Unraveling Human Intelligence

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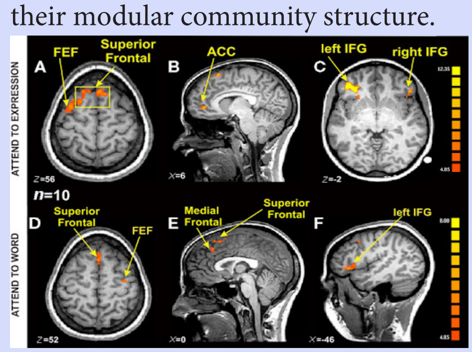
Research in the psychological and brain sciences are constantly reevaluating the embodiment of human intelligence, seeking to better understand the convergence of the diverse array of differences in intellectual abilities and the variety of neurobiological mechanisms that drive this overall impact on an individual. The Network Neuroscience Theory of Human Intelligence, brain networks, differences between fluid and crystalized intelligence, pattern separation, memory encoding, and how a person's genetics intersects with their environment are all critical components that drive the overall impact on an individual's intelligence.

The Network Neuroscience Theory prompts a discussion of how the brain network topology translates to general intelligence and differences at the individual level. The human brain's community structure alongside the functional topology heavily utilizes resting-state functional MRI (fMRI) in which neurologists have the ability to extract information such as the spontaneous low frequency fluctuations of the blood oxygen-level dependent (BOLD) signal (Barbey 2017). The BOLD imaging technique utilizes the regional differences in cerebral blood flow to describe regional activity and consequently produces images in fMRI studies. The capability for network states to efficiently and easily transition amongst one another lays the foundation for the general intelligence, also known as the g factor and denoted as g, which delegates the instantaneous exchange of information across networks and depicts individual variations of information on a global scale (Barbey 2017). An individual's general intelligence consists of a wide array of cognitive abilities that avail them in gaining knowledge and solving complex problems.

In essence, g allows researchers to better understand individual distinctions on the premises of studying brain network topology and dynamics (Barbey 2017). This imaging method displays consistency across spatially distributed regions that further impart intrinsic connectivity networks. To its core, intrinsic connectivity networks (ICNs) serve as a foundational aspect for organizational elements of the human brain architecture. In a like manner, ICNs have been used in multivariate decompositions of fMRI data alongside the use of independent component analysis. Independent component analysis is particularly useful for the field of digital imaging as it serves as a statistical and computational technique that bestows various subcomponents derived from the separation of multivariate signals. This method concludes that the subcomponents are classified as non-Gaussian signals and that they remain statistically independent of each other. Furthermore, independent component analysis falls under the category of blind source separation. Blind source separation is the process of differentiating between mixed signals and a set of source signals whilst having none or next to a limited amount of information in regards to the mixing process and source signals. To put source separation into a real world application, the human "cocktail party problem" describes a phenomenon where the brain has the ability to focus on one stimulus in the midst of a noisy social setting (Bee and Micheyl 2009).

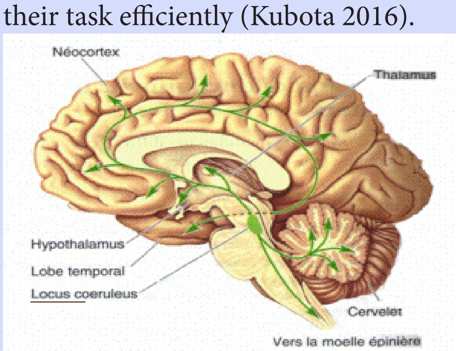
ICNs ultimately encapsulate how task-based neuroimaging and resting state data portrays resting state networks. These networks are areas of the brain that delineate discrete compositions of brain function. Additionally, resting state networks incorporate the selection of large-scale functionality connected brain networks. These networks are a collection of widespread brain regions that utilize statistical analysis through the use of methods such as the fMRI BOLD signal, PET, and EEG (Laird et al. 2011). The Network Neuroscience Theory additionally suggests that the g arises "from individual differences in the system-wide topology and dynamics of the human brain" (Barbey 2017). This new found perspective stimulates the conversation that the small-world topology of brain networks composes an instantaneous rearrangement of their modular community structure.



In this image, figure (A) is representative of the Axial view and presents the Superior Frontal activation. Figure (B) displays a lateriles FEF activation of the left hemisphere. Figure (C) presents an axial image of the bilateral IFG a7tivation. In figure (D) there is an Axial view that presents the Superior Frontal activation alongside a lateralized FEF activation on the right hemisphere. Figure (E) illustrates a Sagittal view that depicts a centered position of the Superior and Medial Frontal regions. Figure (F) depicts a Sagittal view that is centered on the left.

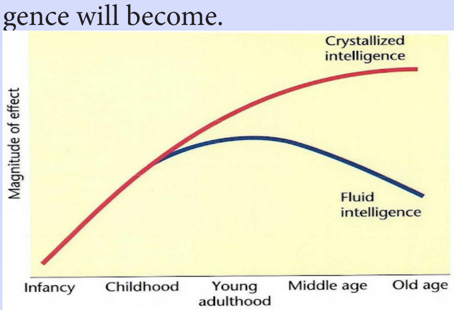
In essence, globally interrelated mental representations are generated in addition to the events that need to be carried out in order to attain the desired goal-state (Barbey 2017).

In the light of analyzing the interactions between brain networks, Stanford scientists have conducted research encompassing the complex fluctuations in our brain networks and how the oscillating patterns begs the question on why certain tasks are learned at a more rapid pace in some individuals in comparison to others. Researchers utilized pupil size measurements to gauge at how the brain reacts to shifts in connectivities. The significance of pupil size is that it measures the activity of the locus coeruleus, which is located in the upper region of the brainstem and is responsible for brain synthesis of the noradrenaline as well as regulating signals throughout the brain. Adding more power to the amplification of strong signals alongside the muting of weak signals across the brain are characteristic of an increase in pupil size (Kubota 2016). In essence, the researchers derived a link between changes in brain connectivity during rest and pupil size and found that larger pupils were linked to greater connectedness. This erudite finding ultimately led to the proposal that the noradrenaline is the impeccable impetus that makes the brain more cohesive in the midst of demanding cognitive tasks, which overall benefits the individual as they perform their task efficiently (Kubota 2016).



This diagram illustrates the anatomy of the locus coeruleus.

Fluid intelligence denotes a higher dynamic connectivity and network flexibility than crystallized intelligence, because of this, it exhibits more inconsistencies on the topic of age and over the course of generations. Intelligence goes beyond the scope of being able to recollect and recite vast amounts of information. It epitomizes one's ability to digest new information and use it in various applications. Intelligence encapsulates being able to solve problems through the convergence of a multitude of abilities such as memory, learning, perception, problem solving, and reasoning. Crystalized intelligence stems from knowledge that is acquired through the basis of past experiences and previous information learned. As a person gets older, they will gain more knowledge and develop a stronger understanding of various subject matters. Therefore, crystalized intelligence and age display a positive and linear trend. With that, the older a person is in age, the stronger their crystallized intelligence will become.



This graph illustrates how the magnitude of effect in terms of fluid intelligence declines over the course of infancy to old age. The opposite is seen here when the magnitude of effect in terms of crystalized intelligence continuously increases until it begins to level off when an individual reaches old age.

Fluid intelligence demonstrates the ability to solve problems through abstract thinking and reasoning. Fluid intelligence does not involve any prior experience or education and is solely based on one's ability to reason and solve complex problems upon initial exposure to them. Fluid intelligence forces an individual to adapt and think abstractly when faced with a new problem that he has never seen before. When scrutinizing the network states concerned in both fluid and crystallized intelligence, crystallized intelligence recruits easy-to-reach network states, which retrieve experiences and previous knowledge gained. In contrast, fluid intelligence assembles difficult-to-reach network states that are responsible for aiding in cognitive function, versatile reasoning, and problem-solving (Barbey 2017).

Unlike crystallized intelligence, fluid intelligence declines during late adulthood as these critical cognitive abilities decrease with age. Accordingly, crystallized intelligence reaches its apex typically between the age range of 60 to 70 years old while fluid intelligence has the potential to reach its climax around the age of 20 years old and consequently begin to level off following this age (Trafton 2015). On the contrary, a study encompassing the peak of cognitive abilities in an individual's lifetime in the Psychological Science Journal denotes that subjects are capable of reaching the peak of their fluid intelligence well into their 40s or later (Hartshorne and Germine 2015).

There has also been increasing evidence that engenders the idea that individual differences in crystallized and fluid intelligence emulate vast differences in terms of the ability of each ICN to transition between network states. To extend, population studies have revealed that generational changes, in addition to a decrease in cognitive abilities, have a larger effect on fluid intelligence as opposed to crystallized intelligence. In a like manner, the Network Neuroscience Theory adjudges these results in terms of global network dynamics. Global network dynamics showcase correlation patterns that are suited in accordance to the empirical BOLD functional connectivity (Cabral 2014).

In a like manner, memory encoding plays a substantial role in emphasizing human intelligence and furthermore distinguishing humans from all other organisms. One study gave each of their subjects standardized neuropsychological tests which were used to measure intelligence, and language and memory functionality (Morcom 2003). The experiment was designed to administer the exams in an hour and a half session before the MRI scanning session was set to begin

(Morcom 2003). The Folstein Mini Mental State test (MMS) was the first exam given to the older participants and the National Adult Reading Test (NART) was utilized to measure crystallized verbal intelligence. The Raven's Advanced Progressive Matrices II was used to measure 'fluid' non-verbal intelligence and the subjects were not timed when taking this exam. The results of the neuropsychological test performance demonstrated that the older subjects displayed a higher verbal IQ based off of their performance on the National Adult Reading Test. In contrast, the older participants displayed a much lower fluid IQ which was measured by the Raven's Advanced Progressive Matrices and a much worse long-term memory in respect to the younger subjects.

It is unreasonable to delineate an exact or approximate age at which an individual's cognitive abilities will peak or begin to decline as several cognitive functions differ drastically from each other and are independent from one another. Joshua Hartshorne, a postdoc in MIT's Department of Brain and Cognitive Sciences, states the discrepancies between being able to pinpoint ages throughout a lifespan, "At any given age, you're getting better at some things, you're getting worse at some other things, and you're at a plateau at some other things. There's probably not one age at which you're peak on most things, much less all of them" (Trafton 2015). This discovery changed the way that psychology and neuroscience tracks the progress of cognitive abilities and drastically contradicts the conventional perspectives.

The study of neurons and their role in memory storage in mehumans ultimately lays the foundation and epitomizes human intelligence such as creative thinking and generalization. The hippocampus is the brain region responsible for memory storage and ensures that memories are independent of one another by storing them into separate groups of neurons (University of Leicester 2020). Pattern seperation is a fundamental principle of neuronal coding that discerns the differences between memories and experiences in the hippocampus (University of Leicester 2020). Several studies have put a primary focus on examining pattern separation in individuals well into their late adulthood. One laboratory conducted several experiments on the basis of behavioral pattern separation and configured recognition tasks that prompted regions within the parahippocampal gyrus to either reject or recall the tasks (Kirwan and Stark 2007). The recall-to-reject process is commonly used in associative-recognition tasks and gives an individual plenty of time during the recall process when imparting recognition judgements (Rotello et al. 2000). During the task, pictures of objects were repeatedly shown or shown once to the individual throughout the duration of the task. Some objects heavily resembled the ones previously shown and this conjoining aspect of the study encouraged pattern separation processes. Functional magnetic resonance imaging (fMRI) was used to monitor activity in the dentate gyrus (DG). This particular brain region was sensitive to the lures used throughout the tasks and this demonstrated a critical contribution to pattern separation in both an indirect and direct rendition of the task (Stark et al. 2010). Researchers Chelsea K Toner, Eva Pirogovsky, C Brock Kirwan, and Paul E Gilbert presented the idea that older adults have a greater likelihood of categorizing the lures as repeated in comparison to younger adults in the experiments (Stark et al. 2010).

When we think of intelligence, some may automatically direct attention to natural born capabilities or genetic influences, but intelligence is rather a combination of environmental and genetic factors that drive an individual's overall intelligence. Likewise, the heritability of traits is measured on a scale of 0 to 1.0. Eye color is highly genetic with a heritable score of 0.99. Intelligence depicts a heritability score of 0.8 which is considerably high but researchers frequently point out the misconceptions centered around this score and misconstruing the significance that the environment plays in determining an individual's overall intelligence. An individual's intelligence is most malleable when he/she begins early elementary school. Opportunities within their schooling system and community will ultimately reinforce the prosperity of cognitive abilities over time. Louis Matzel, a professor of psychology at Rutgers-New Brunswick, speaks to the importance of an individual's environment by stating, "the environment is the critical tool that allows our genetic equipment to prosper" (Branson 2018). Dana Charles McCoy, assistant professor at the Harvard Graduate School of Education, led the examination of the influence of classroom-based early childhood education (ECE) specifically focused on grade retention, high school graduation, and special education placement (Walsh 2017). The main takeaway stands that children attending high-quality ECE programs are less likely to be held back in a grade level, less likely to be put into special education, and have a higher chance of graduating from high school than individuals not placed in these programs over the course of the last 40 years (Walsh 2017). Special education is defined as instruction that is specifically tailored to the individual in order to meet their unique needs of an individual with a disability (U.S. Department of Education 2017).

Numerous opportunities presented during a child's early education are the cornerstone at which they can grow tremendously. Taking full advantage of these endless possibilities is an excellent way for children to excel early on in their lives. McCoy calls attention to families and encourages them that their child's education is a valuable investment as she states, "...it plays an important role in supporting children's cognitive ability in language, literacy, and math, as well as social skill development and emotional growth"

(Walsh 2017).

Intelligence is a pliable ability that can improve with time given that an individual is continuously promoting healthy lifestyle habits for themselves such as exercising regularly, which promotes the growth of neurons, augmenting brain function and structure and increasing the volume of the hippocampus (Brinke et al. 2015). In addition to being physically active, getting an adequate amount of sleep is another key method in promoting prime cognitive function and ensuring that one is ready to learn something new. Through the power of generalization and epitome of creative thought, humans cultivate the true meaning of intelligence and within their unique abilities in memory storage. Although genetics play a substantial role in intelligence, the opportunities and an individual's upbringing can create a significant impact as well. Through the Network Neuroscience Theory, one can utilize the brain network topology to decipher between intellectual differences at the individual level.

References

Aron K. Barbey. (2018) Network Neuroscience Theory of Human Intelligence, Trends in Cognitive Sciences, Volume 22, Issue 1, Pages 8-20, ISSN 1364-6613, https://doi.org/10.1016/j.tics.2017.10.001.

Bee, Mark A, and Christophe Micheyl.(2008) "The cocktail party problem: what is it? How can it be solved? And why should animal behaviorists study it?." Journal of comparative psychology (Washington, D.C. : 1983) vol. 122,3: 235-51. doi:10.1037/0735-7036.122.3.235

Branson, Ken.17 Jan. 2018, "Inherited IQ Can Increase in Early Childhood." Rutgers University, www.rutgers.edu/news/inherited-iq-can-increase-early-childhood.

Davies, Huw. "Functional Magnetic Resonance Imaging [FMRI]." EBME, EBME, www.ebme.co.uk/articles/clinical-engineering/functional-magnetic-resonance-imaging-fmri.

Hartshorne, Joshua K, and Laura T Germine. 4 (2015), "When does cognitive functioning peak? The asynchronous rise and fall of different cognitive abilities across the life span." Psychological science vol. 26: 433-43. doi:10.1177/0956797614567339

Joana Cabral, Morten L. (2014) Kringelbach, Gustavo Deco,Exploring the network dynamics underlying brain activity during rest, Progress in Neurobiology, Volume 114, Pages 102-131, ISSN 0301-0082, https://doi.org/10.1016/j.pneurobio.2013.12.005. (http://www.sciencedirect.com/science/article/pii/S0301008213001457)

Kirwan, C Brock, and Craig E L Stark. 6 Sep. 2007, "Overcoming interference: an fMRI investigation of pattern separation in the medial temporal lobe." Learning & memory (Cold Spring Harbor, N.Y.) vol. 14,9 625-33. doi:10.1101/lm.663507

Kubota, Taylor. 30 Sept. 2016, Stanford Scientists Uncover How a Fluctuating Brain Network May Make Us Better Thinkers, Stanford News Service, news.stanford.edu/press-releases/2016/09/30/fluctuating-brai-better-thinkers/.

Laird, Angela R et al. (2011) "Behavioral interpretations of intrinsic connectivity networks." Journal of cognitive neuroscience vol. 23,12: 4022-37. doi:10.1162/jocn_a_00077

"Sec. 300.39 Special Education." 2 May 2017, Individuals with Disabilities Education Act, Individuals with Disabilities Education Act, sites.ed.gov/idea/regs/b/a/300.39. https://sites.ed.gov/idea/regs/b/a/300.39

Stark, Shauna M et al. 21 May. 2010, "Individual differences in spatial pattern separation performance associated with healthy aging in humans." Learning & memory (Cold Spring Harbor, N.Y.) vol. 17,6 284-8 doi:10.1101/lm.1768110

ten Brinke, Lisanne F et al. 4 (2015), "Aerobic exercise increases hippocampal volume in older women with probable mild cognitive impairment: a 6-month randomised controlled trial." British journal of sports medicine vol. 49: 248-54. doi:10.1136/bjsports-2013-093184

Trafton, Anne. 6 Mar. 2015, "The Rise and Fall of Cognitive Skills." MIT News | Massachusetts Institute of Technology, Massachusetts Institute of Technology, news.mit.edu/2015/brain-peaks-at-different-ages-0306. https://news.mit.edu/2015/brain-peaks-at-different-ages-0306

Laird, Angela R et al. (2011) "Behavioral interpretations of intrinsic connectivity networks." Journal of cognitive neuroscience vol. 23,12: 4022-37. doi:10.1162/jocn_a_00077

"Sec. 300.39 Special Education." 2 May 2017, Individuals with Disabilities Education Act, Individuals with Disabilities Education Act, sites.ed.gov/idea/regs/b/a/300.39. https://sites.ed.gov/idea/regs/b/a/300.39

Stark, Shauna M et al. 21 May. 2010, "Individual differences in spatial pattern separation performance associated with healthy aging in humans." Learning & memory (Cold Spring Harbor, N.Y.) vol. 17,6 284-8 doi:10.1101/lm.1768110

ten Brinke, Lisanne F et al. 4 (2015), "Aerobic exercise increases hippocampal volume in older women with probable mild cognitive impairment: a 6-month randomised controlled trial." British journal of sports medicine vol. 49: 248-54. doi:10.1136/bjsports-2013-093184

Trafton, Anne. 6 Mar. 2015, "The Rise and Fall of Cognitive Skills." MIT News | Massachusetts Institute of Technology, Massachusetts Institute of Technology, news.mit.edu/2015/brain-peaks-at-different-ages-0306. https://news.mit.edu/2015/brain-peaks-at-different-ages-0306

University of Leicester. 5 November 2020 ,"Human intelligence just got less mysterious." ScienceDaily. ScienceDaily. <www.sciencedaily.com/releases/2020/11/201105113006.htm>.

Caren M Rotello, Neil A Macmillan, Gordon Van Tassel, Recall-to-Reject in Recognition: Evidence from ROC Curves, Journal of Memory and Language, Volume 43, Issue 1, 2000, Pages 67-88, ISSN 0749-596X, https://doi.org/10.1006/jmla.1999.2701. https://www.sciencedirect.com/science/article/pii/S0749596X99927018?via%3Dihub