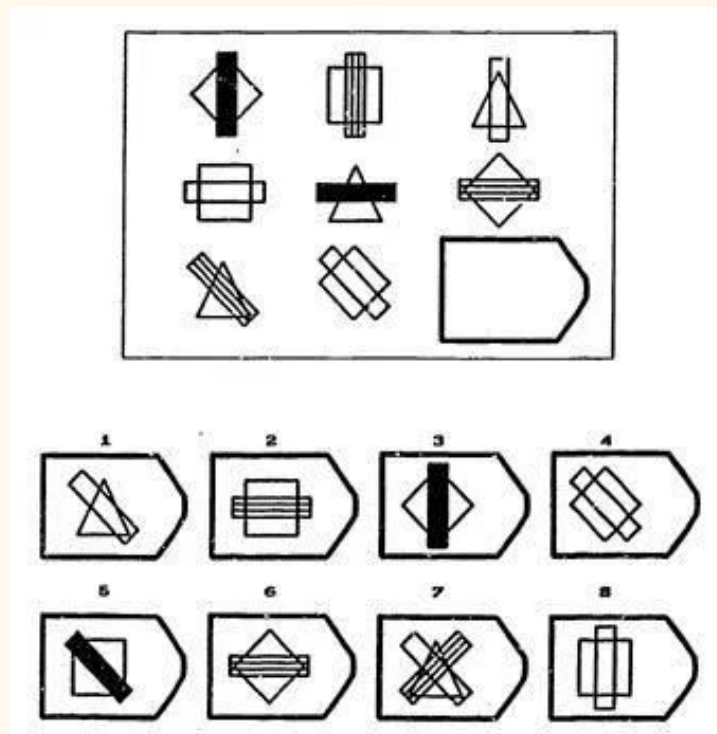
In what way are a lion and a tiger alike?

In what way are a saw and a hammer alike?

In what way are an hour and a week alike?

In what way are a circle and a triangle alike?

Gf IQ subtest questions

Gf IQ subtest question

Visuospatial processing (*Gv*)

Visual processing or visual-spatial intelligence (*Gv*) involves the ability to visualize, remember and manipulate images or shapes in the 'mind's eye'. This kind of intelligence is measured by tasks where you need to mentally simulate how complex patterns might look when transformed (visualisation) or remembering complex patterns over short periods of time (visual memory).
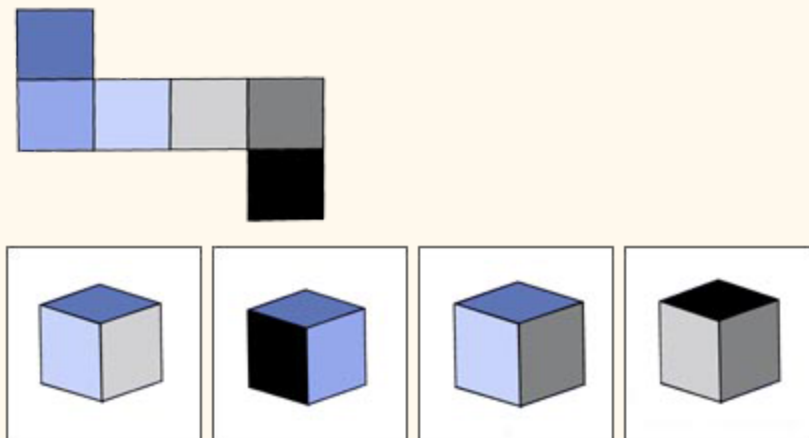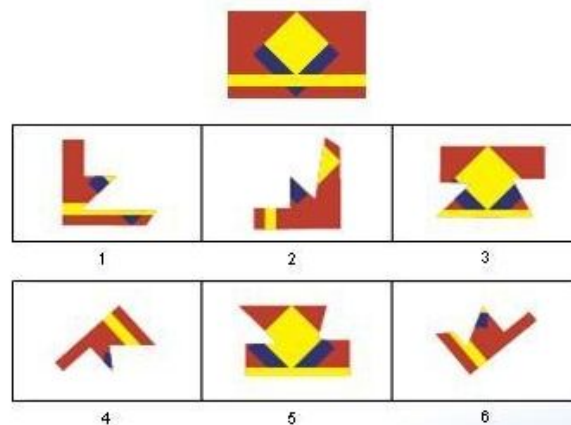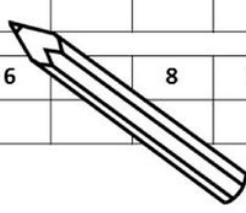

Gv IQ subtest questions

Processing speed (*Gs*)

Processing speed (Gs) is attention-focused speediness – your ability to automatically and fluently perform basic cognitive tasks (such as scanning or key pressing) that do not require much thinking - but still require concentration. This is measured by IQ sub-tests such as digit symbol matching (see below).

Gv IQ subtest question

Working Memory (Gwm)

Also referred to in the CHC theory as Short Term Memory (*Gsm*). This is a **'mental workspace'** memory system that holds in current awareness information needed to problem solve, comprehend, reason, make decisions and so on. Unlike the unbounded long term memory, this is a **limited capacity** system that loses information quickly if it is not maintained in goal-directed cognition. It is measured by subtests such as memory span - both forwards and reversed.

designed to measure attention span and working memory, which holds information in storage temporarily.

Digits forward	Correct response
3-9	3-9
4-2-6	4-2-6
7-1-8-7	7-1-8-7
5-8-2-3-9	5-8-2-3-9
Digits backward	Correct response
4-7	7-4
3-9-1	1-9-3
2-1-4-6	6-4-1-2
8-5-6-3-1	1-3-6-5-8

Gwm IQ subtest question

Quantitative Knowledge (*Gq*)

Quantitative knowledge (*Gq*) is mostly built up during formal educational experiences. Gq is a person's store of acquired mathematical knowledge and well practiced techniques for solving mathematical and quantitative problems. An example subtest for *Gq* is Figure-Weights.
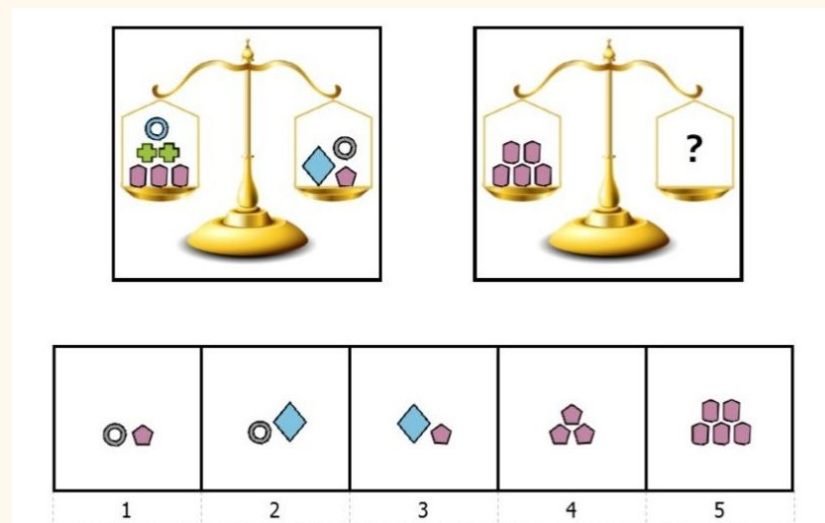

Gq IQ subtest question

The Cognitive Performance Model

The Cognitive Performance Model (CPM) was developed by Richard Woodcock, one of the developers of the Woodcock Johnson test (e.g. WJ-IV) ([ref](#)).

According to CPM, the broad abilities of intelligence are organized into three information processing systems: (1) stores of **Acquired Knowledge**, (2) **Thinking Abilities**, and (3) **Cognitive Efficiency** ([ref](#)).
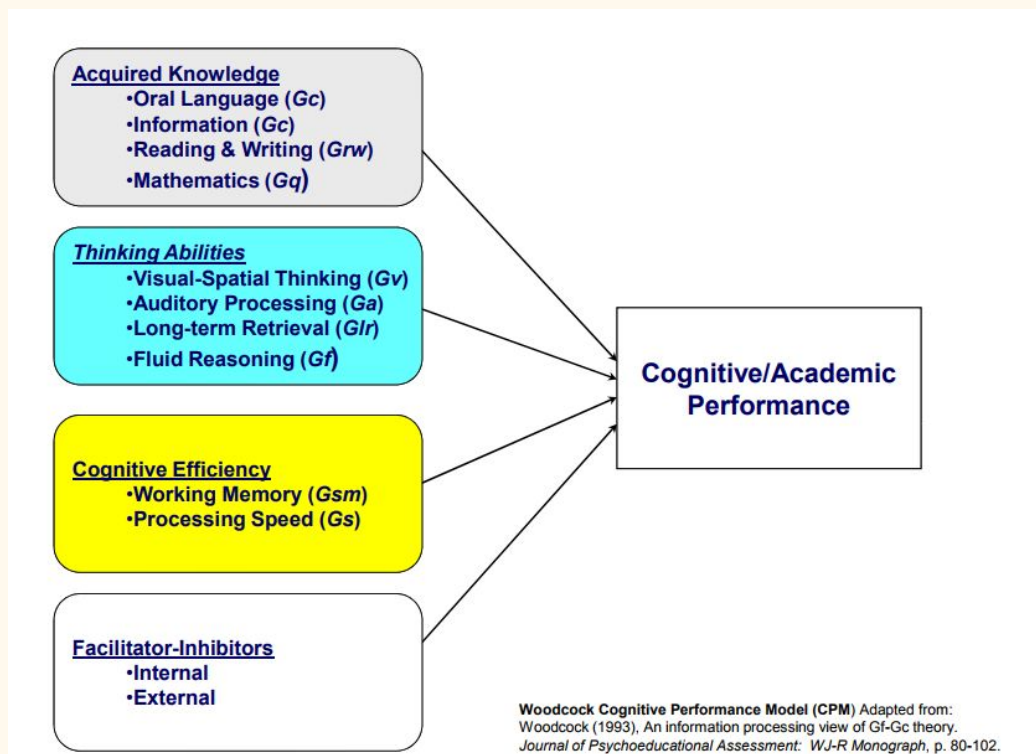
The Cognitive Performance Model

Acquired Knowledge

This includes general knowledge, spoken language ability, math skills, reading and writing skills. The quality of learning and performance is dependent on the relevant knowledge a person has. Knowledge is like scaffolding. Once information is learned, it can become a basis for new learning; missing information or knowledge can obviously

impede future learning. Instruction strategies and opportunities for enrichment can affect a person's level of performance in this system.

All performance, automatic or new learning, is constrained by the store of knowledge that is available.

Thinking Abilities

The thinking ability includes the ability to abstract ideas, to solve new problems, to process visual and auditory stimuli and to learn and to retrieve information from long term memory.

Cognitive Efficiency

The cognitive efficiency system includes the capacity of working memory - our mental workspace - as well as processing speed - the ability to perform a task quickly and with attentional focus. Automatic performance of the sort that is shown by experts is constrained by short-term memory and processing speed.
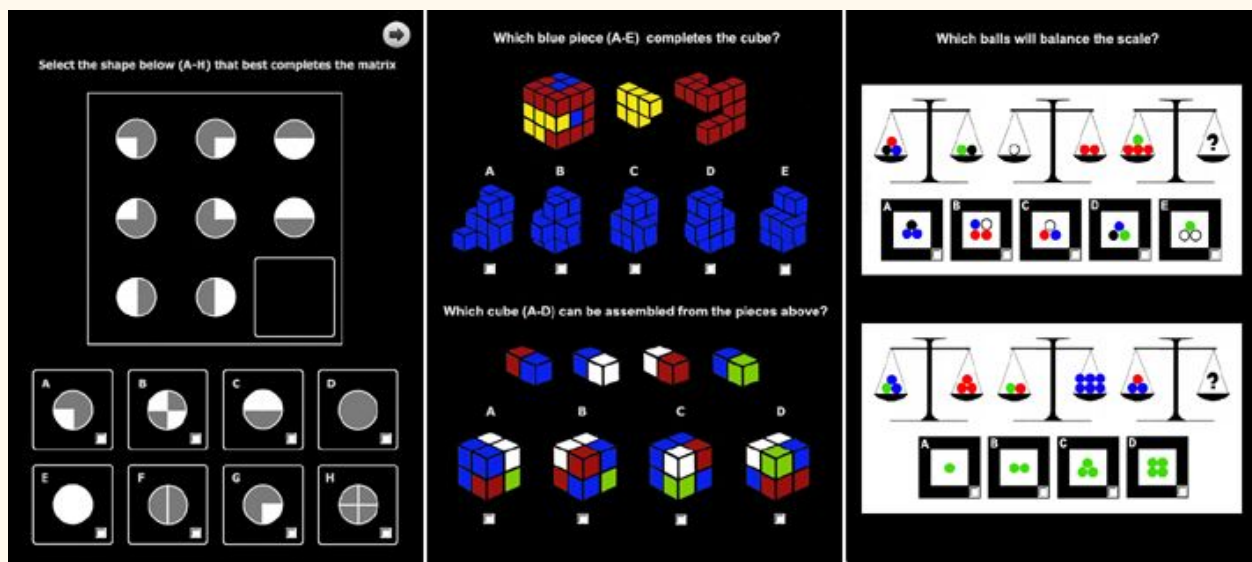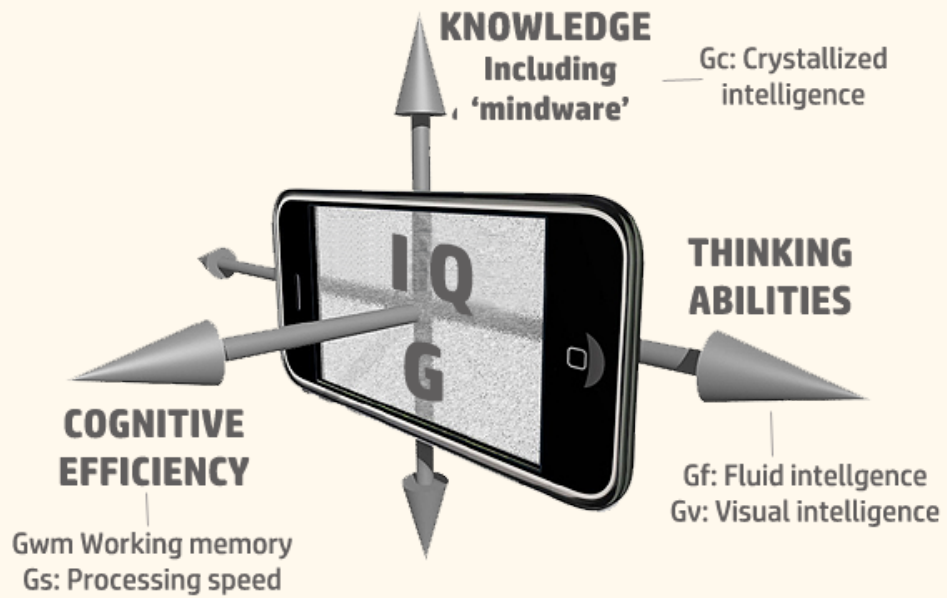
Cognitive performance is a result of the combined action of the three systems and facilitating/inhibiting factors.

Facilitators-Inhibitors

Internal- e.g. health, emotional state, personality & motivation. For instance, low motivation for learning or low interest in the contents learned may affect the extent of effort a person makes.

External - e.g. external distractions, culture and instruction methods, features of the tests taken.

This cognitive performance model is used in the design of the [i3 Mindware app](#).

KNOWLEDGE
Including 'mindware'
Gc: Crystallized intelligence

IQ
G

THINKING ABILITIES

COGNITIVE EFFICIENCY

Gf: Fluid intellgence
Gv: Visual intelligence

Gwm Working memory
Gs: Processing speed

Example IQ subtest problems for Gf, Gv and Gq in the **i3 Mindware** app

Working Memory, Attention Control & Intelligence

i3 Mindware - and other evidence-based brain training apps that augment IQ - is designed to train working memory (WM) and attention control.

> *Working memory involves the short-term maintenance of information in the absence of sensory input.*

According to research (ref1, ref2), WM maintenance in our 'mental workspace' depends on an **executive attention control** process that activate contents from **long-term memory** (LTM). The source of this attention-control is called a 'Central Executive' because it exerts top-down control of **goal-directed** cognition and behavior. The information selected in WM from LTM is used to reason, solve a problem, comprehend something and so on.
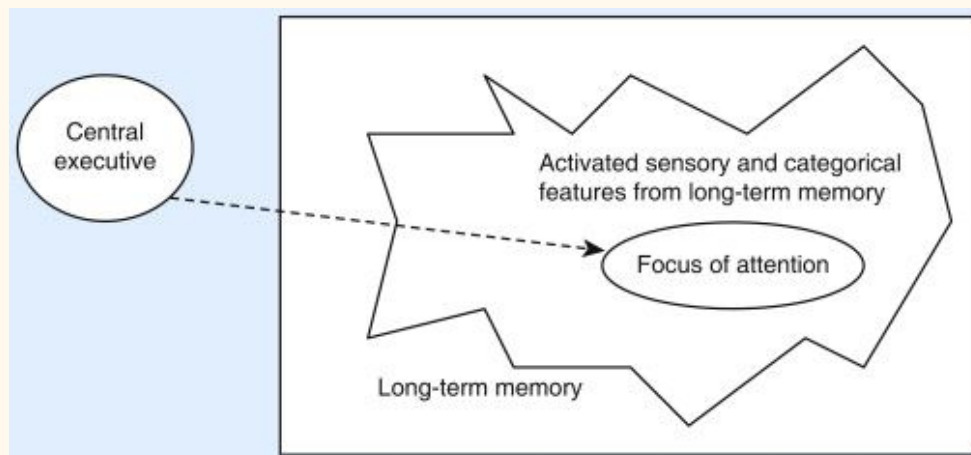

Cowan's model of working memory (1988) (ref)

Attention control involves different **executive processes** : shifting attention, sustaining attention, inhibiting distractions, updating the contents of attention and making decisions or selecting responses. These executive processes are built into the working-memory system (*Gwm*).

Thus *Gwm* is an **attention control system** sometimes called the *working memory-attention complex* (ref1, ref2). *Gwm* can be defined as:

the ability to maintain and manipulate information in active attention.
Kevin McGrew

For an example of how this works, let's look at reading comprehension. The brain's circuitry for visual perception processes the visual words and sentences. Information in activated working memory (the attention focus zone) can then be connected with prior knowledge from long-term memory for reading comprehension.
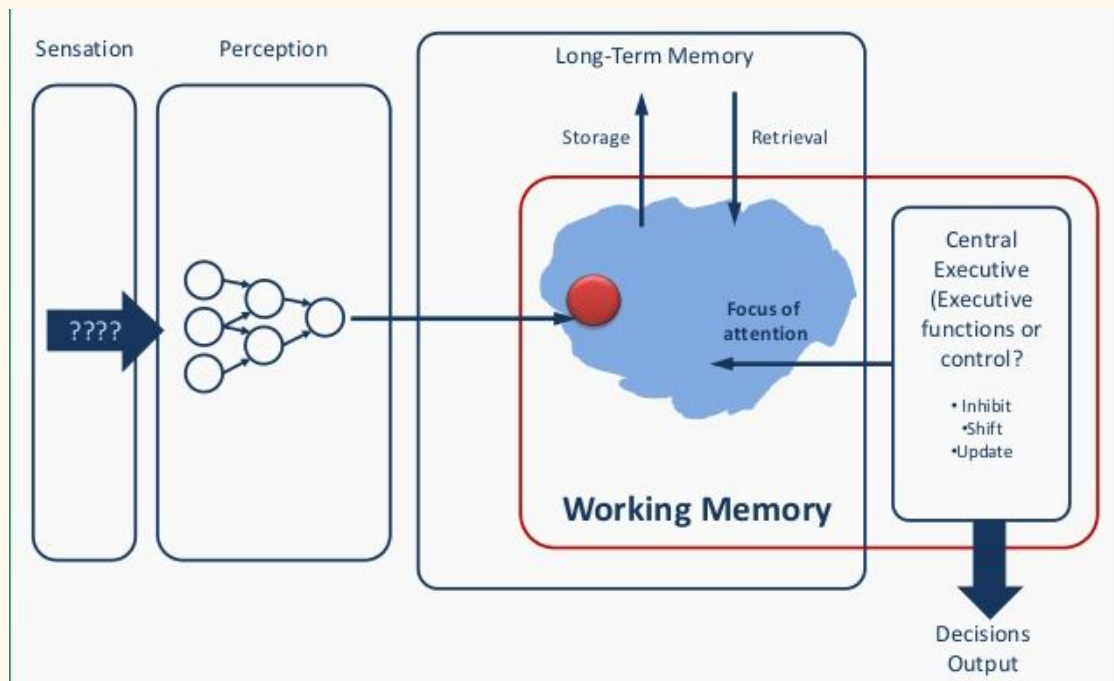

Attention Control System: Adapted from Schneider & McGrew, 2012/2013

The amount of information that can be selected by active attention and maintained in working memory is called **working memory capacity**. WM capacity differs from individual to individual, and those with greater capacity tend to have a higher general intelligence (*g*). In the example above, a person with greater WM capacity can maintain more complex language information in active attention in their mental workspace, and thus activate more material from Long Term Memory and make more relevant associations within WM.

Attention Control System Theory of Intelligence

Tying all the threads together, Schneider and McGrew propose an **Attention Control System theory of intelligence** that tells us how the broad abilities of CHC theory may be structured. Working memory and attention control act as a hub and - because they are limited in capacity like a computer RAM and processing speed - are a 'bottleneck' in cognitive and motor performance. The greater our WM efficiency and capacity, the less restricting the bottleneck, and the more capacity we have for intelligent information processing and performance.

The Attention Control System theory of intelligence is shown below with the broad ability factors of intelligence (*Gv, Ga, Gwm, Gf, Glr, Gc, Grw, Gs*) all labelled.

Schneider & McGrew's Attention Control System Theory of Intelligence (2012/2013) (ref)
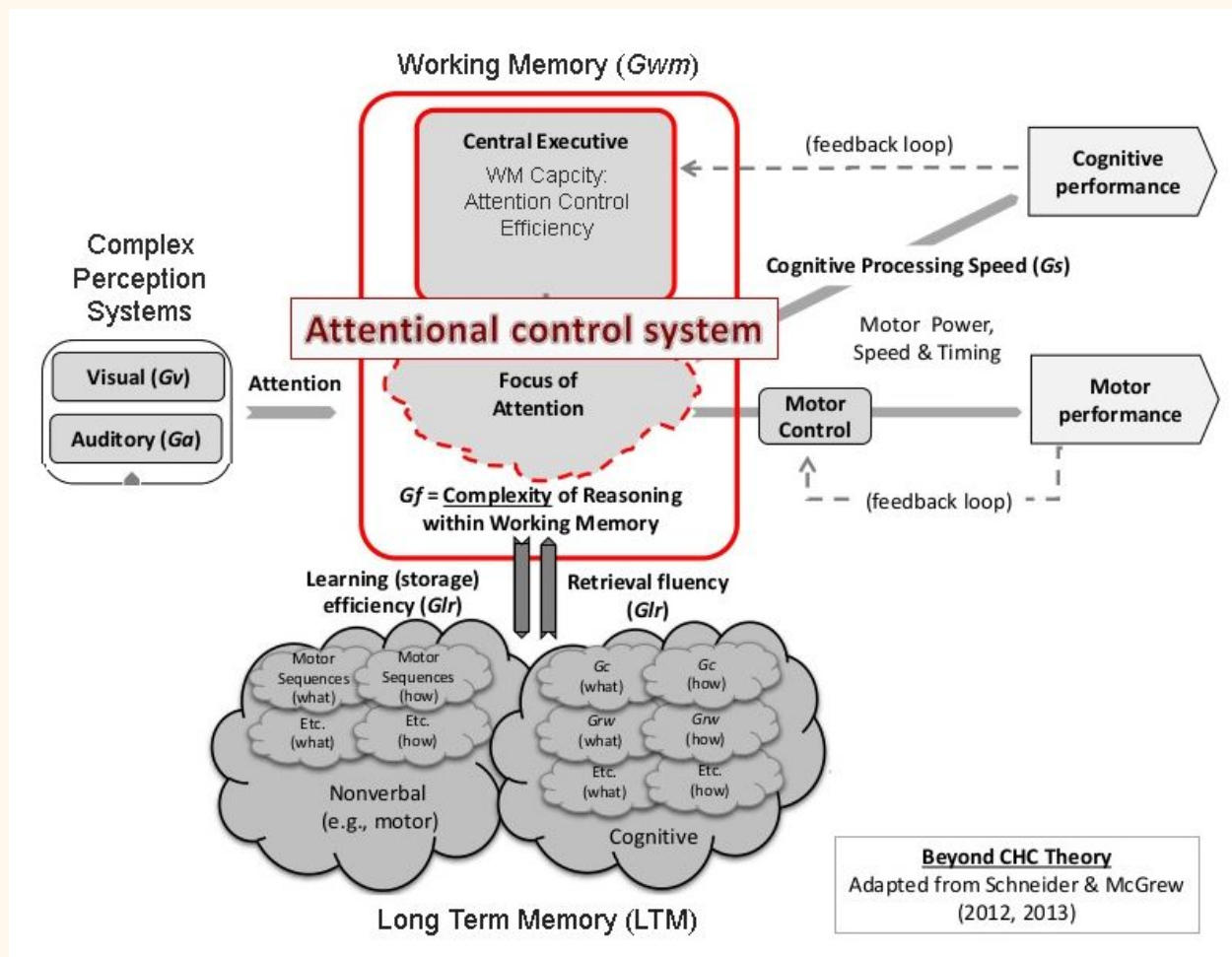
According to this theory, **fluid intelligence** (*Gf*) is the *complexity of reasoning and problem solving within working memory*. *Gf* is thus closely bound to the efficiency of attention-based executive processes such as focus and inhibition of distractors. *Gf* a system for flexible problem solving and adaptation to new task-demands - particularly in the face of interference ([ref](#)). It should thus not be just thought of as just abstract reasoning ability.

BRAIN BASIS OF INTELLIGENCE

1: The Parietal-Frontal Integration Theory of Intelligence (P-FIT)

Different brain regions interact when we use our working memory including 'executive' regions in the **prefrontal cortex** and **parietal cortex** (shown in blue) as well as regions specialized for long term memory representations (shown in green).
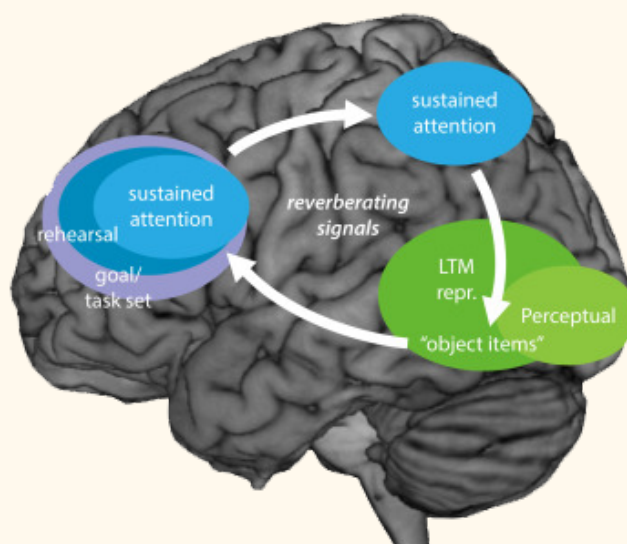
From Eriksson et al, 2015 ([ref](#))

Doing tasks involving controlled attention, working memory, executive processes, and fluid reasoning (*Gf*) have been consistently linked in in the research to electrical signalling activity in the **prefrontal** and **parietal** lobes of the brain. These findings have resulted in the influential **Parieto-Frontal Integration Theory of intelligence (P-FIT)** ([ref](#)).

According to P-FIT, information processing within a **fronto-parietal network** during IQ demanding tasks is directly related to individual differences in intelligence. Differences in the functioning of this 'intelligence' (*g*) network underlie differences in IQ test scores.

The P-FIT theory of intelligence can be understood as the *biological basis of the Attention Control Network Theory of intelligence* that put working memory and attention control at the center: they are consistent with each other, and mutually support each other in terms of the evidence - both psychometric and biological.
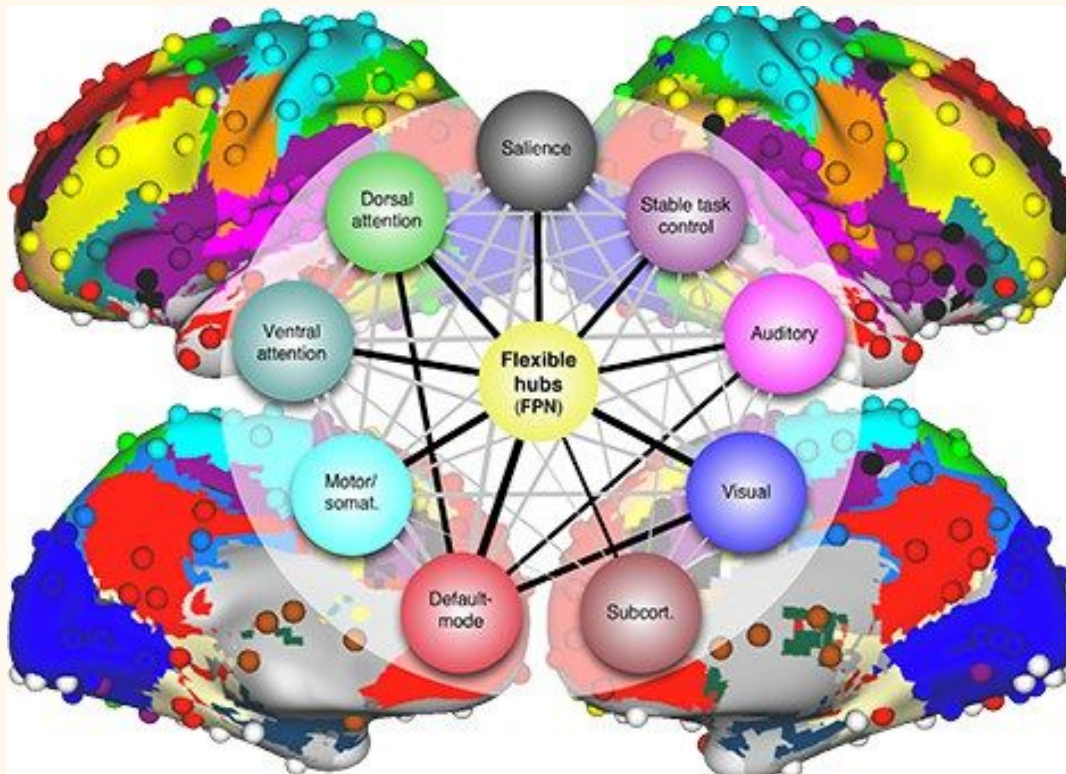
2: The Fronto-Parietal Network Hub

The P-FIT theory is based on looking at brain activity when doing IQ-demanding tasks such as doing math reasoning. The parieto-frontal network is the group of brain regions that co-activate during these IQ-demanding tasks

But there is another neuroimaging research tradition ([ref 1](#), [ref 2](#)) that looks at spontaneous brain activity of brain regions **at rest** - when not doing any tasks. This approach has revealed a number of 'resting state' functional networks in the brain - color coded in the figure below.

Functional Power et al., 2011
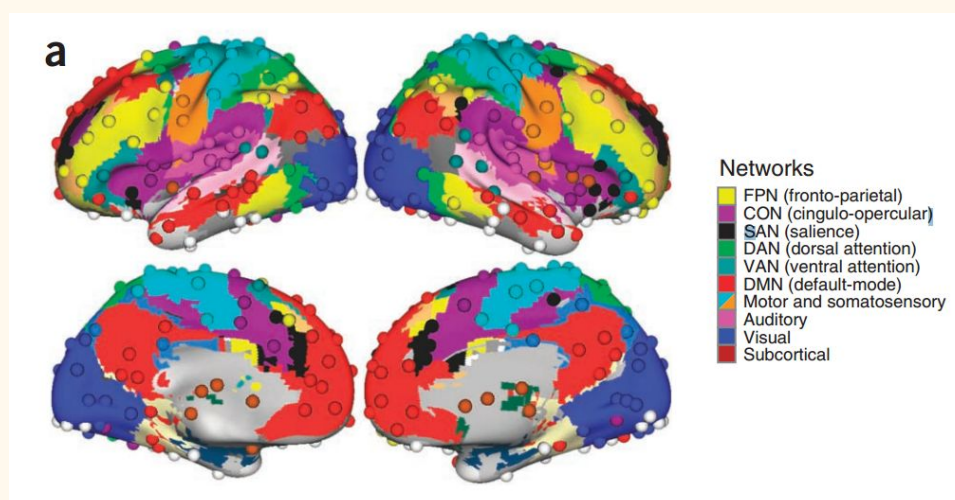
One of these networks called the Fronto-Parietal Network (FPN) (shown in yellow above) is connected to other networks like a hub in a wheel.

The Fronto-Parietal Network (PFN) Hub ([Ref](Ref))

This enables it to have top down **executive control**, flexibly shunting information flow across the other large-scale functional networks depending on the current task demands ([ref](ref)). In this way it allows for quick, intelligent adaptation to new task demands, overcoming automatic rigid habits. This is precisely the job of fluid intelligence (*Gf*), and the FPN network can be seen as another view on the P-FIT theory of intelligence discussed above.

i3 Brain Training: P-FIT & FPN

Working memory brain training implemented in i3 Mindware is known from multiple studies (ref 1, ref 2, ref 3) to result in neuroplasticity change in the the Fronto-Parietal Network (FPN). Some of this evidence is listed below. For a full review follow this link.

1. Brain training affects activity in the executive control FPN. Functional connectivity within this network increases following training, and the magnitude of increased connectivity is tied to improvements in task performance (ref).

Journal article link

2. With working memory training there is increased grey matter volume in the FPN ([ref](ref)).

3. Working memory training results in neuroplasticity change in dopamine receptors in the FPN. The neurotransmitter dopamine is very important for working memory and working memory performance is affected by dopamine in the prefrontal cortex, with dopamine release observed during the performance of working memory tasks ([ref1](ref1), [ref2](ref2)).

4. Working memory training results in increased 'small-world' network efficiency within the FPN ([ref](ref)).

Pre-training vs post WM-training FPN network efficiency ([ref](ref))

Summary

In this eBook we've taken a tour of three **psychometric** theories of general intelligence (*g*) and broad cognitive abilities as measured by IQ test scores: the CHC, Cognitive Performance and Attention Control System theories. We've also seen how this psychometric work ties in with the **cognitive neuroscience** research that has reveals an executive control Fronto-Parietal Network (FPN) subserving general intelligence that is formalized in the.influential Parietal-Frontal Integration Theory (P-FIT) of intelligence.

The evidence-based [i3 Mindware app](#) has been built on this scientific body of work specifically.