The Evolution of the Cattell-Horn-Carroll (CHC) Theory of Intelligence

This presentation is based on Schneider, W. J., & McGrew, K. S. (in press). The Cattell-Horn-Carroll Theory of Cognitive Abilities. In D. P. Flanagan & Erin M .McDonough (Eds.), *Contemporary intellectual assessment: Theories, tests and issues* (4thed.,) New York: Guilford Press.

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* Conflict of interest disclosure: Financial relationship and interest in IM; Coauthor of WJ III and WJ IV (royalty interest)

Dr. Kevin McGrew, coauthor of the WJ IV, is responsible for the content of this PPT module.

The information, hypotheses, and opinions expressed in this PPT module do not necessarily represent the opinions of the other WJ IV authors or HMH (the publisher of the WJ IV)

We will only cover a portion of the material in Schneider & McGrew (in press) chapter

The Cattell-Horn-Carroll Theory of Cognitive Abilities

(Schneider & McGrew, in press)

Introduction

Beyond CHC: The evolution of the theory and assessment of cognitive abilities

The Continuing Impact of CHC Theory

- CHC is now global
- CHC cross-disciplinary research and applied impact
- Intelligence test battery theoretical framework convergence?
- CHC-based neuropsychological research and assessment

Criteria for Updating CHC Theory

- To overturn the measured opinions of Cattell, Horn, and Carroll requires robust evidence
- Introducing new ability constructs to CHC theory
- Reorganizing CHC Theory

CHC model revisions and extensions

- CHC cross-battery research
- The Glr divorce: Gl and Gr
- Tentative CHC broad sibling: Ge

CHC Theory Described and Revised

General Intelligence (g)

-Gf-Gc Theory

- The Fluid-Crystallized Metaphor
- Evidence for the Distinction between Fluid and Crystallized Intelligence
- Cattell's gf and gc as elaborations of Spearman's
- Cattell's gf-gc vs. Horn's Gf-Gc
- Cattell's Investment Theory

We will only cover a portion of the material in Schneider & McGrew (in press) chapter

Fluid Reasoning

- Definition of Gf
- Narrow Abilities within Fluid Reasoning
- Tentative Narrow Factors
- Assessment Recommendations for Gf
- Comments and Unresolved Issues Related to Gf

Memory: General Considerations

- Working Memory Capacity (Gwm)
- Learning Efficiency (Gl)Retrieval Fluency (Gr)

General Cognitive Speed: Considerations

- ➢ The difference between Gs and Gt
- ➢ What does recent factor analysis tell us about Gs and Gt?
- ➢ A hypothesized hierarchy of speed abilities

- Processing Speed (Gs)
- Reaction and Decision Speed (Gt)
- Psychomotor Speed (Gps)

Acquired Knowledge

- Comprehension-Knowledge (Gc)
- Domain-Specific Knowledge (Gkn)
- Reading and Writing (Grw)
- Quantitative Knowledge (Gq)

Sensory/ and Motor-linked Abilities

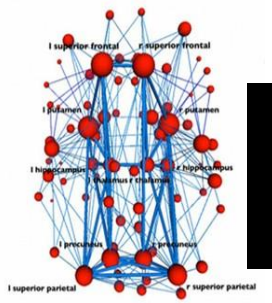
- Visual Processing (Gv)
- Auditory Processing (Ga)
- Olfactory Abilities (Go)
- Tactile Abilities (Gh)
- Kinesthetic Abilities (Gk)
- Psychomotor Abilities (Gp)
- Emotional Intelligence (Gei)

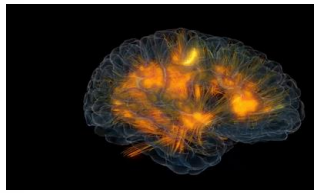
CHC Abilities as Parameters of Information Processing

Each broad domain has similar subheadings (not included on this slide)

Intelligence Testing Related Research: Levels of theoretical reductionism and explanation

(Adapted from conceptual distinctions of Earl Hunt, 2011)





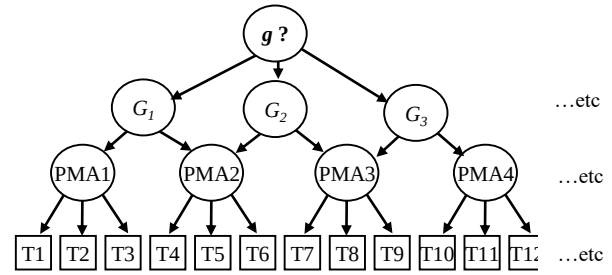
White matter tract organization, integrity & efficiency

Measurable cognitive behaviors (psychometric models)

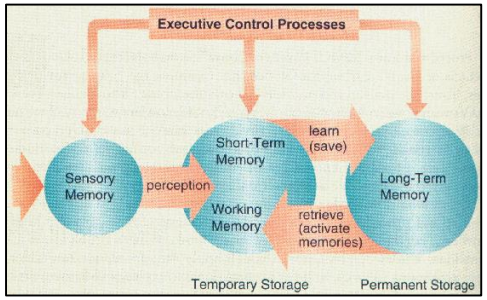
Information processing (mechanical models)

Brain function & networks (biological & neurocognitive models)

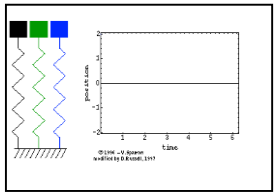
Neural efficiency (biological & neurocognitive models)



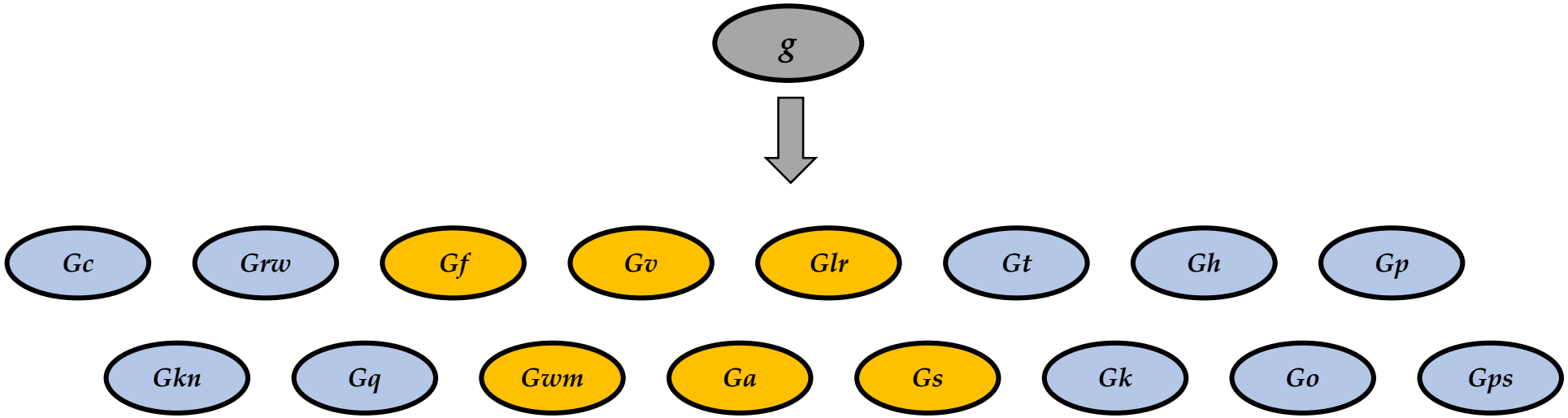
(Consensus Cattell-Horn-Carroll Hierarchical Three-Stratum Model)

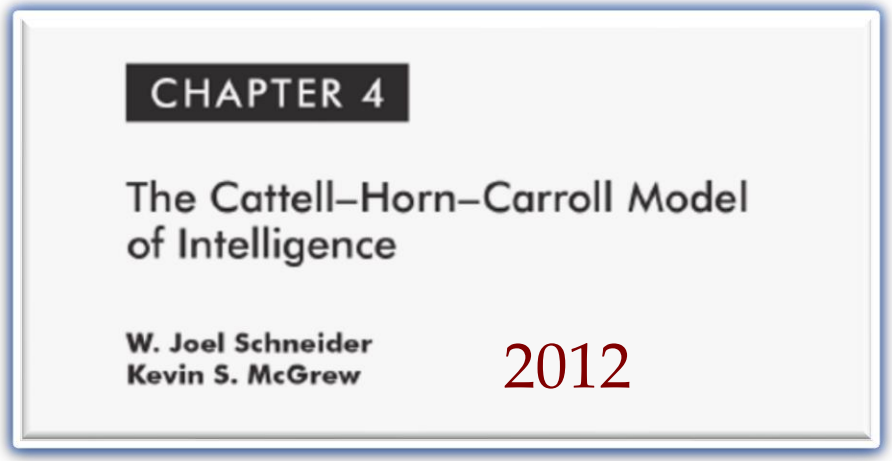


-Human Connectome
-Functional brain networks (Bressler & Menon, 2010)
-"Rich club" network hubs
- P-FIT model

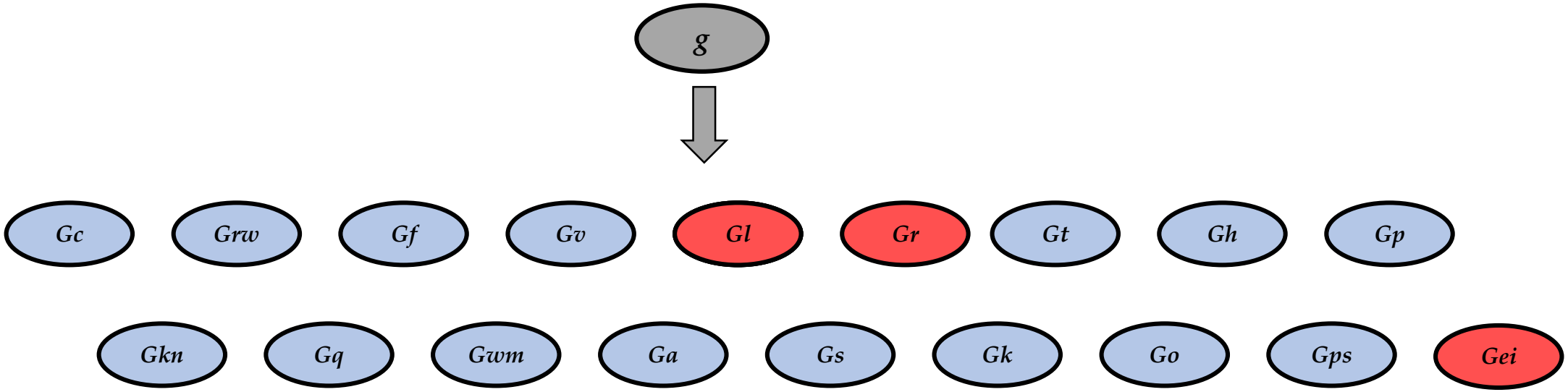


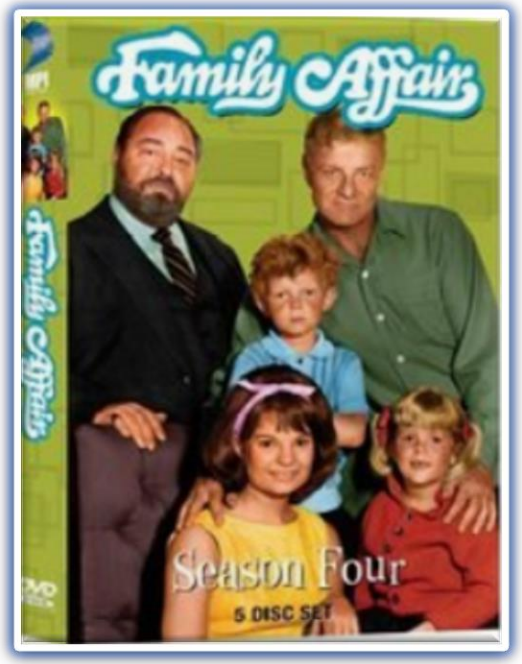
-rate of neural oscillations
-neural synchronization
-Reaction-time and temporal *g*
-ERP's (e.g., ABR)



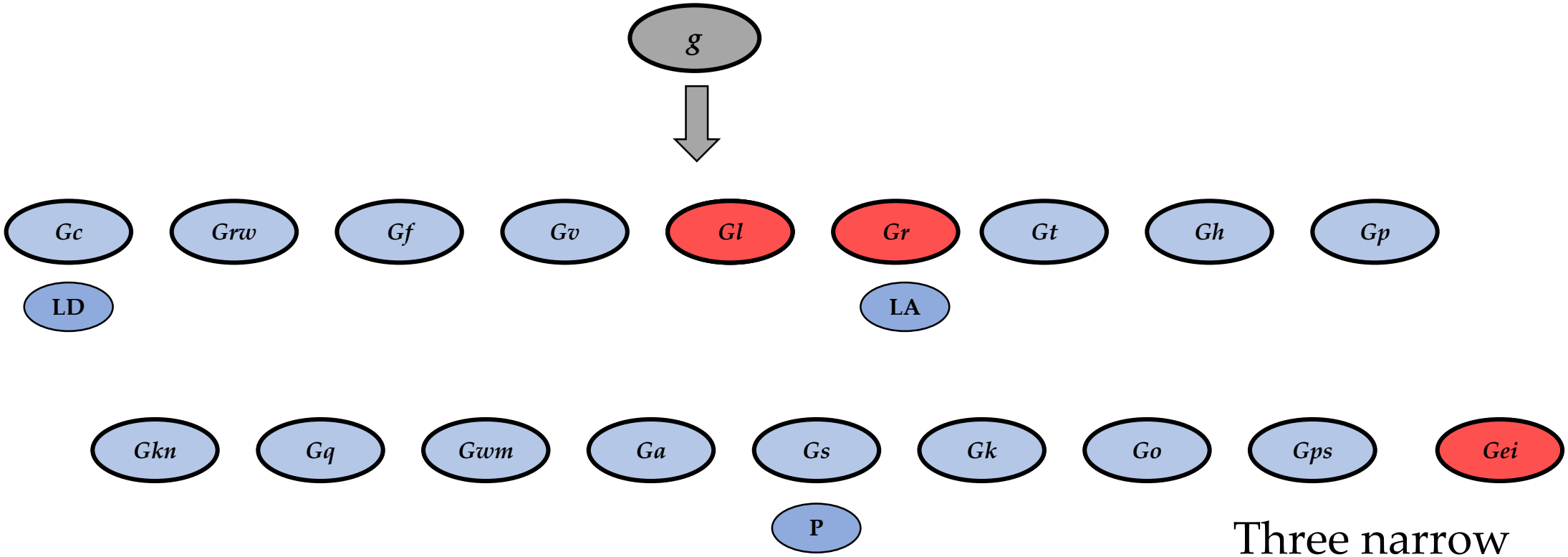


Today's update will focus primarily on six broad domains





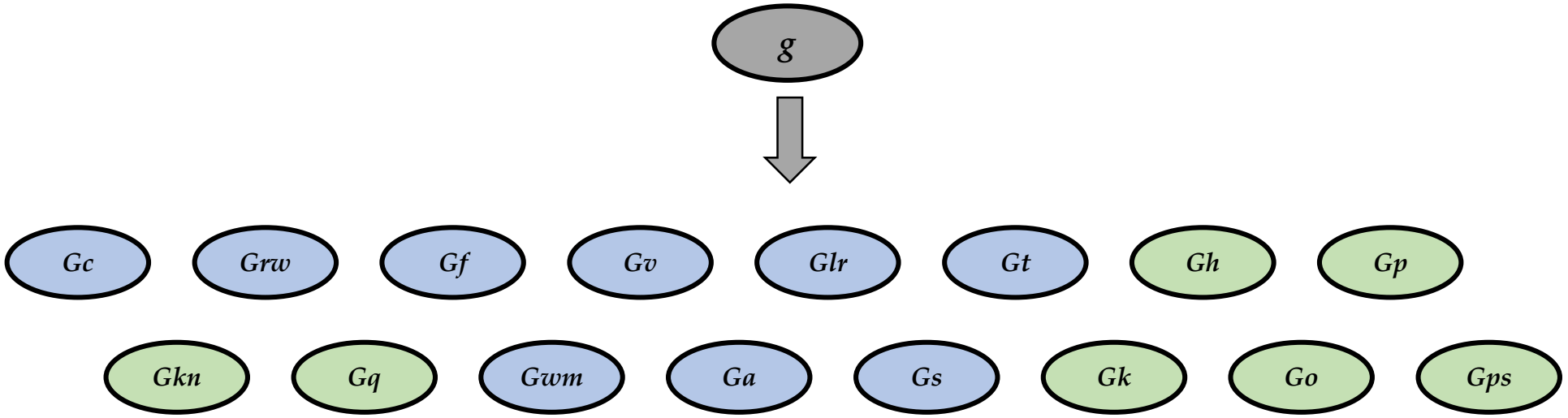
Three narrow abilities are promoted to intermediate stratum level abilities



- **Language Development (LD):** An intermediate stratum level ability to comprehend and communicate using language. The general understanding of spoken language at the level of words, idioms, and sentences.
- **Perceptual speed (P):** An intermediate stratum level ability that can be defined as the speed and fluency with which similarities or differences in visual stimuli (e.g., letters, numbers, patterns, etc.) can be searched and compared in an extended visual field.
- **Speed of lexical access (LA):** The intermediate stratum level ability defined as the ability rapidly retrieve words from an individual's lexicon. Verbal efficiency or automaticity of lexical access.

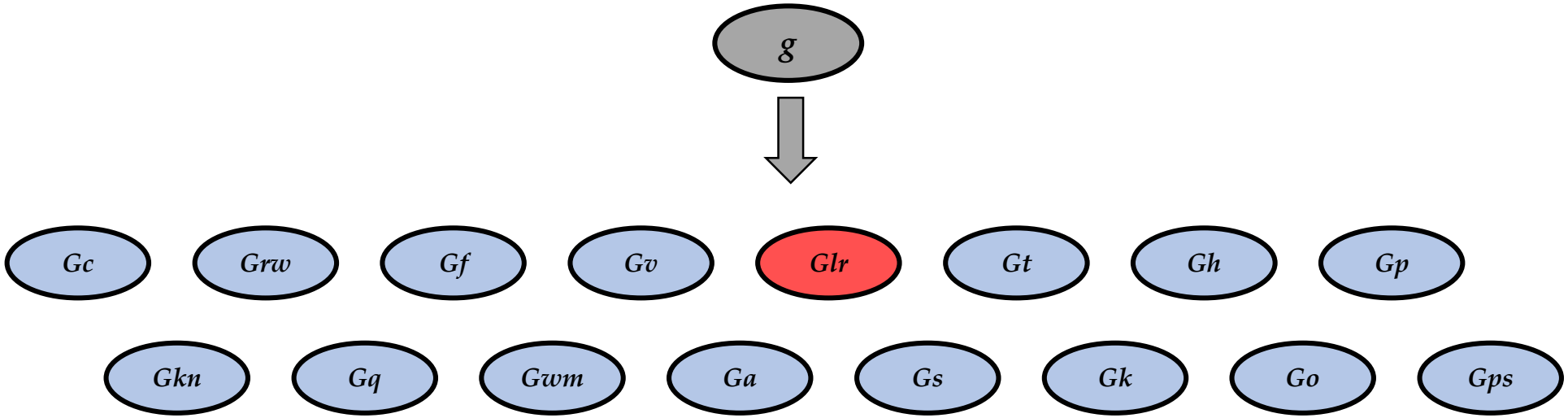
Three narrow abilities are promoted to intermediate stratum level abilities

CHC theory circa 2017/2018 (Schneider & McGrew)



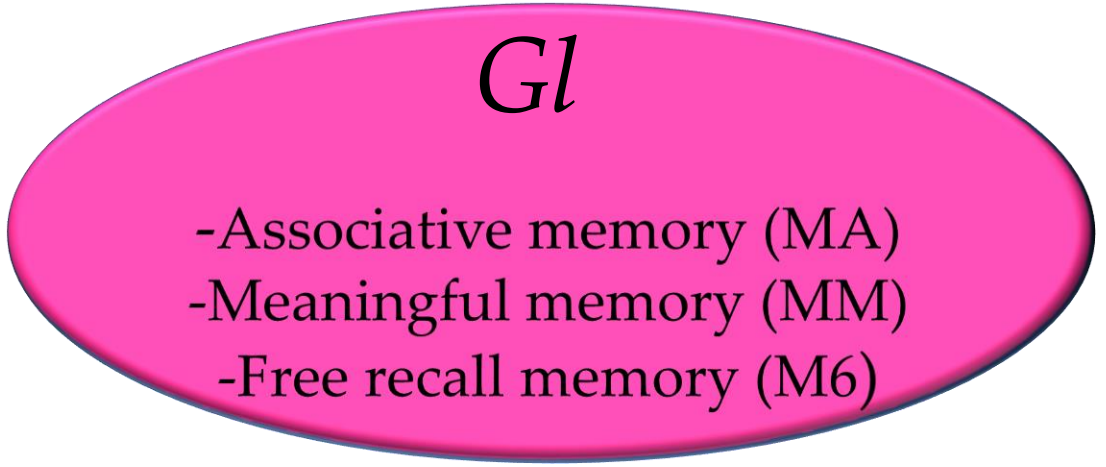
Reminder. A significant number of CHC broad ability domains were "bycatch" abilities in Carroll's (11993) seminal analysis. The factor structure of these domains have not been thoroughly mapped. They likely contain more narrow abilities than are currently listed in the CHC model.

Bycatch is a term from the fishing industry where untargeted fish or marine life are caught in fishing nets. The term also refers to untargeted material gathered in other forms of animal harvesting or collecting.



Learning efficiency (*Gl*):

The ability the ability to learn, store, and consolidate new information over periods of time measured in minutes, hours, days, and years.



— Learning efficiency is primarily based upon individual performance during learning when accounting for the incremental costs associated with the learning process…Incremental costs mean factors such as time taken, effort invested, or error rates incurred.

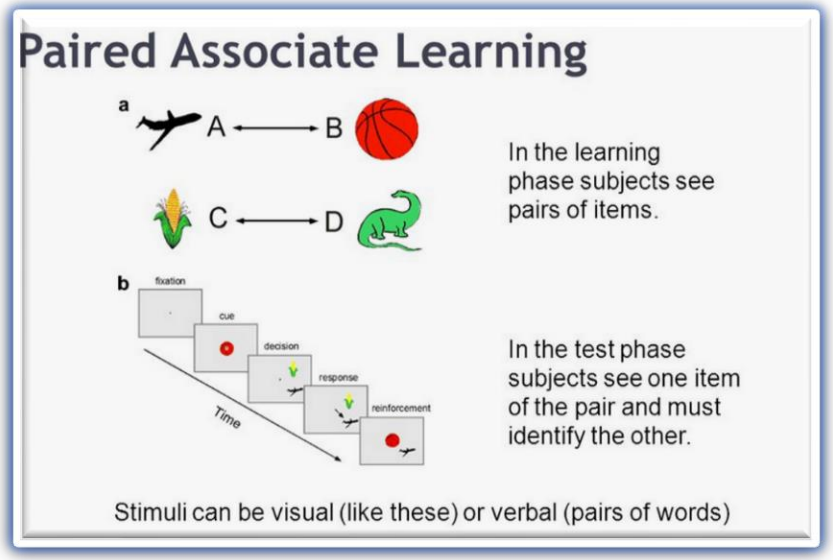
For example, to learn and retain a certain amount of information (e.g., a 16-word list), some individuals would need to exert more effort than others. To achieve the same outcome, they would need more learning inputs (e.g., more learning trials or more time to study).

[Not efficiency as conveyed by the Gs + Gwm mental efficiency notion present in certain intelligence composite scores (WJ III WJ IV Cognitive Efficiency cluster; Wechsler batteries Cognitive Proficiency Index).]

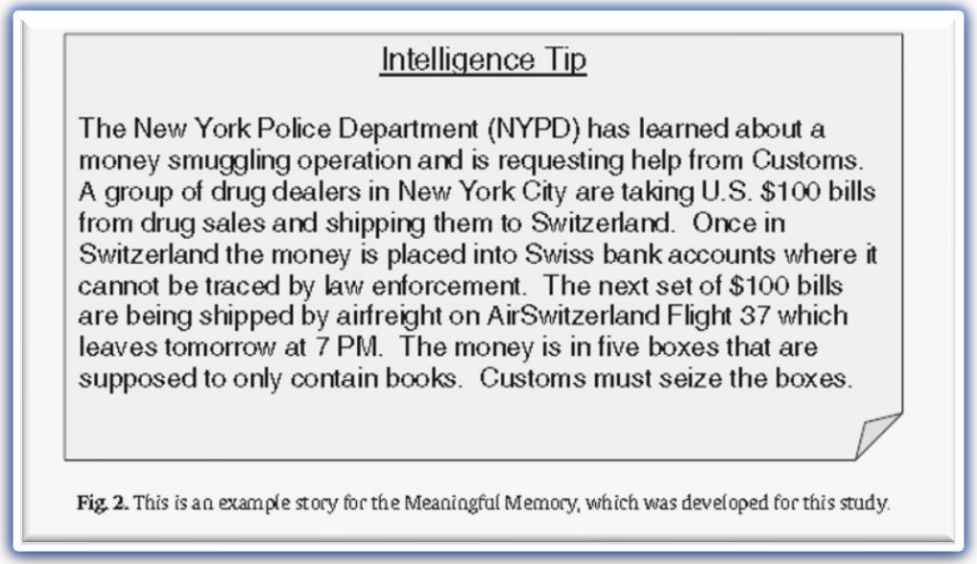
Gl

-Associative memory (MA)
-Meaningful memory (MM)
-Free recall memory (M6)

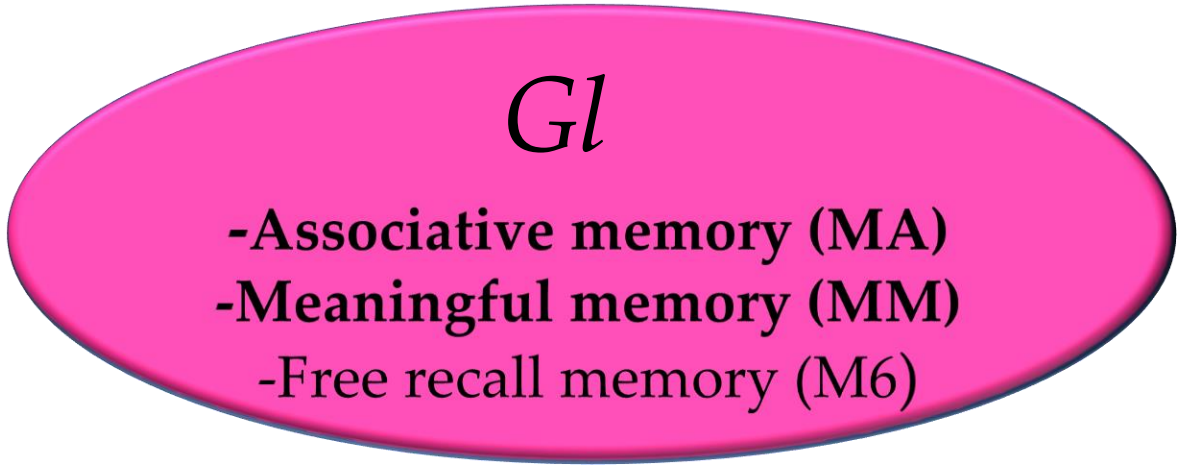
We recommend measuring *Gl* with a structured learning task (e.g., associative memory-MA) and a measure of meaningful memory (MM)



MA types of tasks



MM types of tasks



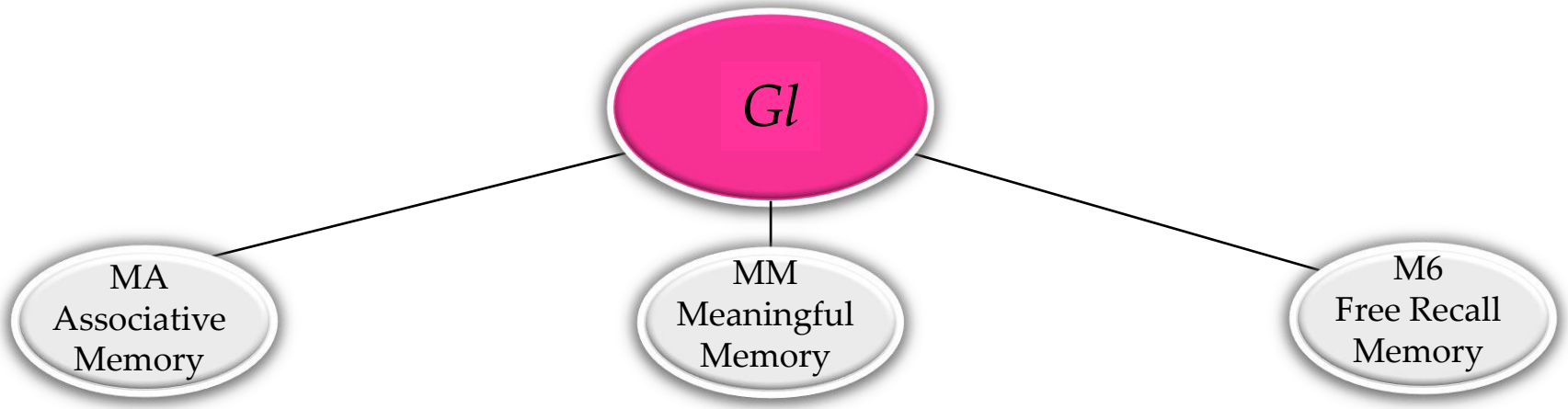
Differences in performance between tests of associative memory (e.g., WJ IV Visual-Auditory Learning test, VAL) and meaningful memory (e.g., WJ IV Story Recall) may be related to:

Differences in type of and degree of meaningfulness of the stimuli.

Differences in the complexity of the associative learning capacity between individuals.

- For example, an associative memory (MA) test like the WJ IV VAL requires learning a series of one-link node pairs, with repeated cumulative study-test phases, while recalling connected discourse (meaningful memory-MM; Story Recall) requires learning a much richer complex network of a larger number of interconnected nodes (more linkages and more nodes) in a single supra-span trial.

Sample MA and MM tests and composites from major IQ batteries



- WJ IV Visual-Auditory Learning
- WJ IV Story Recall
- WJ IV ECAD Memory for Names
- **WISC-V Symbol Translation Index**
  - WISC-V Immediate (& Delayed) Symbol Translation
  - WISC-I Recognition Symbol Translation
- DAS-II Recall of Objects-Immediate
- DAS-II Recall of Objects-Delayed

~~Long-term retrieval~~ (*Gl~~r~~*) – Learning efficiency

- KABC-II Atlantis (first and delayed)
- KABC-II Rebus (first and delayed)

Learning/*Gl~~r~~*

(**Bold** designates composites/clusters)

Facets become fashionable in CHC theory

THE ORGANIZATION OF HUMAN ABILITIES[1]

LLOYD G. HUMPHREYS

University of Illinois

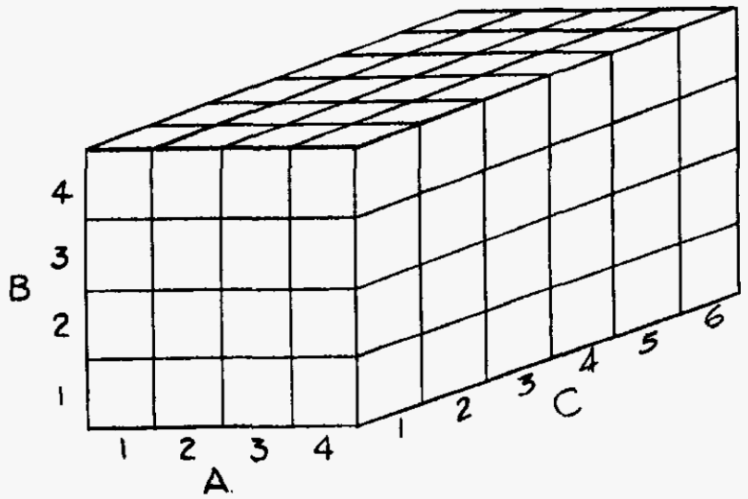


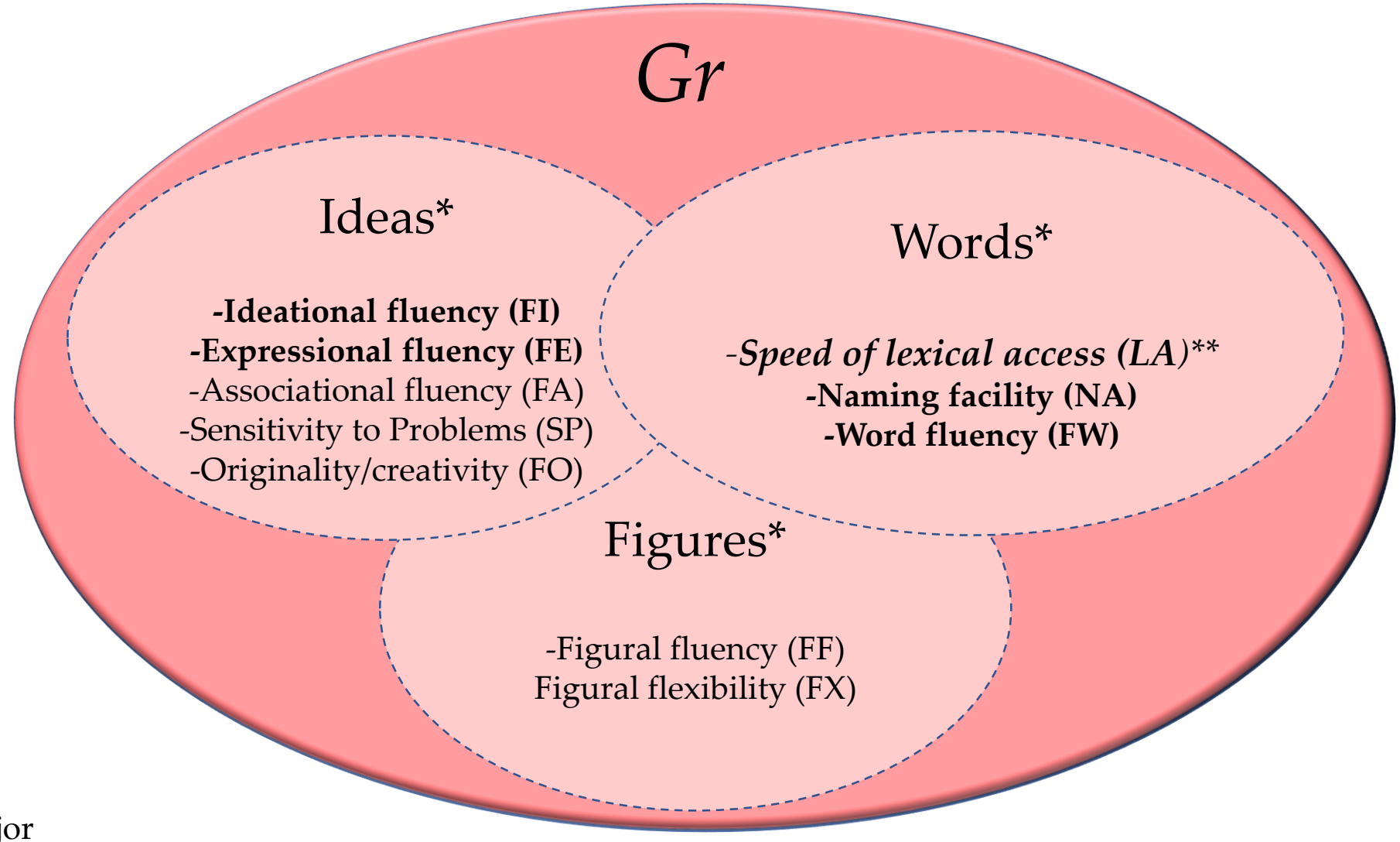
FIG. 3. Three facets creating 96 simple combinations of elements.

Facets are based on facet theory and represent logical based classifications of test materials as per stimulus content characteristics (e.g., verbal, numerical, figures, etc.) and are not to be confused with ability factors. See Humphreys (1962).

Facet-nating !

Retrieval fluency (*Gr*)

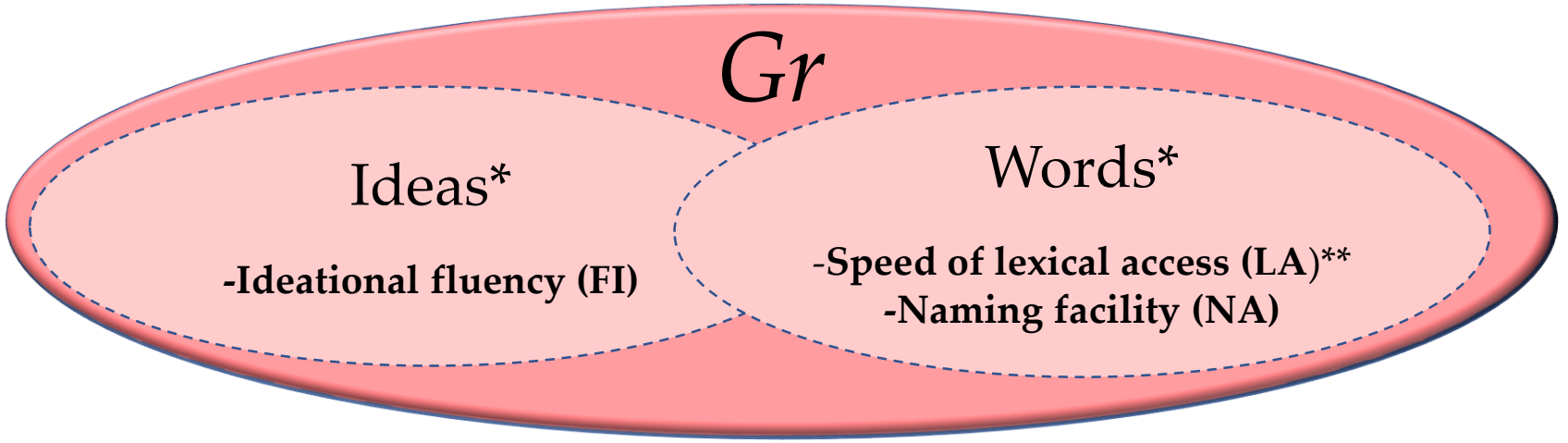
The rate and fluency at which individuals can produce and selectively retrieval verbal and nonverbal information or ideas information stored in long-term memory.



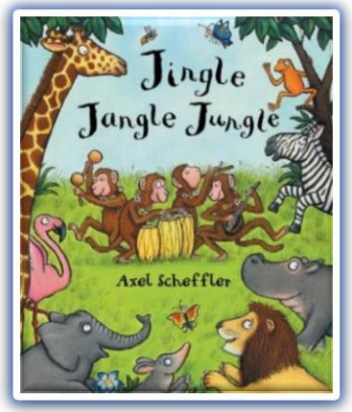
Bold font indicates major (vs minor) narrow abilities

* Facets

** Speed of lexical access (LA) is likely an intermediate stratum ability that subsumes Naming Facility (NA) and Word Fluency (FW)



We recommend measuring *Gr* with a measure of ideational fluency (FI) and speed of lexical access (LA) or naming facility (NA; aka RAN)



Words*

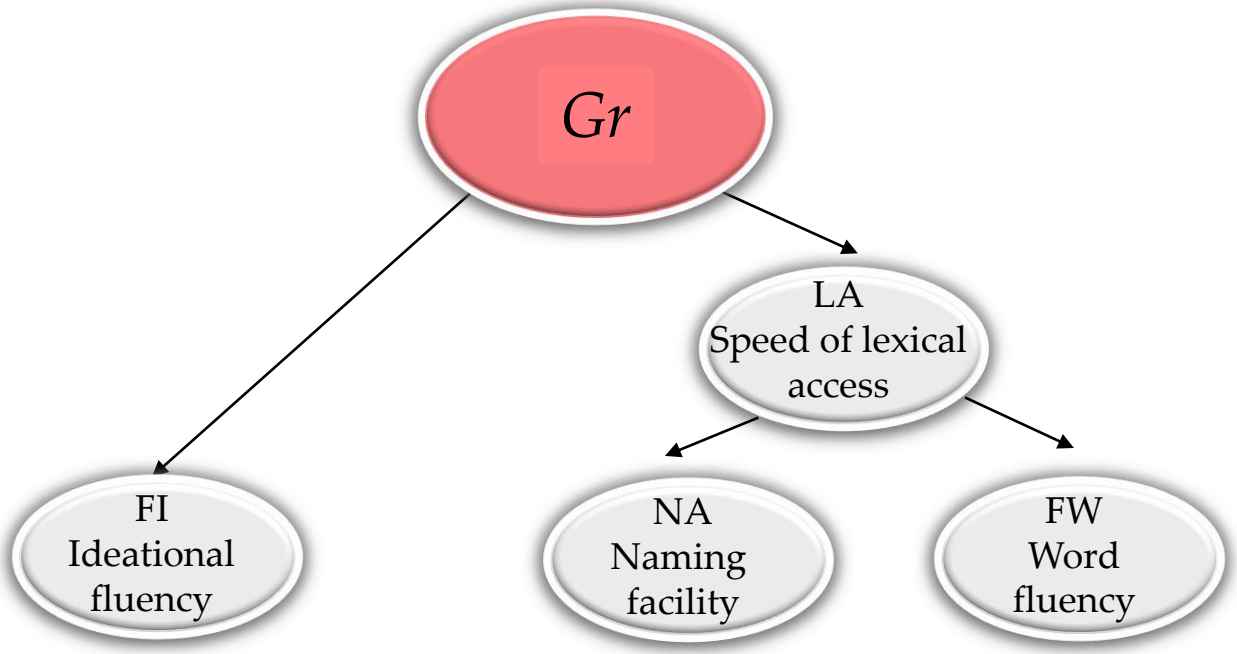
-Speed of lexical access (LA)**
-Naming facility (NA)
-Word fluency (FW)

The RAN, NA, WFD and LA jingle-jangle jungle *

Psychology has had an interest in rapid naming task since the late 1800's (Carrol, 1993). Despite this long history, there is considerable overlap and confusion across the similar, yet different, definitions derived from factor analysis research (NA-naming facility; Carroll, 1993), rapid automatic naming (RAN) reading research (Norton & Wolf, 2012), speed of lexical access (LA) and lexical quality hypothesis reading research (C. A. Perfetti, 2007), and the word finding difficulty (WFD) language research (Messer & Dockrell, 2006). A close inspection of all definitions reveals discussions and controversies regarding the role of multiple and different underlying cognitive processes (e.g., phonological access; lexical access; orthographic processing; processing speed, executive functions). We cannot resolve the similarities and differences between these related terms in this chapter—it would require a separate chapter and possibly even a book. There is a critical need for joint or cross-battery studies, as well as CHC-based causal modeling research, with the most used and psychometrically sound measures of RAN, NA, WFD, and LA, together with other Gr fluency abilities, to carve a path through this jingle-jangle jungle.

The *jingle-jangle-jungle*, is when erroneous assumptions that two different things are the same because they have the same name (jingle fallacy) or identical or almost identical things are different because they are labeled differently (jangle fallacy).

Sample FI and LA/NA tests and composites from major batteries



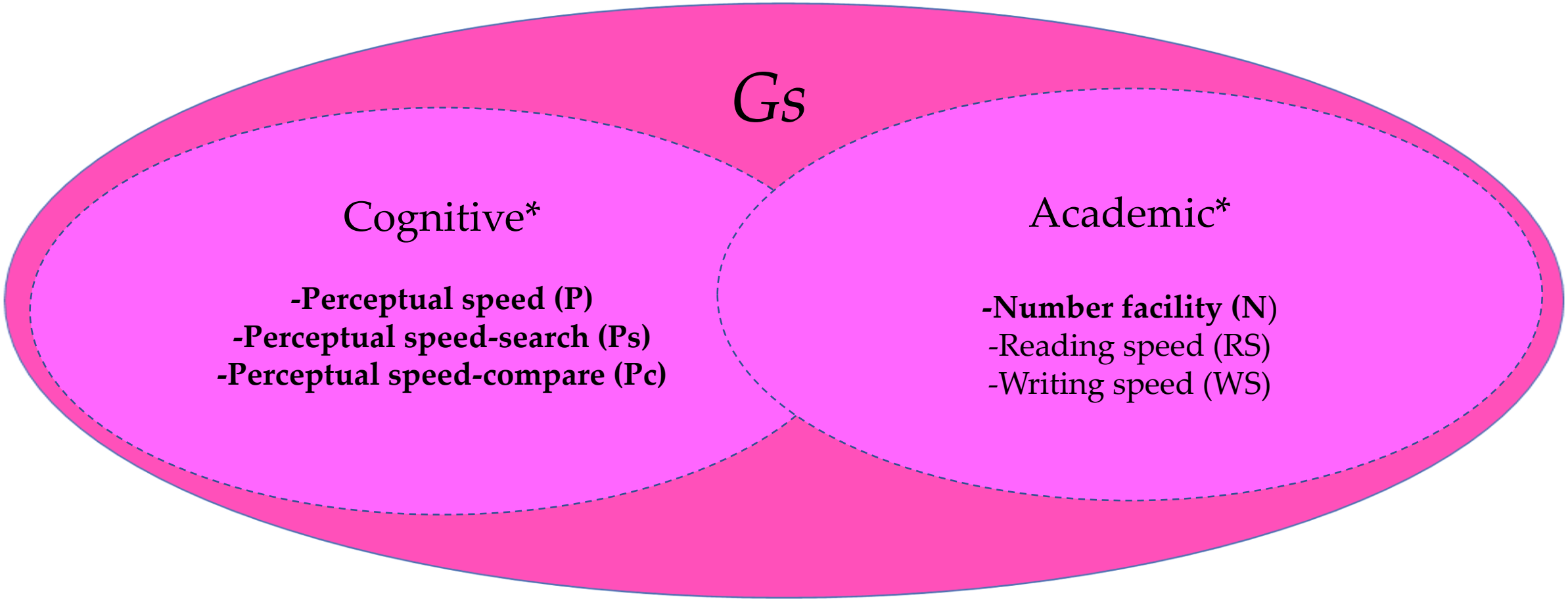
- WJ IV OL Retrieval Fluency
- WJ IV OL Rapid Picture Naming

OL Speed of Lexical Access (*Gr*-LA)

- **WISC-V Naming Speed**
  - WISC-V Naming Speed Literacy
  - WISC-IV Naming Speed Quantity
- DAS-II Rapid Naming

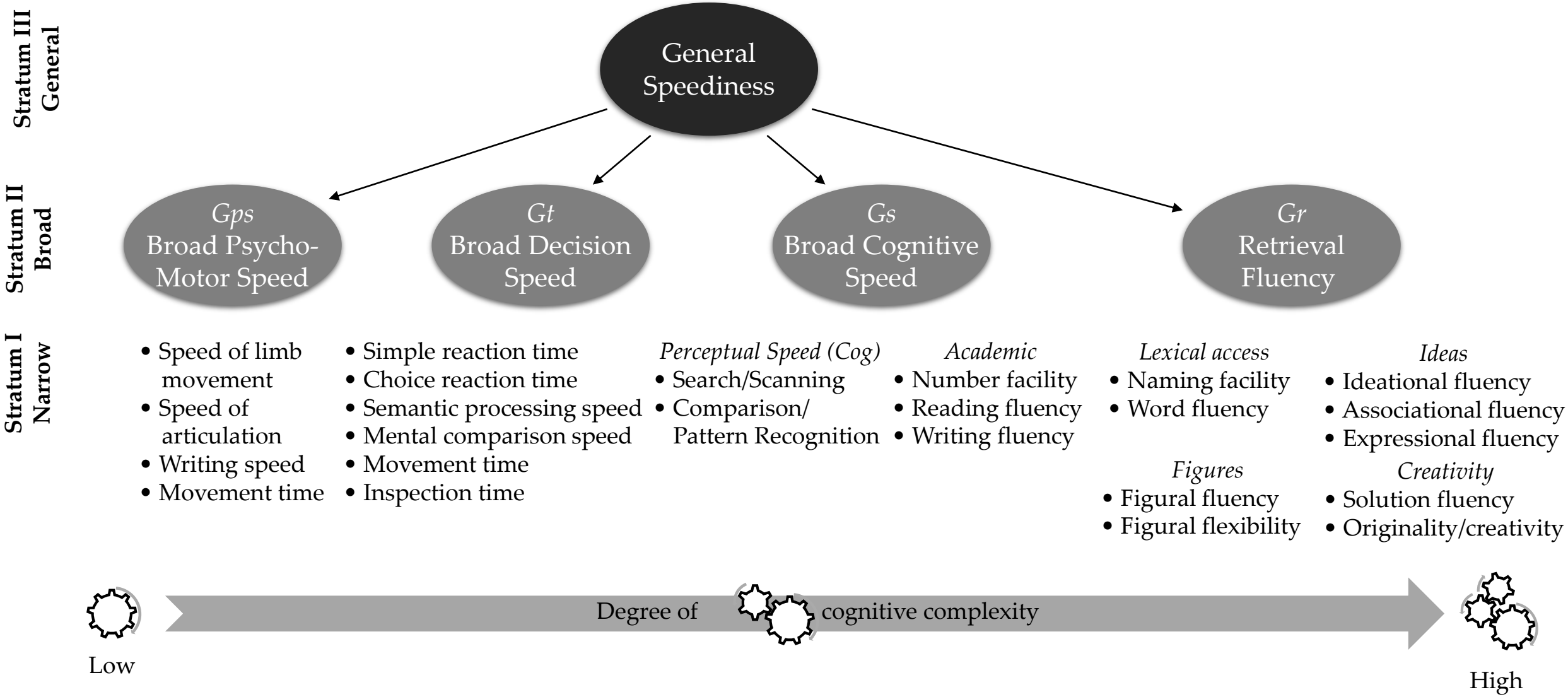
(**Bold** designates composites/clusters)

Facet-nating !



Bold font indicates major (vs minor) narrow abilities

* Facets



Gs Broad Cognitive Speed

- P has been one of the more studied cognitive abilities (circa, since 1951).
- Early & contemporary factor analysis research has always suggested that the P factor may include multiple sub-factors.
- P tests come in many flavors.
- Carroll (1993) suggested that the various tests of P consist of two types:
  - **Searching and Comparing.** (Similar to Ackerman et al.'s first two, of four, P sub-factors)
  - Carroll (1993) characterized the myriad of possible P factors by means of a mapping sentence:
    - Speed in **[searching for and finding/correctly finding]** [one/or more] **[literal/digital/figural]** stimuli in a visual field arranged **[by pairs/by rows/in columns/at random]** for **[identity/difference/size/etc]**

Gs
Broad Cognitive Speed

R9 (rate-of-test-taking) should never have been part of the CHC taxonomy. A careful review of the results from the 12 studies and Carroll's own statements suggest this factor never should have been accorded serious status in the CHC framework.

R9 has become a "I don't know" or "other" classification. Conversely, all *Gs* tasks could be classified R9. The R9 classification, as currently used, has little convergent/divergent validity.

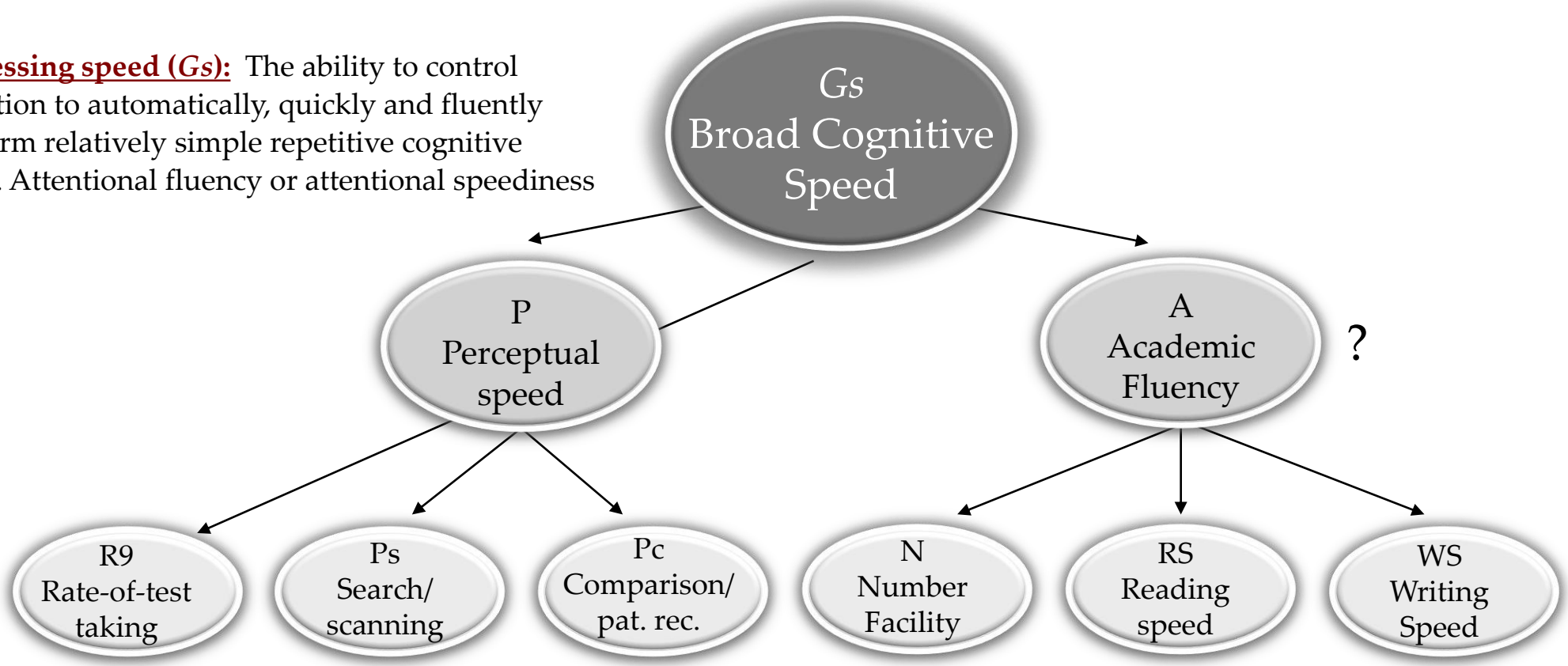
- **Perceptual speed (P):** An intermediate stratum level ability that can be defined as the speed and fluency with which similarities or differences in visual stimuli (e.g., letters, numbers, patterns, etc.) can be searched and compared in an extended visual field.
- **Perceptual speed-search (Ps):** The speed and fluency of searching or scanning an extended visual field to locate one or more simple visual patterns
- **Perceptual speed-compare (Pc):** The speed and fluency of looking up and comparing visual stimuli that are side-by-side or more widely separated in an extended visual field.
- **Number facility (N):** The speed, fluency and accuracy in manipulating numbers, comparing number patterns, or completing basic arithmetic.
- Reading speed (fluency) (RS): The speed and fluency of reading text with full comprehension. Also listed under *Grw*.
- Writing speed (fluency) (WS): The speed and fluency of generating or copying words or sentences. Also listed under *Grw* and *Gps*.

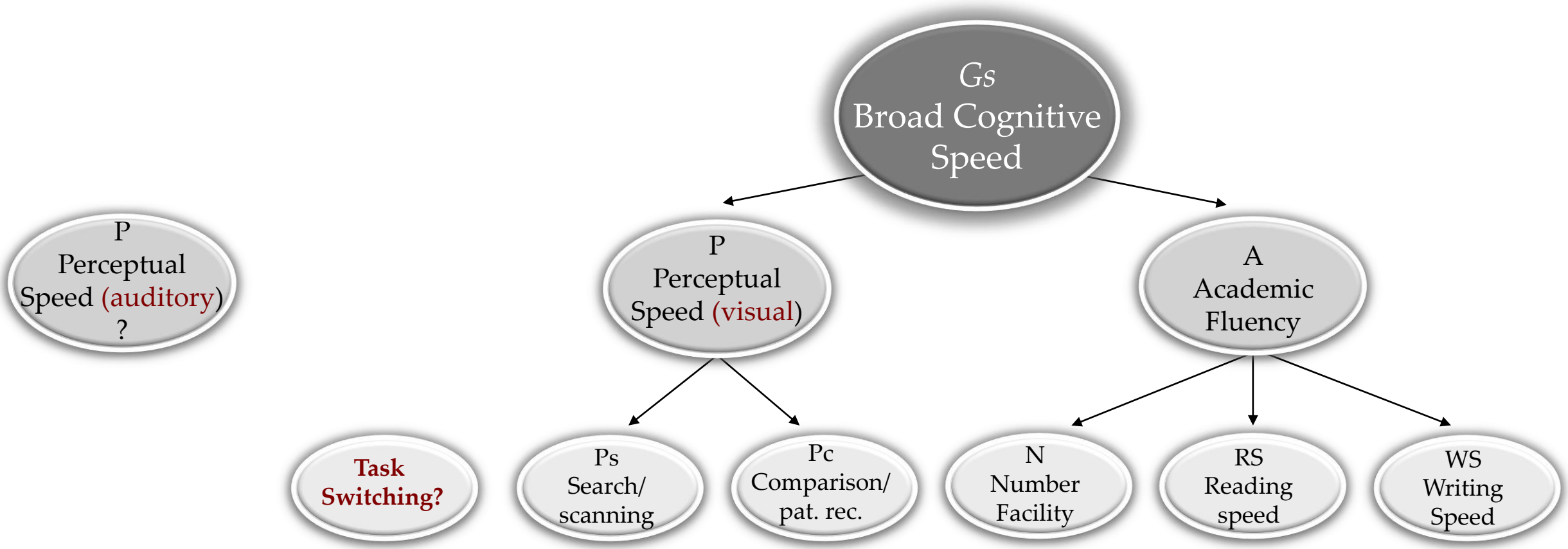
Stratum II Broad

Processing speed (*Gs*): The ability to control attention to automatically, quickly and fluently perform relatively simple repetitive cognitive tasks. Attentional fluency or attentional speediness

Stratum I.5 Intermediate

Stratum I Narrow

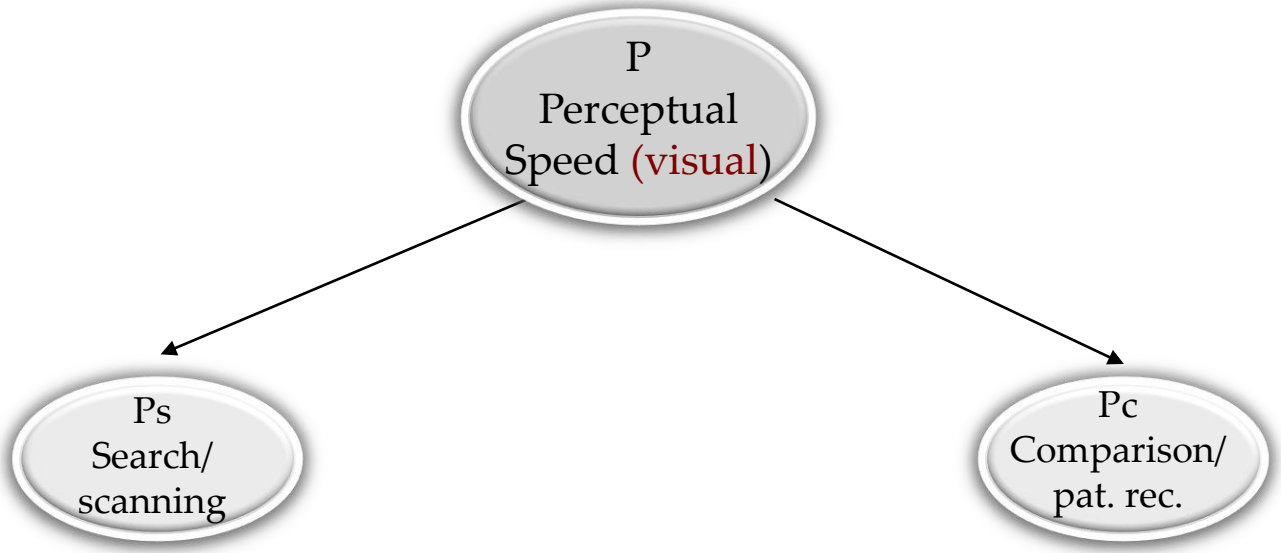




Measure P with one Ps an one Pc test

- WJ IV Letter-Pattern Matching
- WJ IV Number-Pattern Matching
- Wechsler Symbol Search
- WJ IV Pair Cancellation
- Wechsler Cancellation
- Wechsler Coding ?

We also suggest that examiners classify the primary content facet of Ps and Pc tests.

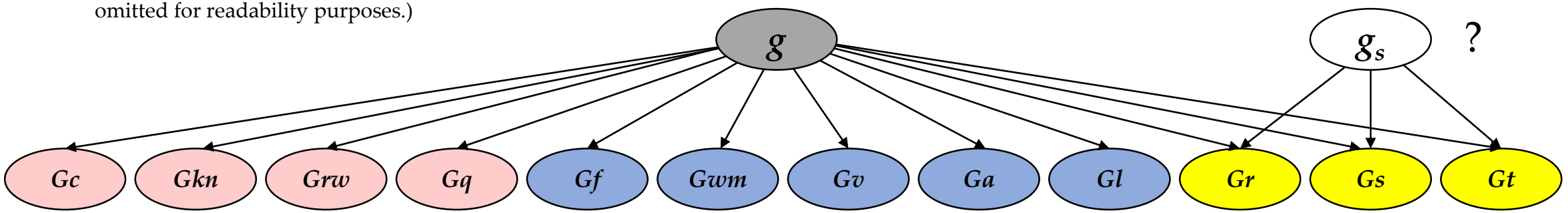


- WJ IV Letter-Pattern Matching **(Ps-Grw)**
- WJ IV Number- Pattern Matching **(Ps-Gq)**
- Wechsler Symbol Search **(Ps-Gv)**
- WJ IV Pair Cancellation **(Pc-Gv)**
- Wechsler Cancellation **(Pc-Gv)**
- Wechsler Coding ? **(Pc-Gv/Gq)**

The Cattell-Horn-Carroll (CHC) taxonomy of human abilities

A higher-order conceptualization based on MDS of the WJ IV norm data (McGrew & Schneider, 06-20-16)

(The tentative broad abilities of *Gh, Gk, Go, Gk, Gp, Gps* & *Gei* and all broad domain level I narrow abilities omitted for readability purposes.)



Intelligence-as-Knowledge (Ackerman)

Acquired knowledge systems

g_c **Cattell**

Intelligence-as-Process (Ackerman)

System 2 (controlled deliberate cognitive operations/processes) (Kahneman)

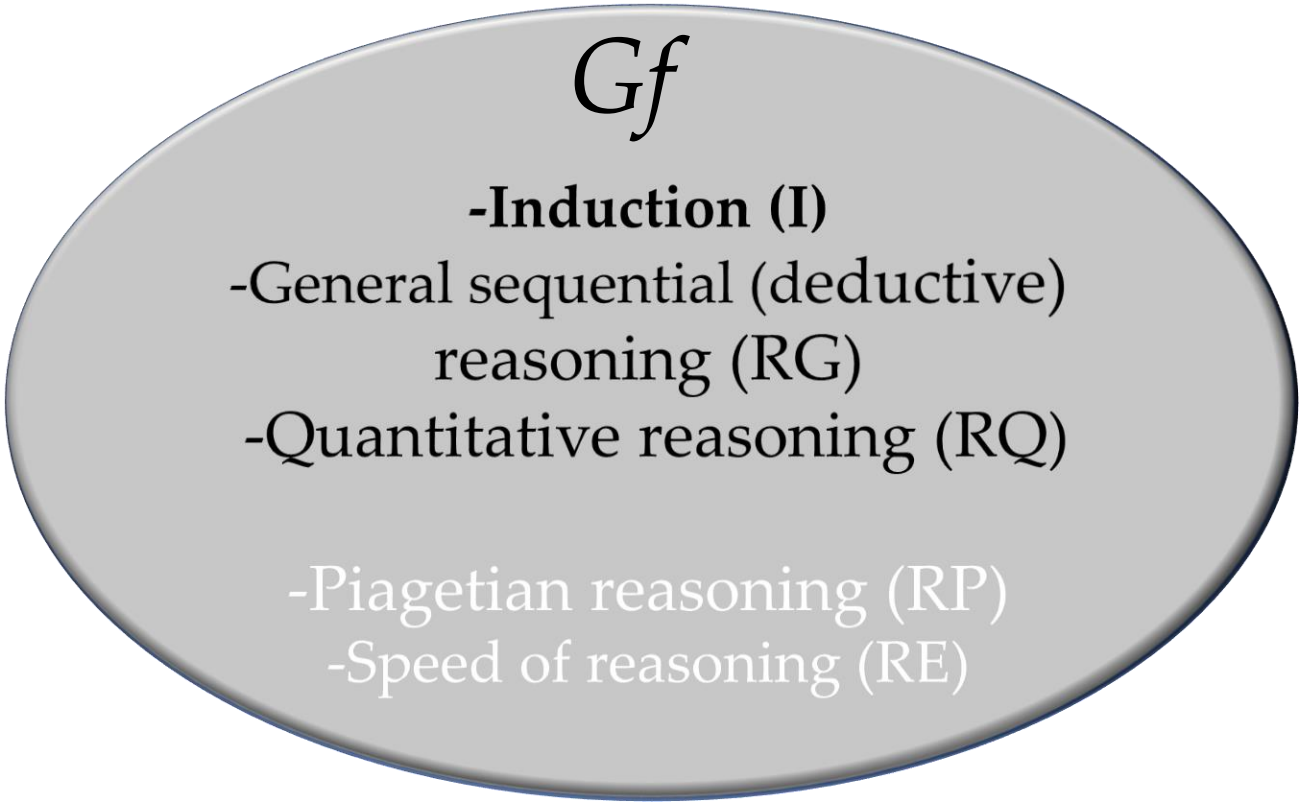
g_f **Cattell**

Intelligence-as-Process: Speed/fluency (Ackerman)

System 1 (automatic rapid cognitive processes) (Kahneman)

g_s **– General speed factor**

Fluid reasoning (*Gf*): The use of deliberate and controlled procedures (often requiring focused attention) to solve novel "on the spot" problems that cannot be solved by using previously learned habits, schemas, and scripts.

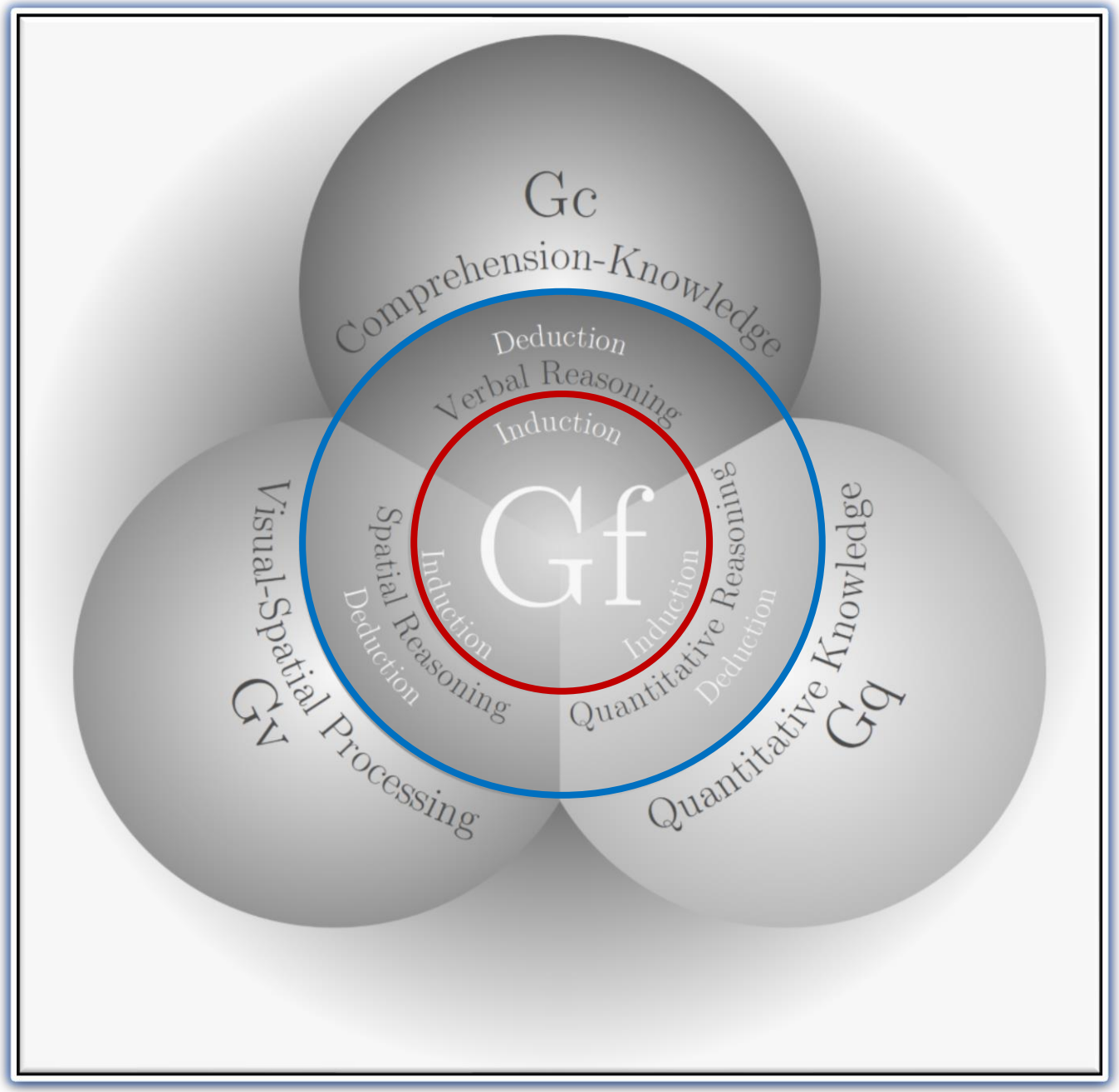


- **Induction (I):** The ability to observe a phenomenon and discover the underlying principles or rules that determine its behavior. This ability is also known as rule inference.
- General sequential reasoning (RG): The ability to reason logically using known premises and principles. This ability is also known as deductive reasoning or rule application.
- **Quantitative reasoning (RQ)**: The ability to reason with quantities, mathematical relations, and operators.
- *Reasoning Speed (RE):* The ability to reason with quantities, mathematical relations, and operators.
- *Piagetian Reasoning (RP):* Seriation, conservation, classification and other cognitive abilities as defined by Piaget's developmental theory.

Facet-nating !

A Conceptual Map of Fluid Reasoning(Gf) and Its Overlap with Other Broad Abilities (Gc, Gv, Gq).

Fluid Reasoning (Gf) likely has both a **process** facet (inductive vs. deductive reasoning) and a **content facet** (verbal, spatial, quantitative, and possibly others), each of which overlaps with other broad abilities.



Group Activity

Lets place each of the following tests in the figure

WISC-V Matrix Reasoning

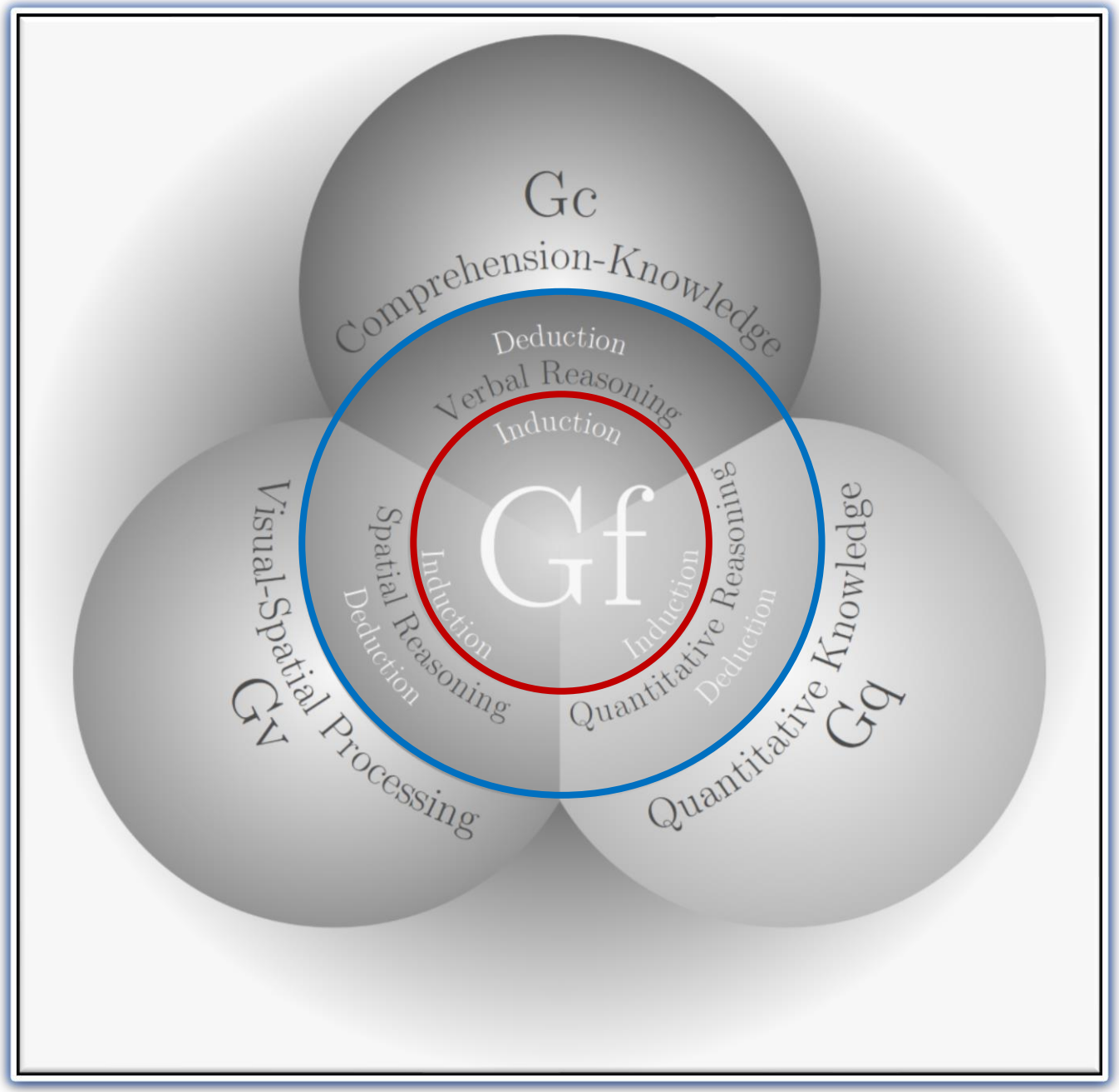
WISC-V Picture Concepts

WISC-V Figure Weights

WJ IV Number Series

WJ IV Analysis-Synthesis

WJ IV Concept Formation



Two other (related) dimensions to consider in selecting and interpreting *Gf* tests

- Degree of cognitive load

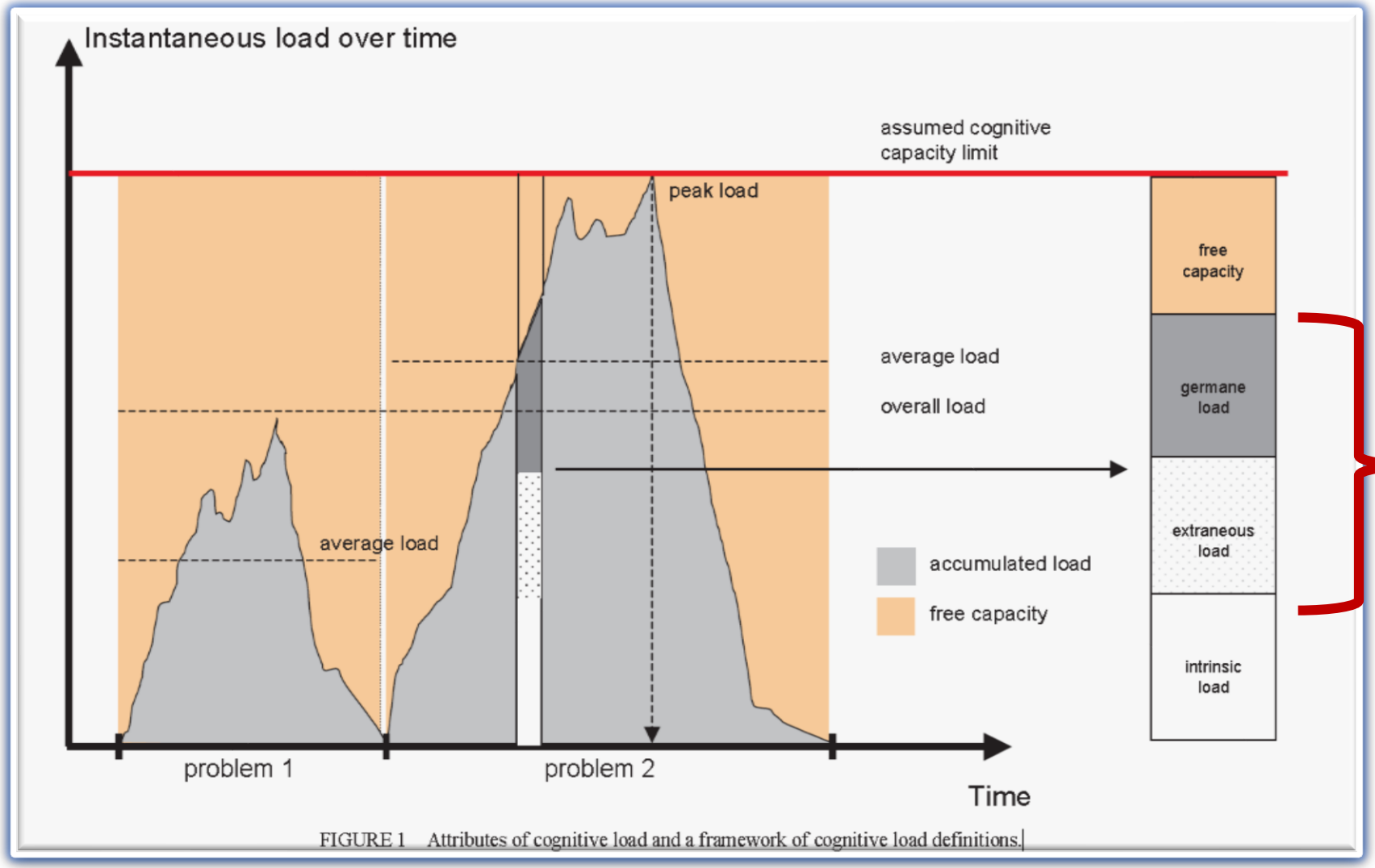


FIGURE 1 Attributes of cognitive load and a framework of cognitive load definitions.

Under control of instructional designers

Two other (related) dimensions to consider in selecting and interpreting *Gf* tests

- Amount of external scaffolding vs *Gf* "in the wild"

WISC-V Matrix Reasoning

WISC-V Picture Concepts

WISC-V Figure Weights

WJ IV Number Series

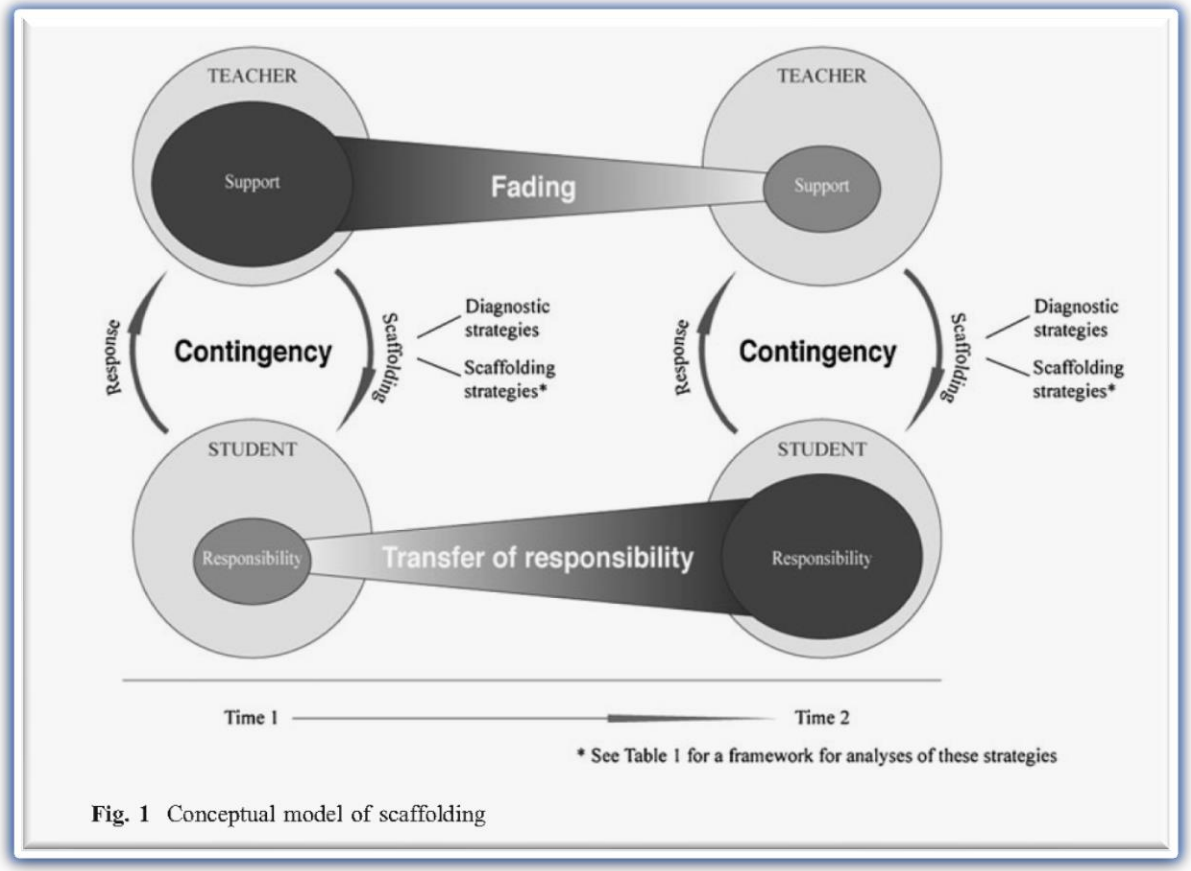
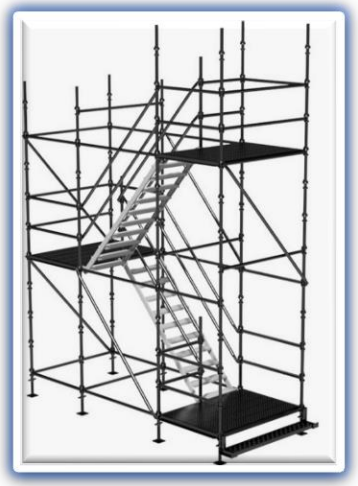


Fig. 1 Conceptual model of scaffolding



WJ IV Analysis-Synthesis

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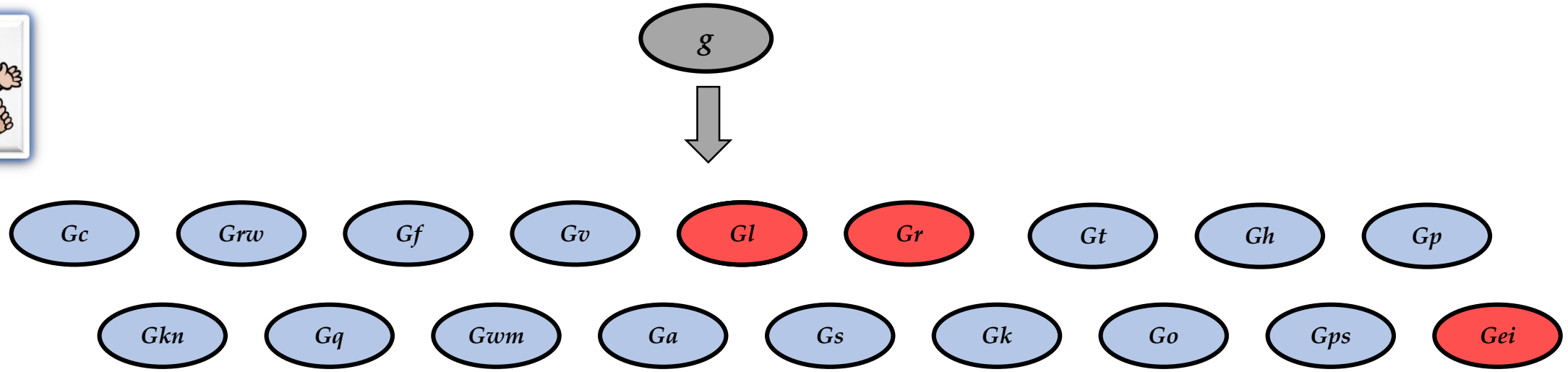
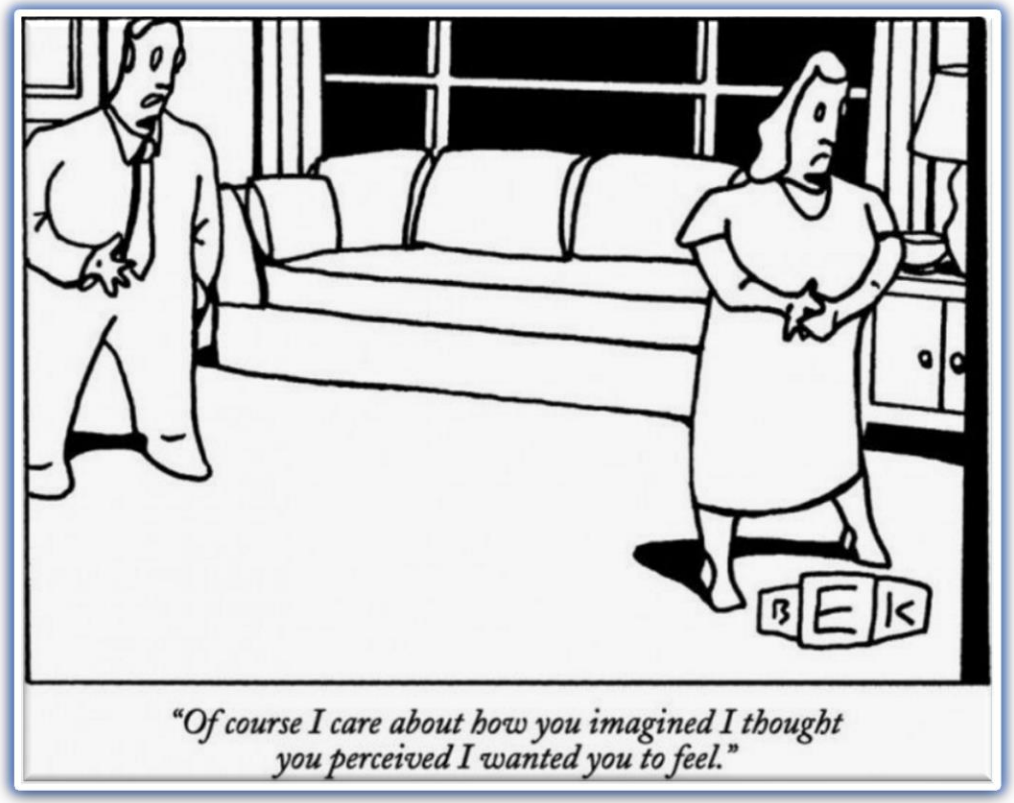
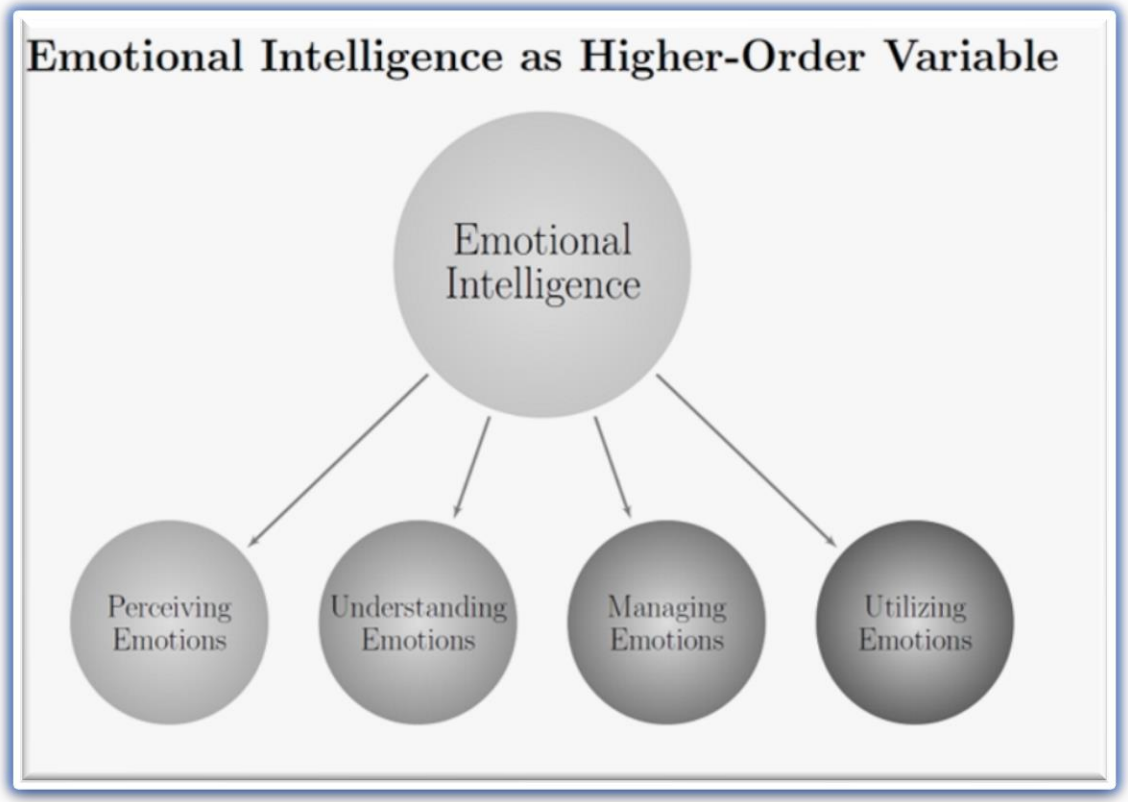


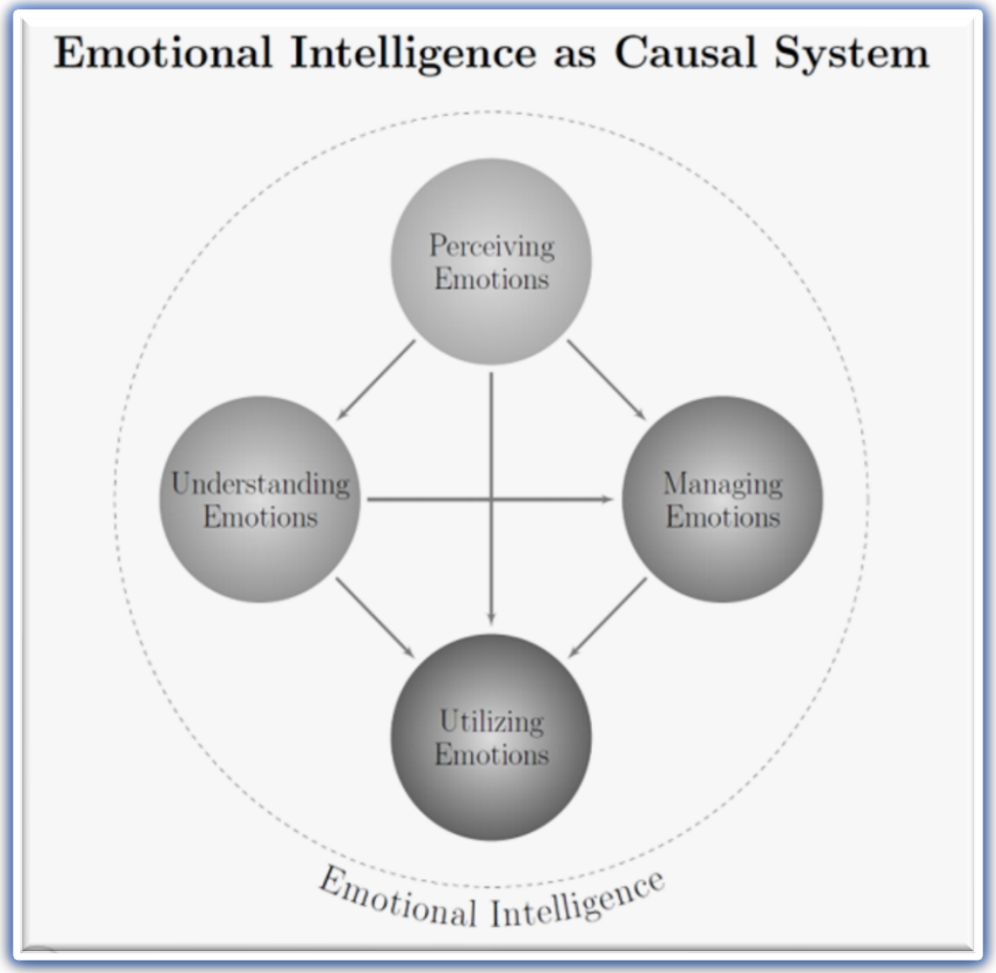


"Of course I care about how you imagined I thought you perceived I wanted you to feel."

Emotional intelligence (*Gei*): The ability to perceive emotions expressions, understand emotional behavior, and solve problems using emotions.

- **Emotion perception (Ep):** The ability to accurately recognize emotions in the face, voice, and behavior.
- **Emotion knowledge (Ek):** Knowledge of the antecedents of emotions and the consequences of emotional expression.
- **Emotion management (Em):** The ability to regulate one's emotions deliberately and adaptively.
- **Emotion utilization (Eu):** The ability to make adaptive use of emotion, especially to facilitate reasoning.





Two Conceptualizations of Emotional Intelligence

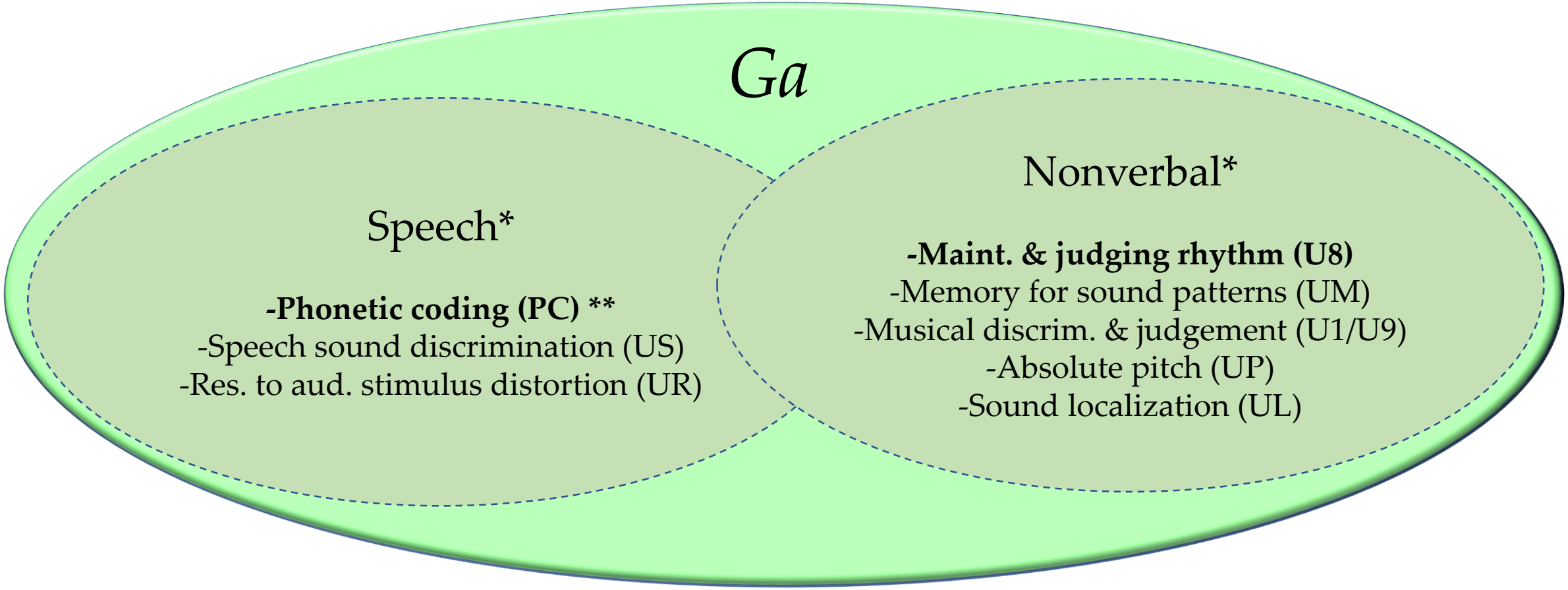
We present the Mayer-Salovey-Caruso Four-Branch Model of Emotional Intelligence, with the following caveats and comments

- There have been few exploratory efforts to uncover the narrow emotional intelligence abilities.
  - Most research is focused on overall emotional intelligence, requiring only a few tests, typically from the MSCEIT.
- Although there are many questionnaire measures of emotional intelligence, we recommend using well-normed ability tests like the MSCEIT or Advanced Clinical Solutions of the WAIS-IV.
- The least controversial aspects of *Gei* are related to emotion perception and emotion knowledge.

Auditory Processing (*Ga*) abilities should no longer be considered the Rodney Dangerfield of CHC abilities

Auditory processing (Ga) is the "ability to discriminate, remember, reason, and work creatively (on) auditory stimuli, which may consist of tones, environmental sounds, and speech units" (Conzelmann & Süß, 2015, p. 28).

Facet-nating !



Bold font indicates major (vs minor) narrow abilities

* Facets

** PC appears to be differentiated primarily along a single developmental psychological sensitivity dimension (Pufpaff, 2009). PC tasks are likely differentiated as per two facets—linguistic (phoneme/syllable vs. morpheme) and cognitive complexity (Blending/Segmentation vs. Manipulation) (Wolff & Gustafsson, 2015).

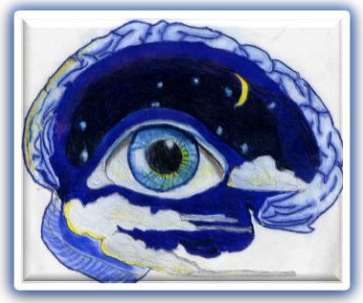
Ga has long been the Rodney Dangerfield ("I don't get no respect") of CHC abilities. *Ga* often considered the "secondary" sense behind *Gv*. This Ga-neglect is no longer scientifically sustainable.

- *Ga* serves the important function of providing perceptual and cognitive scaffolding ("auditory scaffolding") for many temporal-based higher-order cognitive functions such as language.
- *Ga* abilities play important roles in such diverse activities as conversations, performance bottlenecks (e.g., driving a car), navigating in the dark, musical performance, foreign language acquisition, and understanding of reading and language disorders.
- *Ga* requires multiple cognitive processing mechanisms that are equal to, and in many cases, more complex than those involved in many Gv abilities.

- Rammsayer and colleagues have demonstrated that a temporal *g*-factor demonstrates higher correlations with a psychometric *g*-factor than does a classic Jensen reaction time *g*-factor. The temporal resolution power hypothesis
- The importance of *Ga* is now recognized by an ever-increasing wide-range of research in psychology, psychometric studies of intelligence, neuropsychology and cognitive neuroscience. Unfortunately, this embarrassment of riches has yet to be organized into a coherent inter-disciplinary framework (or frameworks).

Intelligence researchers and applied test developers need to catch the beat and develop psychometrically sound measures of temporal processing (e.g., maintaining and judging rhythm; U8)

- Researchers at the Northwestern Auditory Neuroscience Lab have published a series of studies that demonstrate significant relations between measures of beat synchronization (i.e., the coordination of movement with a pacing sound or metronome) and evoked auditory brainstem response, neural coding of speech, psychometric indicators of reading and language development and specific reading and language disorders in children
- Timing or temporal processing has also been linked to mathematics achievement in children.
- In adults, a battery of rhythm tests suggested two rhythm factors (sequencing and synchronization) that also showed significant relations with measures of brain function and verbal memory and reading.



Gv (visual-spatial) has been the most studied domain

Carroll (1993) summarized three phases of spatial (*Gv*) abilities research

Gv

-Visualization (Vz)

-Spatial relations (SR)

-Imagery (IM)

-Flexibility of closure (CF)

-Closure speed (CS)

-Visual memory (MV)

-Spatial scanning (SS)

-Perceptual illusions (IL)

-Length estimation (LE)

Perceptual alternations (PN)

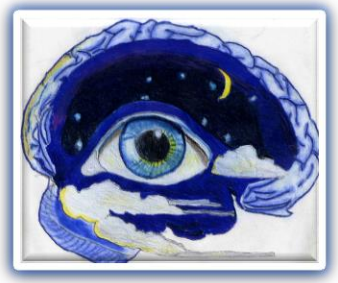
-Perceptual speed (P-Gs)

- Visual processing (*Gv*) can be defined as the ability to make use of simulated mental imagery to solve problems. Perceiving, discriminating, manipulating and recalling non-linguistic images in the "mind's eye."
- Humans do more than "act" in space…we "cognize" about space.
- Some preliminary evidence for a face recognition narrow ability

Gv research is entering a potentially new fourth phase (predict an explosion of theoretical and assessment research and development)

Carroll (1993), the oracle, was prophetic re: two new targets of *Gv* research. "Other possible visual perception factors"

"Ecological" abilities and dynamic vs static



Small-scale vs large-scale (navigation) spatial abilities (typical *r* = .27 in meta-analyses)

Gv

Small-scale spatial (*Gv*) ability

- Involves allocentric spatial transformations
  - "Object-based transformation"
  - "Mental rotation"
  - "Object manipulation"
  - "Psychometric spatial ability"

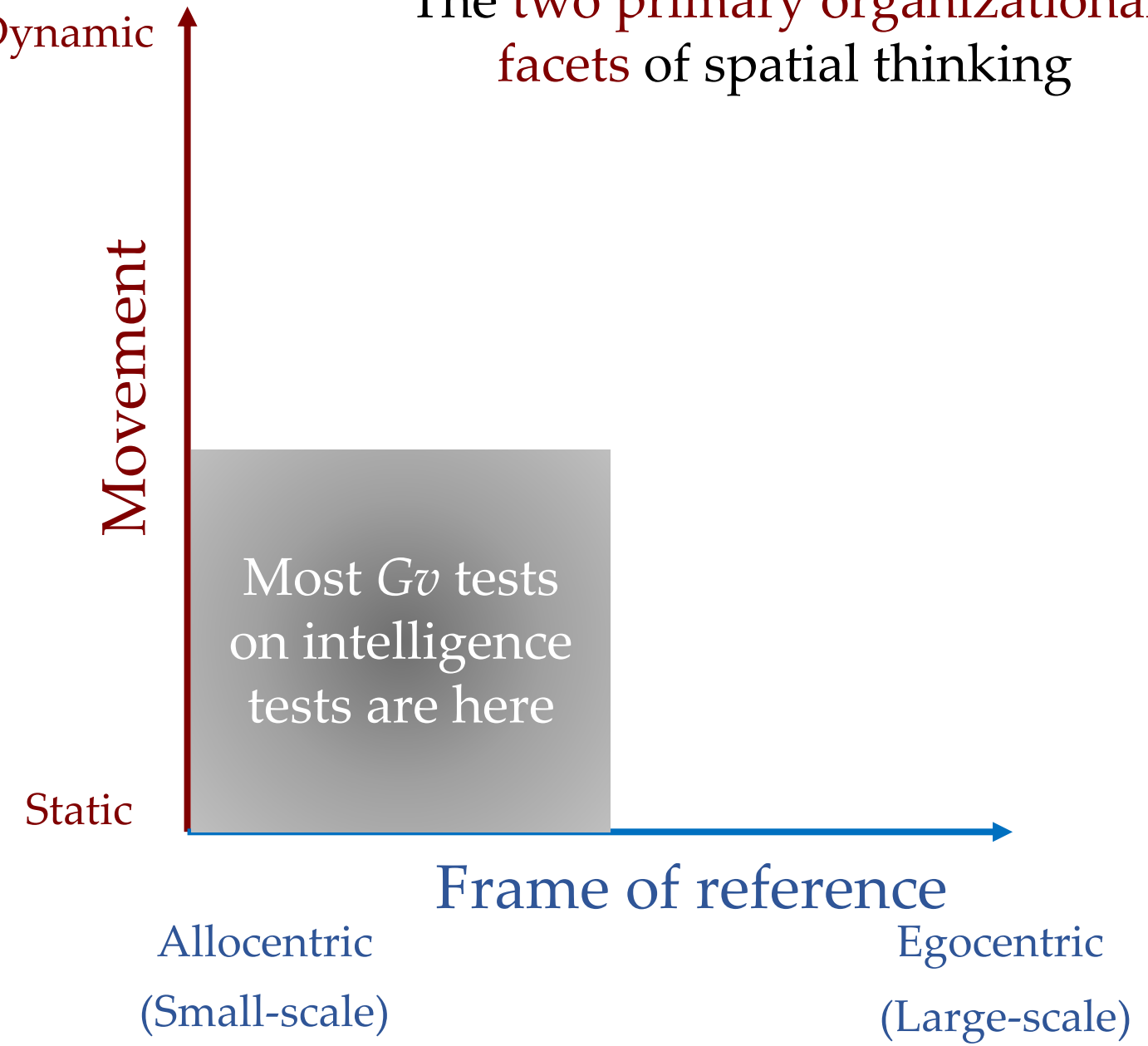
Large-scale spatial (*Gv*) ability

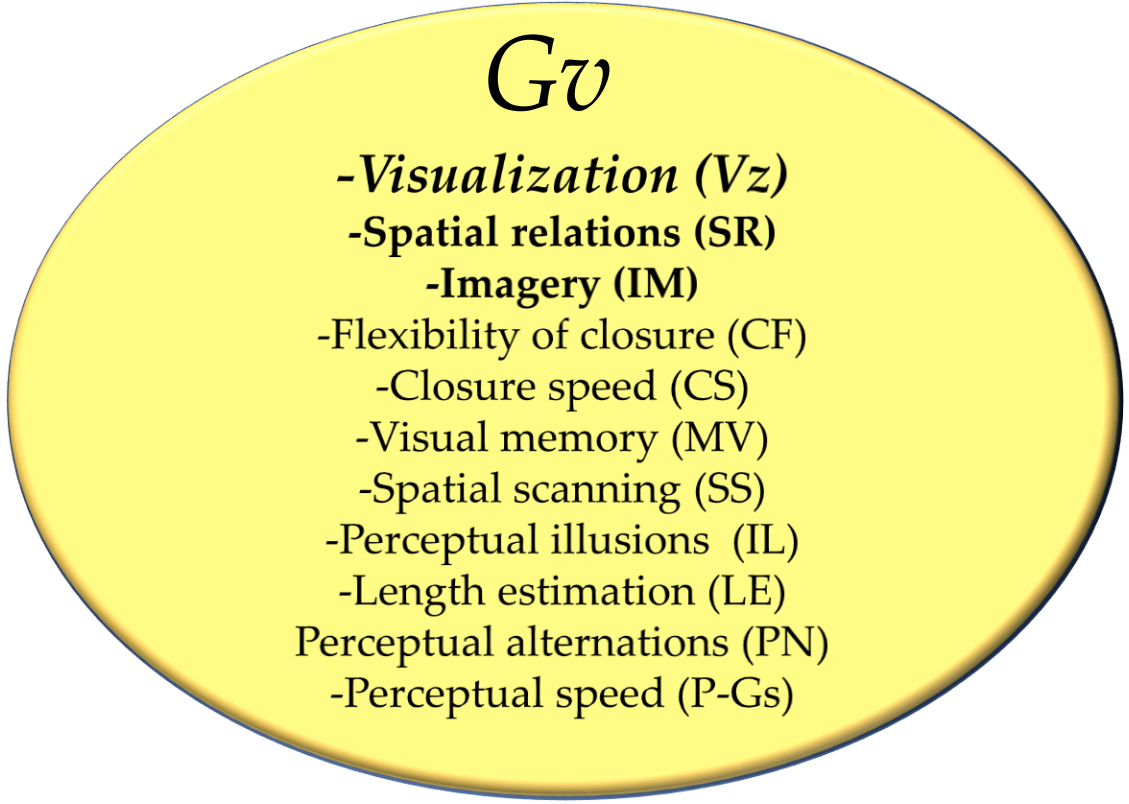
- Involves egocentric spatial transformations
- Viewers perspective changes with respect to larger environment
- Spatial relations among objects are constant
  - "Wayfinding"
  - "Sense of direction"
  - "Perspective taking"
  - "Navigational abilities"

- Neuroscience research suggest they rely on different neural substrates

The two primary organizational facets of spatial thinking

- Dynamic and static spatial tasks differ primarily by the presence or absence of movement.
- "Dynamic spatial ability is one's ability to estimate when a moving object will reach a destination, or one's skill in making time-to-contact (TTC) judgments"
- The ability to catch a football, play a video game, or perform as an air traffic controller would require dynamic spatial abilities.

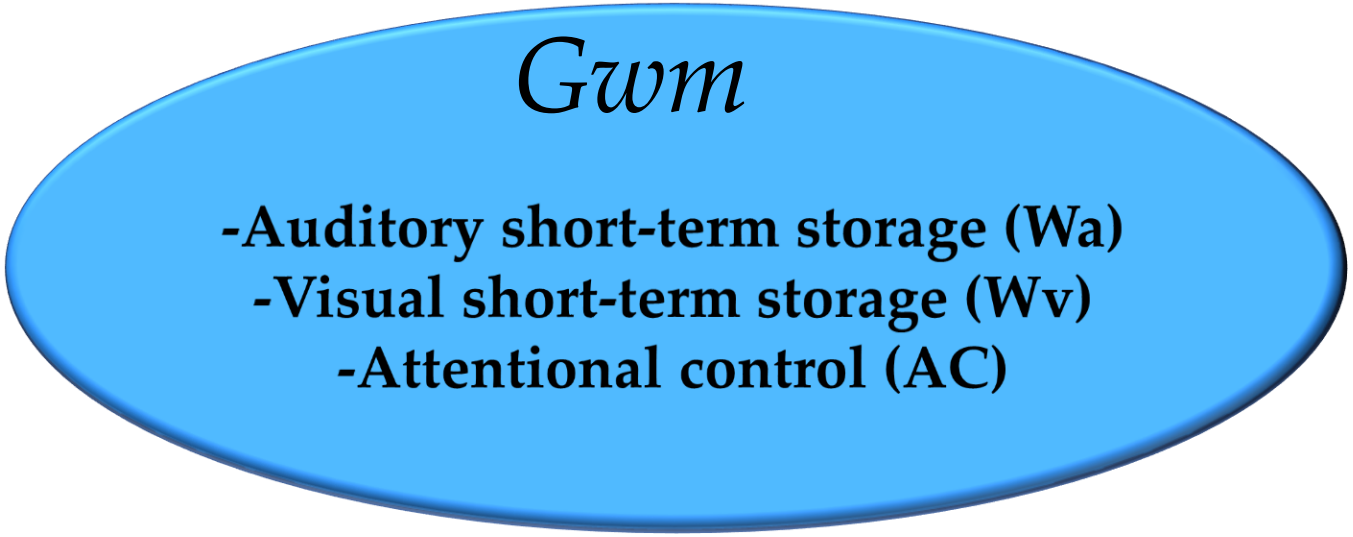




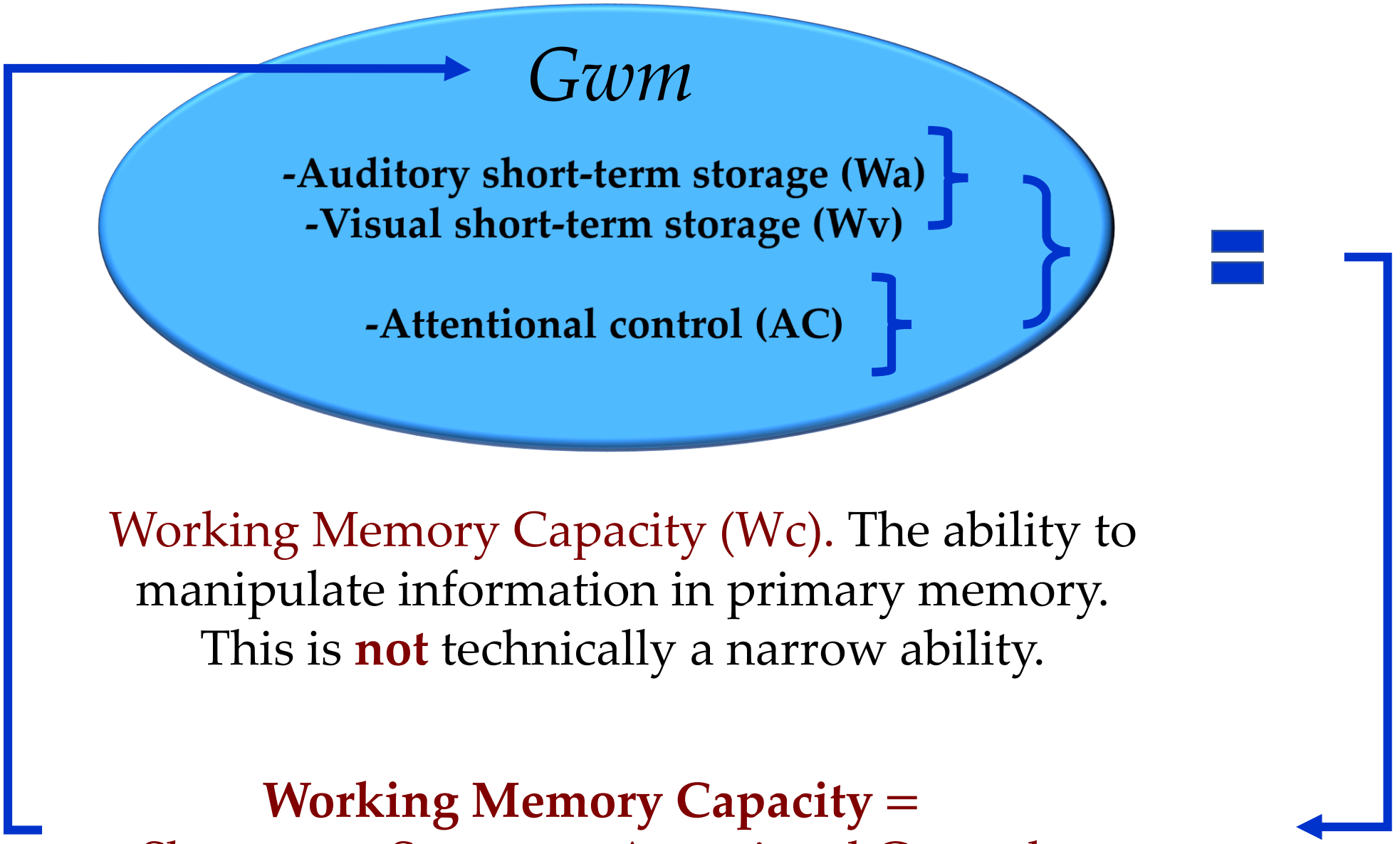
A strong measure (preferably multiple measures) of Vz is required.

- Tests should minimize the amount of *Gp* and *Gps*
- If speed is involved in a test, it should be supplemented with an unspeeded test of Vz.
- Using both 2D and 3D *Vz* measures would be optimal
- We pray (hope) for new sound measures of visual imagery (IM)

Gwm can be defined as the ability to maintain and manipulate information in active attention. Is not an individual differences trait variable



- Auditory Short-Term Storage (Wa). The ability to encode and maintain verbal information in primary memory.
- Visual-Spatial Short-Term Storage (Wv). The ability to encode and maintain visual information in primary memory.
- Attentional Control (AC). The ability to manipulate the spotlight of attention flexibly to focus on task-relevant stimuli and ignore task irrelevant stimuli. Sometimes referred to as spotlight or focal attention, focus, control of attention, executive controlled attention, or executive attention.

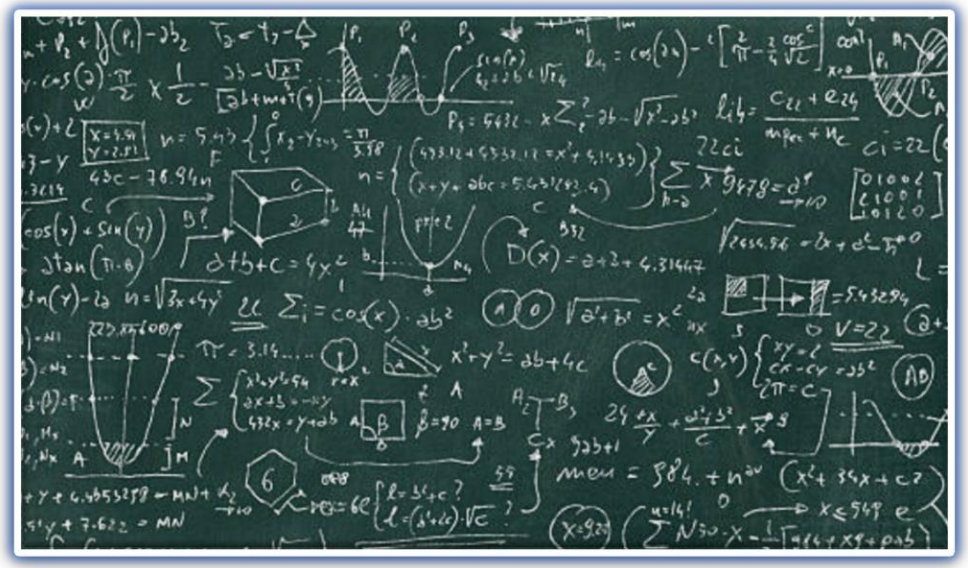


Working Memory Capacity (Wc). The ability to manipulate information in primary memory. This is **not** technically a narrow ability.

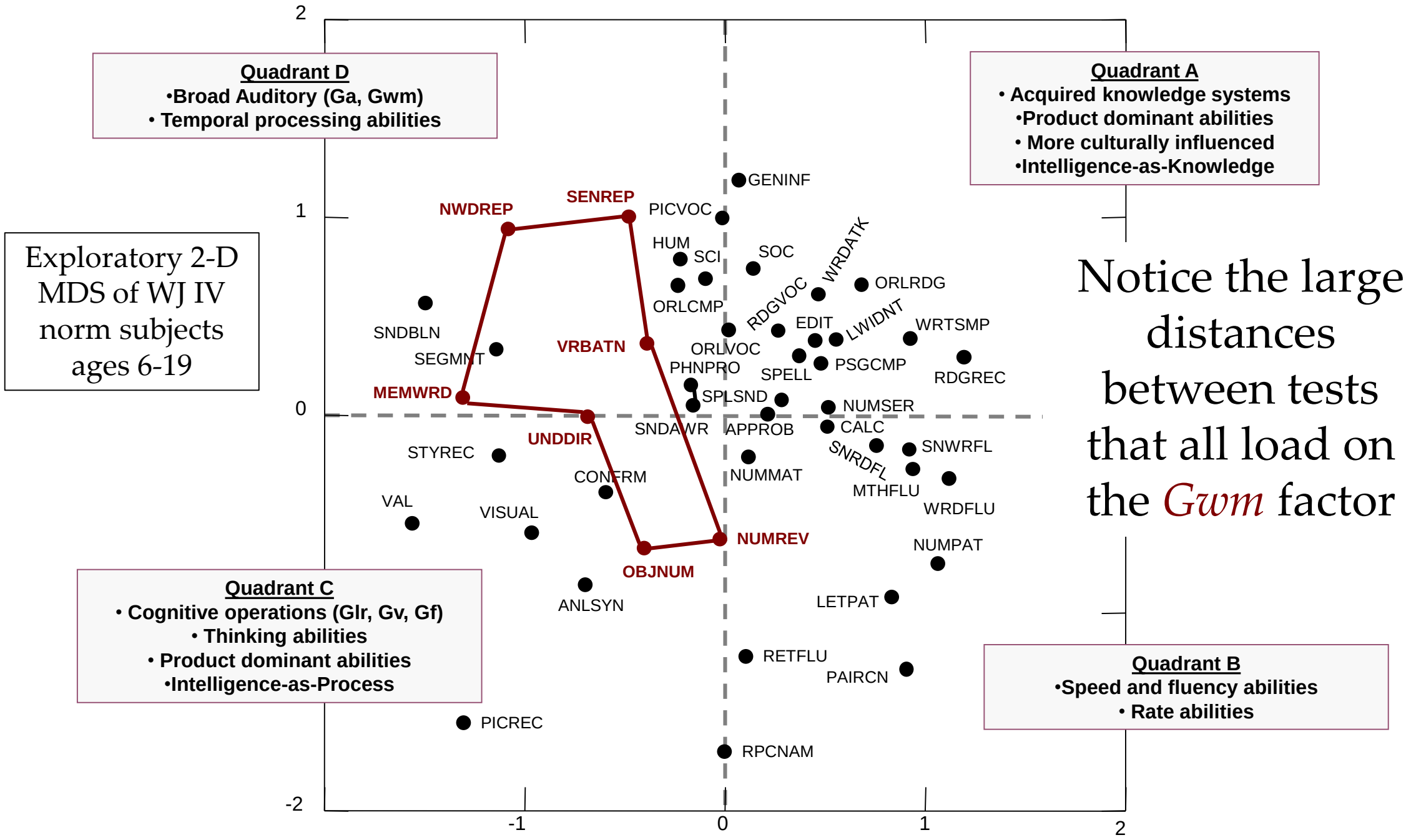
Working Memory Capacity =
Short-term Storage + Attentional Control

Gwm

-Auditory short-term storage (Wa)
-Visual short-term storage (Wv)
-Attentional control (AC)

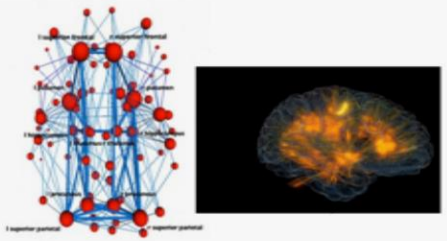


- Working memory is important
- Working memory is complex
- Interpretation of *Gwm* tests is complicated



Intelligence Testing Related Research: Levels of theoretical reductionism and explanation

(Adapted from conceptual distinctions of Earl Hunt, 2011)



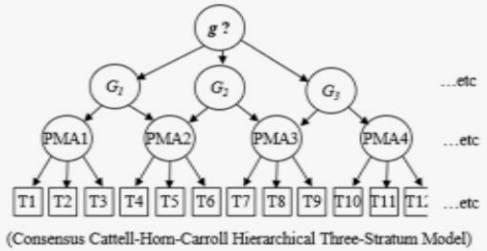
White matter tract organization, integrity & efficiency

Measurable cognitive behaviors (psychometric models)

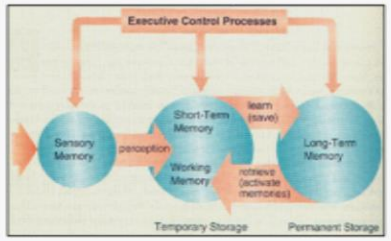
Information processing (mechanical models)

Brain function & networks (biological & neurocognitive models)

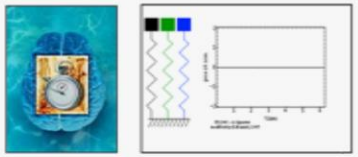
Neural efficiency (biological & neurocognitive models)



(Consensus Cattell-Horn-Carroll Hierarchical Three-Stratum Model)

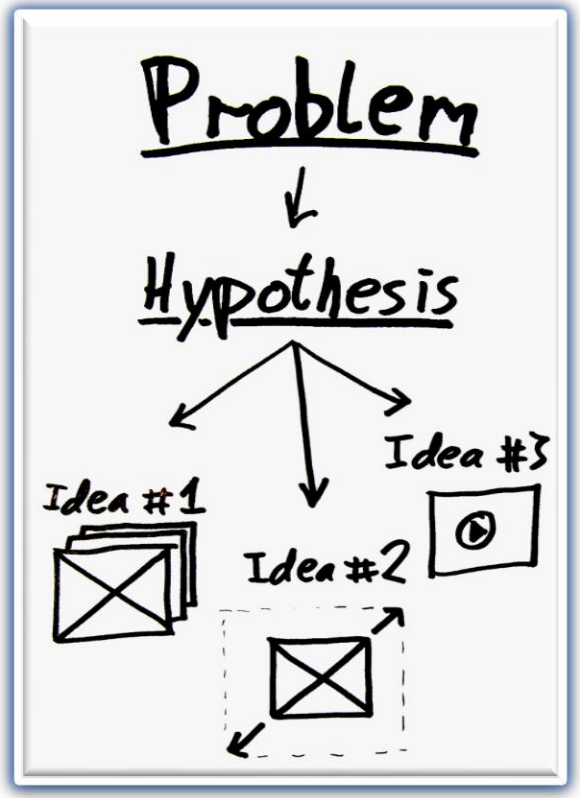


-Human Connectome
-Functional brain networks (Bressler & Menon, 2010)
-"Rich club" network hubs
- P-FIT model



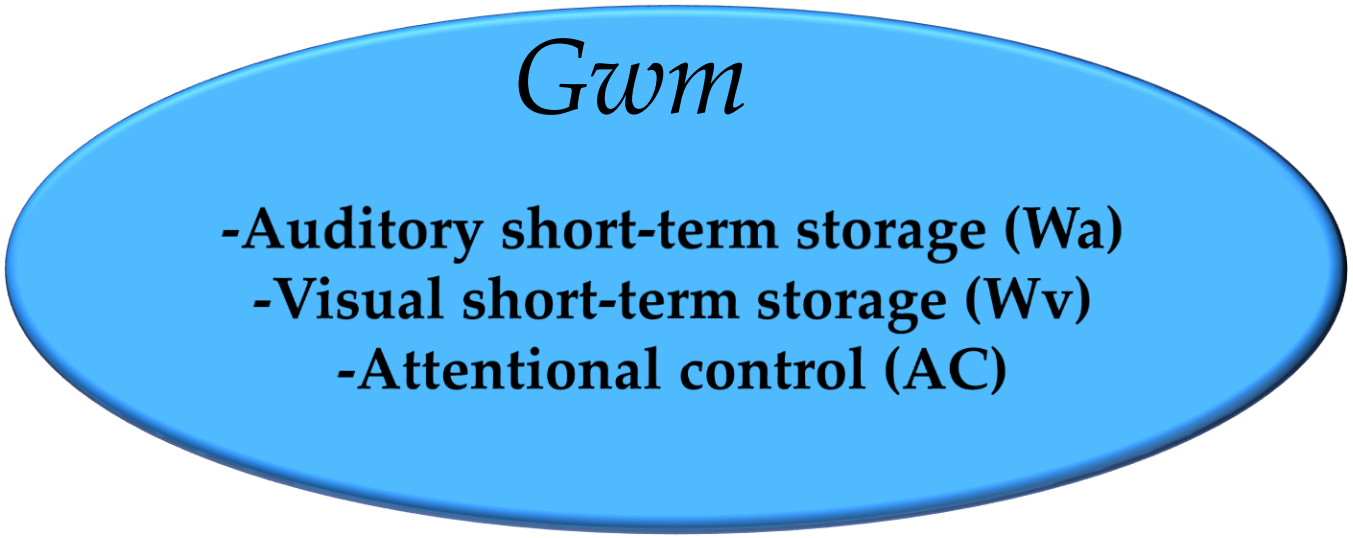
-rate of neural oscillations
-neural synchronization
-Reaction-time and temporal *g*
-ERP's (e.g., ABR)

Interpretation of *Gwm* tests is complicated



The working memory (*Gwm*) literature is extensive and there is no consensus model regarding the mechanisms of working memory.

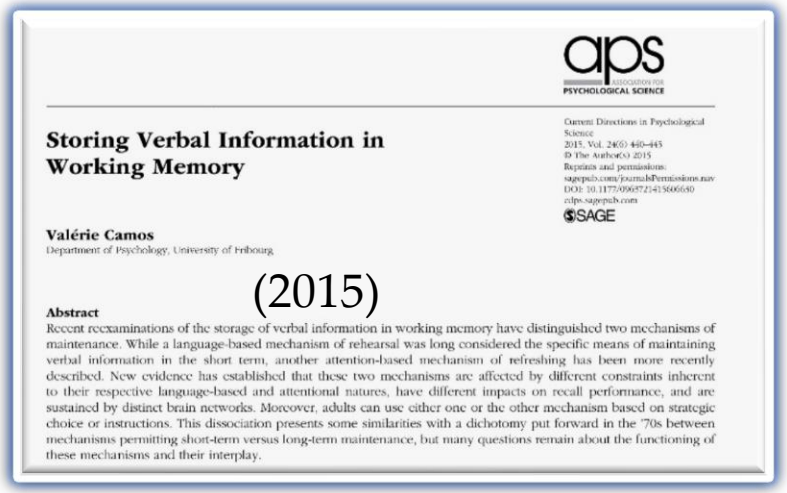
As a result, a number of viable hypotheses need to be entertained when trying to explain *Gwm* test score differences and when deciding which tests to administer.



Interpretation of *Gwm* tests is complicated

- Degree of attentional control
- Degree of linguistic/verbal demand
- Different brain networks
- Degree of cognitive load/complexity (levels of processing required)
- Content facets

There may be two primary mechanisms of verbal working memory maintenance



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Storing Verbal Information in Working Memory

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(2015)

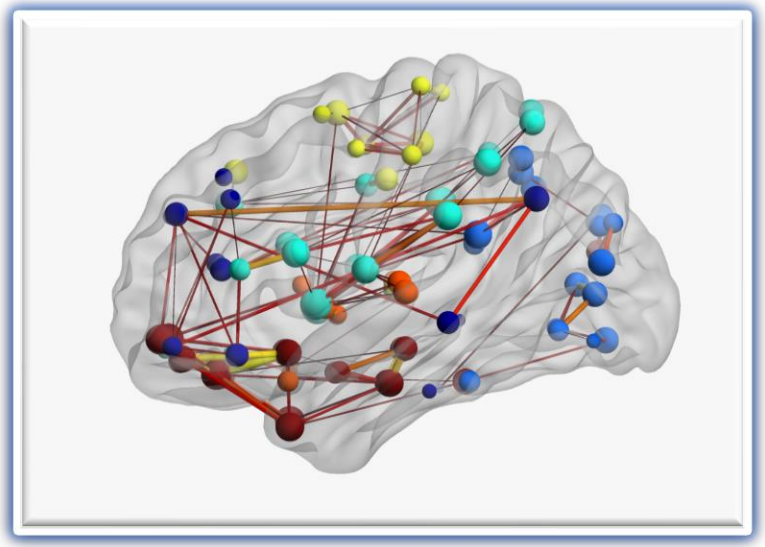
Abstract
Recent reexaminations of the storage of verbal information in working memory have distinguished two mechanisms of maintenance. While a language-based mechanism of rehearsal was long considered the specific means of maintaining verbal information in the short term, another attention-based mechanism of refreshing has been more recently described. New evidence has established that these two mechanisms are affected by different constraints inherent to their respective language-based and attentional natures, have different impacts on recall performance, and are sustained by distinct brain networks. Moreover, adults can use either one or the other mechanism based on strategic choice or instructions. This dissociation presents some similarities with a dichotomy put forward in the '70s between mechanisms permitting short-term versus long-term maintenance, but many questions remain about the functioning of these mechanisms and their interplay.

Tasks that make greater use of the **articulatory rehearsal** maintenance mechanism

- A language production process mechanism
- Phonological effects research
- Covert/overt rehearsal

Tasks that make greater use the of **attentional refreshing** maintenance mechanism

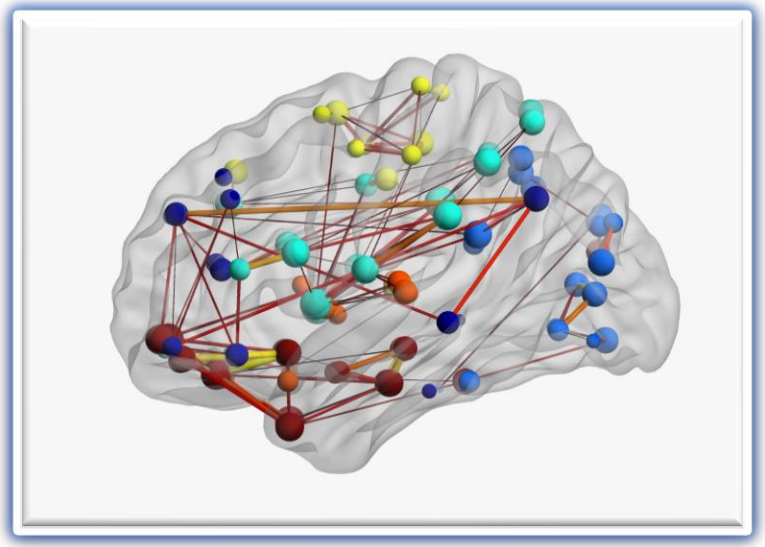
- Reactivation memory trace mechanism across stimulus domains (lang, visual, spatial)
- Increasing focus and inhibiting distractions
- Controlling and directing focus of attention



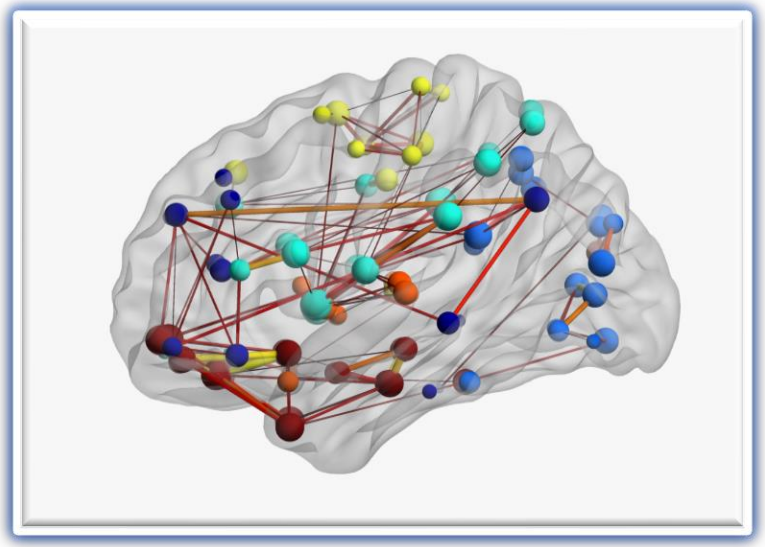
Contemporary brain network research, as well as some classic neuropsychological research, suggests that these two working memory mechanisms likely rely on different brain networks (Bressler & Menon, 2010; Camos, 2015).

Thus, the reason for unusual differences between some working memory tests may be due to different task demands placed on different brain network mechanisms

Verbal/linguistic rehearsal working memory network mechanism

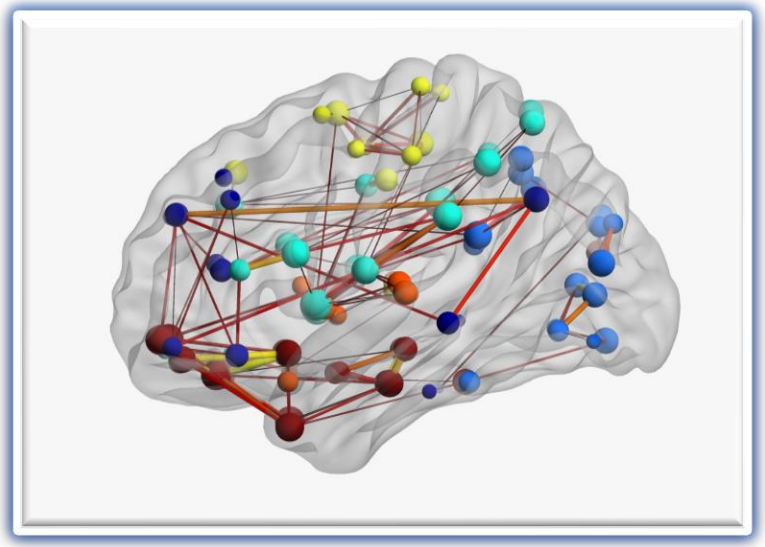


Broca's area, the left premotor cortex, the cortex along the left intraparietal sulcus, and the right cerebellum are active when verbal rehearsal is used. The entire "language network" (e.g., Broca and Wernicke's areas) may be involved (Bresslor & Menon, 2010; Camos, 2015)



Central-executive attentional control network mechanism

The prefrontal and parietal cortex's involved (Bresslor & Menon, 2010; Camos, 2010). Consistent with the Parietal-Frontal Integration (P-FIT) neuro-intelligence model (Cown, 1995; Jung, Haeir, Colom et al.)

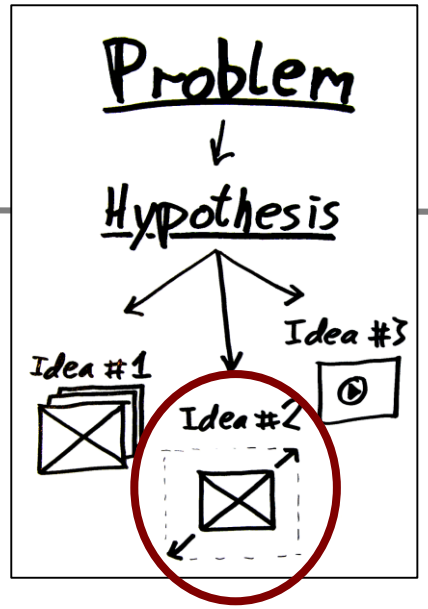


Central-executive attentional control network mechanism

+

Verbal/linguistic rehearsal network mechanism

Research has shown that some individuals can be "adaptive" and switch between these working memory mechanisms based on task demands (Camos, 2015).



Levels of processing differences in *Gwm* tasks

Early memory models (e.g., Craik & Lockart, 1972) proposed that the degree of transfer of information from immediate to long-term memory may depend on whether the material was processed at a surface or shallow level (Type 1) or, in contrast, at a deeper level (Type 2)

Unusual differences between some working memory tests may be due to the *Gwm* domain having a substructure where the level of required cognitive processing demands differ between the tests. It is possible these differential demands may recruit different brain network mechanisms.

High

Hypothesized degree of linguistic or language-domain demand

Low

Distances between tests intended to reflect relative hypothesized differences (not quantified) along two axis

Linguistic/language dimension classifications based on inspection of correlations with other WJ IV tests of *Gc* and *Ga* and Flanagan & Ortiz (2015) linguistic demand classifications

Tasks that make greater use of the *articulatory rehearsal* maintenance mechanism (Camos, 2015)

Verbal/linguistic working memory

Sentence Repetition

Nonword Repetition

Memory for Words

Verbal Attention

Understanding Directions

Object-Number Seq.

Numbers Reversed

Tasks that make greater use the of *attentional refreshing* maintenance mechanism (Camos, 2015)

Attentional control working memory

Low ← Hypothesized degree of central-executive attentional control network (cog. load; attentional control; degree of relational cognitive complexity) → High

Neuron
Perspective
CellPress

Neurocognitive Architecture of Working Memory

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"Many brain regions interact during working memory and include 'executive' regions in the PFC, parietal cortex, and basal ganglia, as well as regions specialized for processing the particular representations to be maintained, such as the fusiform face area for maintaining face information."

"Persistent neural activity in various brain regions accompanies working memory and is functionally necessary for maintenance and integration of information in working memory."

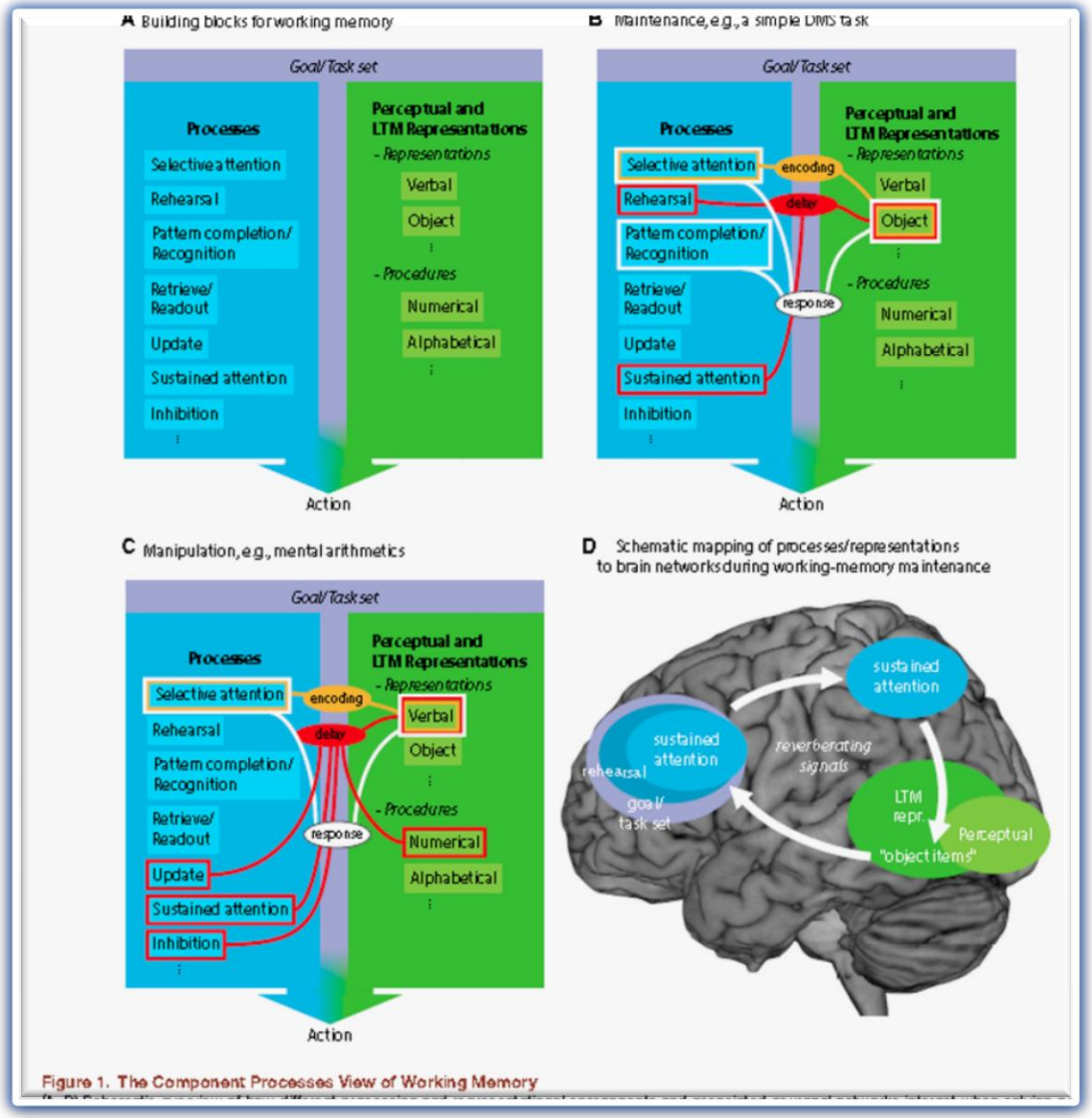
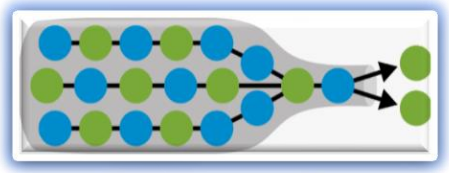
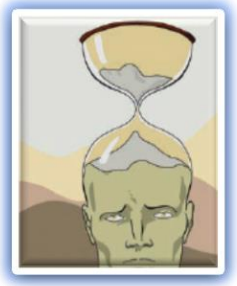


Figure 1. The Component Processes View of Working Memory

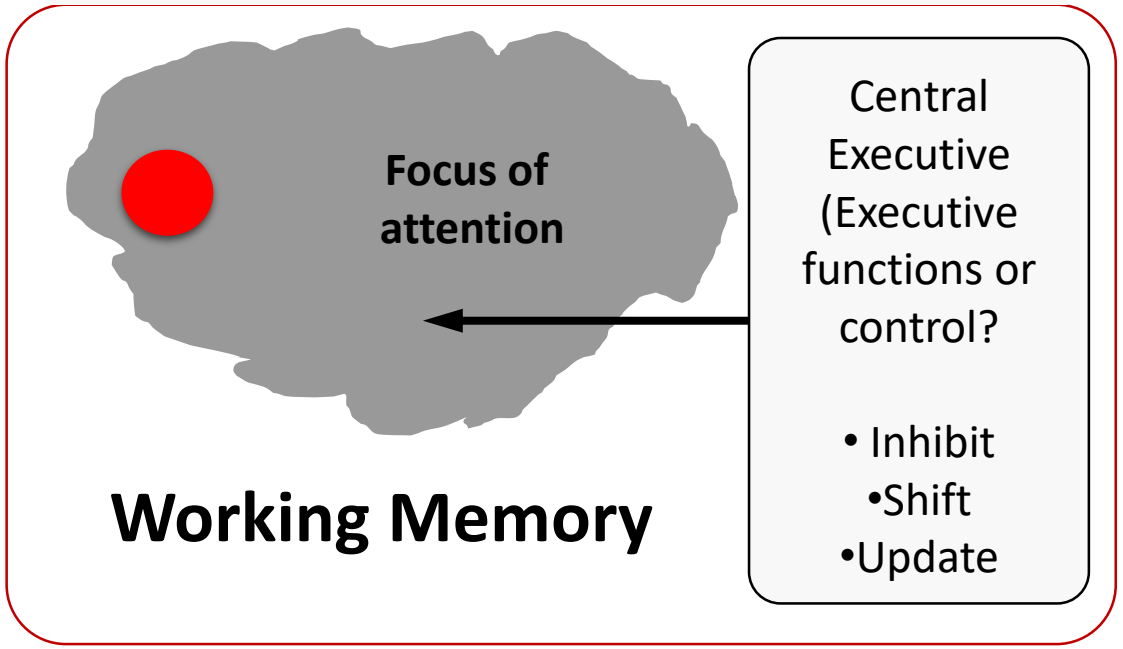
- Focus
  - Attentional Control
    - Working Memory
      - Executive Functioning

Executive control theory

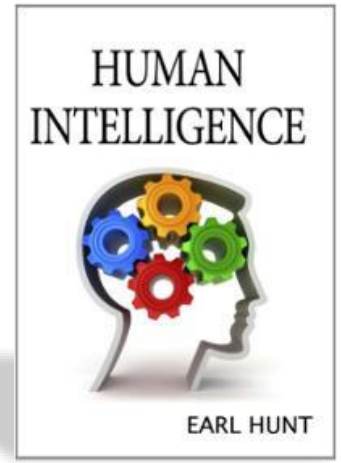


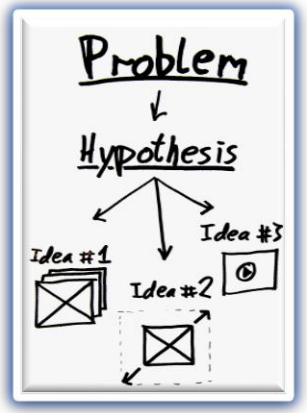


Attentional control system



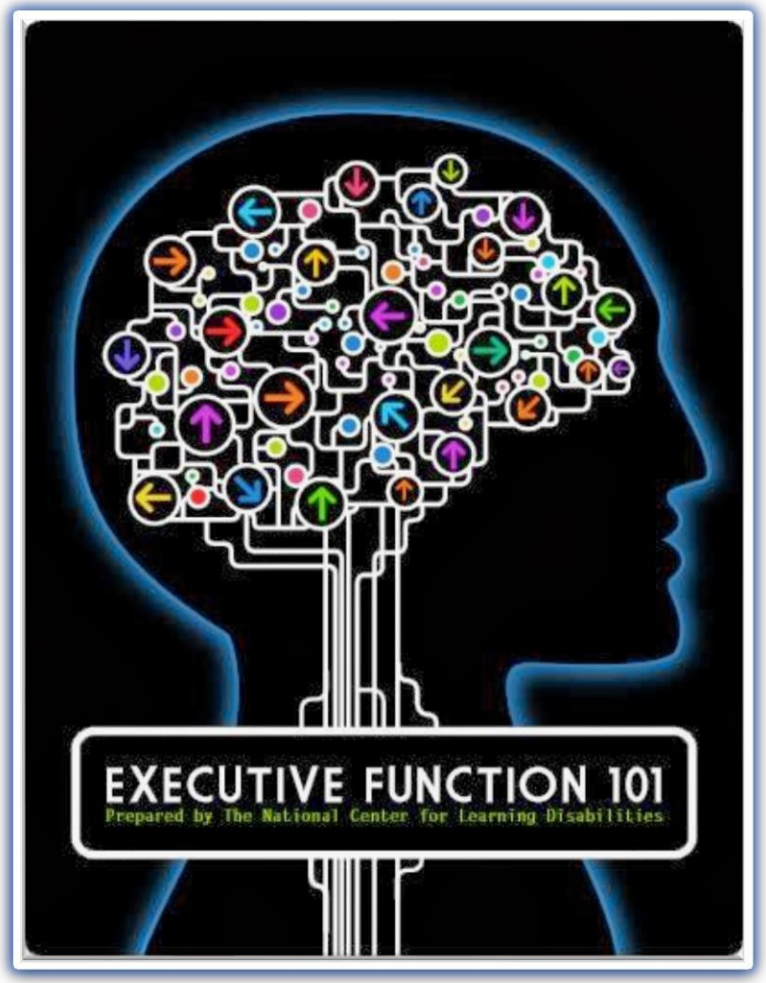
Hunt (2011) refers to this as the working memory—attention complex



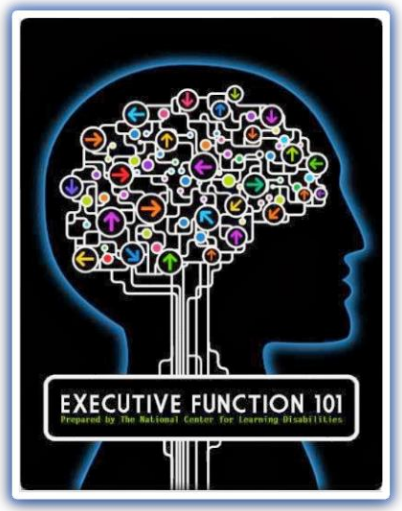


Significant differences between different tests of *Gwm* are to be expected and may be due to numerous variables (content, format, different underlying task demands that recruit different brain networks and cognitive control processes).

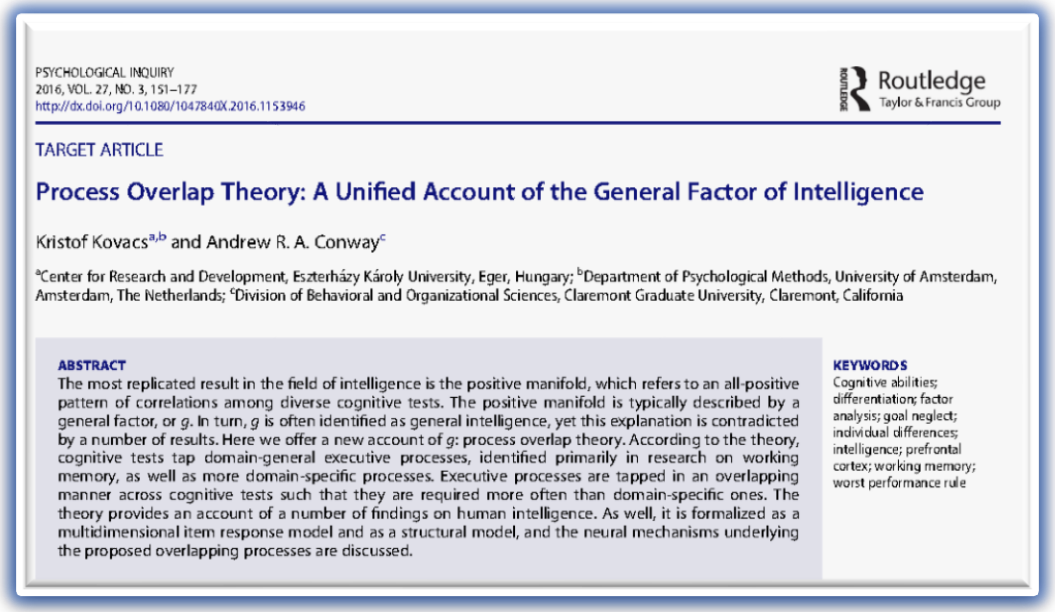
What about executive functions and the CHC model?



CHC-organized executive functions (EF) research



- Executive function does not represent an individual differences trait construct that should be incorporated in the CHC taxonomy.
- EF measures may not represent novel aspects of functioning in normal adults. They appear to be mixtures of CHC abilities.
- Additional research is needed to determine if the components of executive functions mentioned in the neuropsychological literature represent combinations, blends or amalgams of different CHC abilities in a distributed system or some yet to be validated executive function processes that are also part of certain CHC abilities.



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TARGET ARTICLE

Process Overlap Theory: A Unified Account of the General Factor of Intelligence

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ABSTRACT

The most replicated result in the field of intelligence is the positive manifold, which refers to an all-positive pattern of correlations among diverse cognitive tests. The positive manifold is typically described by a general factor, or *g*. In turn, *g* is often identified as general intelligence, yet this explanation is contradicted by a number of results. Here we offer a new account of *g*: process overlap theory. According to the theory, cognitive tests tap domain-general executive processes, identified primarily in research on working memory, as well as more domain-specific processes. Executive processes are tapped in an overlapping manner across cognitive tests such that they are required more often than domain-specific ones. The theory provides an account of a number of findings on human intelligence. As well, it is formalized as a multidimensional item response model and as a structural model, and the neural mechanisms underlying the proposed overlapping processes are discussed.

KEYWORDS

Cognitive abilities; differentiation; factor analysis; goal neglect; individual differences; intelligence; prefrontal cortex; working memory; worst performance rule

It is also possible that executive functions do not represent a real "thing" or psychological trait construct and instead are an emergent variable reflecting "control and controlled processes [which] are colocalized within larger numbers of dispersed computation agents" (and not a factor analytic individual differences variable)

A "set" of executive or control functions that serve as a "bridge" that connect more specialized networks of cognitive functions.

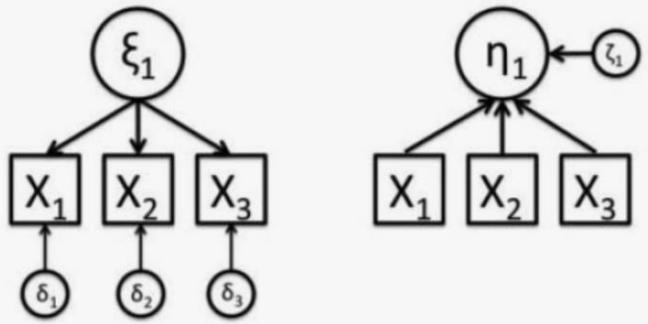


Figure 7. A reflective (left) and a formative (right) model.

PROCESS OVERLAP THEORY

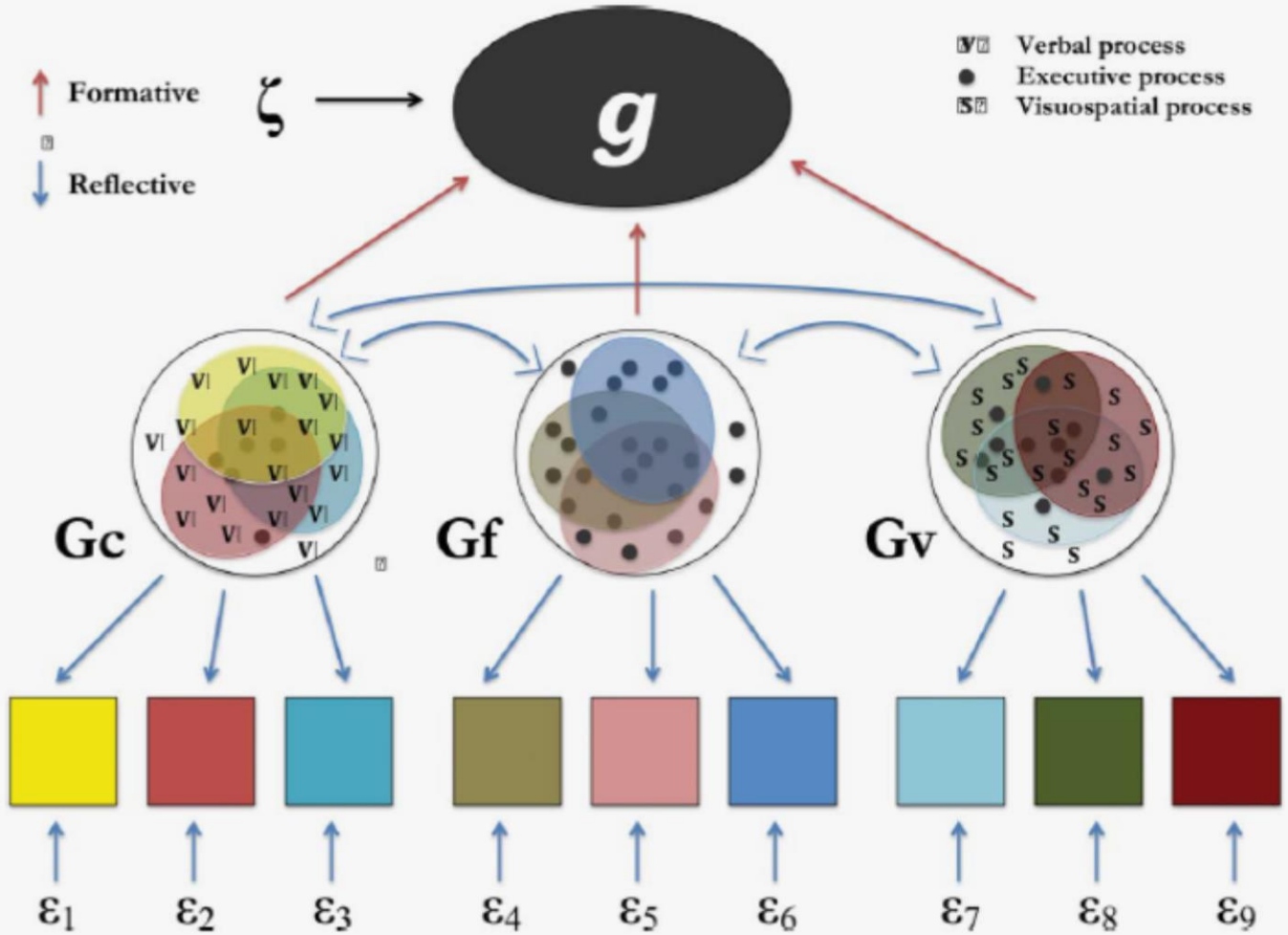
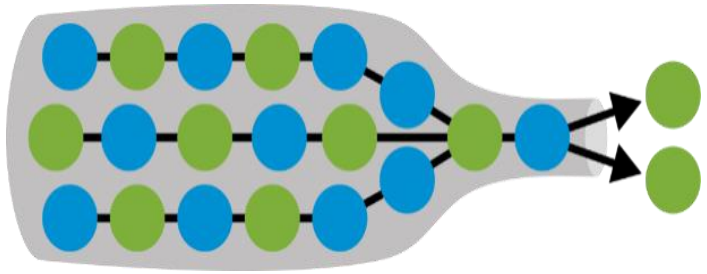


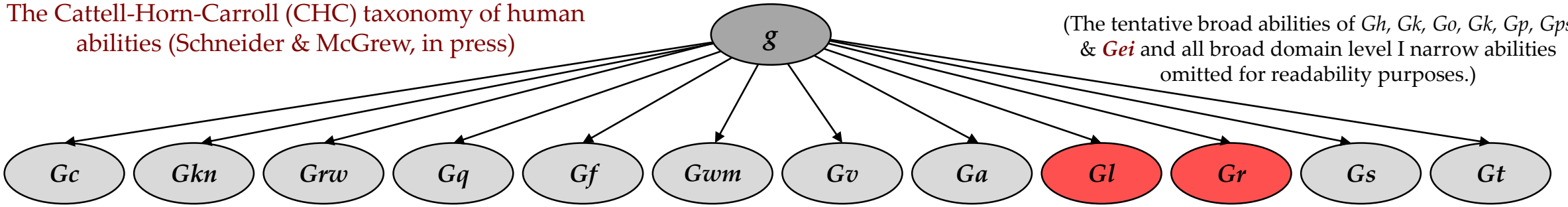
Figure 8. Process overlap theory as a latent variable model.

"Executive process act as a bottleneck"

Therefore, according to process overlap theory, *the processes sampled by different mental test items are not additive.* Each process has its own limitations, and each process has to be functioning at an appropriate level to arrive at a correct answer to a mental test item. Thus, executive processes act as a bottleneck, and they mask individual differences in specific abilities. Even if someone were, in theory, capable of successful performance on the domain-specific aspect of a mental test item, he or she might be unable to arrive at a correct answer because of failing to meet its executive attention demands.



The Cattell-Horn-Carroll (CHC) taxonomy of human abilities (Schneider & McGrew, in press)



(The tentative broad abilities of *Gh, Gk, Go, Gk, Gp, Gps* & ***Gei*** and all broad domain level I narrow abilities omitted for readability purposes.)

Comprehension-knowledge (Gc): The depth and breadth of declarative and procedural knowledge and skills valued by one's culture. Comprehension of language, words, and general knowledge developed through experience, learning and acculturation.	***Visual-spatial processing (Gv):*** The ability to use mental imagery, store images in primary memory, or perform visual-spatial analysis or mental transformation of images in the "mind's eye."
Domain-specific knowledge (Gkn): The depth, breadth, and mastery of specialized declarative and procedural knowledge typically acquired through one's career, hobby, or other passionate interest. The *Gkn* domain is likely to contain more narrow abilities than are currently listed in the CHC model.	***Auditory processing (Ga):*** The ability to perceive, discriminate, and manipulate sounds and information received through the ears. Includes the processing of auditory information in primary memory and/or the activation, restructuring, or retrieval of information from semantic-lexical memory based on phonemes.
Reading and writing (Grw): The depth and breadth of declarative and procedural knowledge and skills related to written language or literacy.	***Learning efficiency (Gl):*** The ability and efficiency to learn, store, and consolidate new information in long-term memory.
Quantitative knowledge (Gq): The depth and breadth of declarative and procedural knowledge related to mathematics. The *Gq* domain is likely to contain more narrow abilities than are currently listed in the CHC model.	***Retrieval fluency (Gr):*** The rate and fluency at which individuals can produce and retrieve verbal and nonverbal information or ideas stored in long-term memory.
Fluid reasoning (Gf): The use of deliberate and controlled focused attention to solve novel "on the spot" problems that cannot be solved solely by using prior knowledge (previously learned habits, schemas, or scripts). Reasoning that depends minimally on learning and acculturation.	***Processing speed (Gs):*** The ability to control attention to automatically and fluently perform relatively simple repetitive cognitive tasks. Attentional fluency.
Short-term working memory (Gwm): The ability to encode, maintain, and/or manipulate auditory or visual information in primary memory (while avoiding distractions) to solve multiple-step problems. The mind's mental "scratchpad" or "workbench."	***Reaction and decision speed (Gt):*** The speed at which very simple perceptual discriminations or decisions can be made.