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Impact of Cognitive Reserve on Cognitive Flexibility; Mediating Role of Education.

Ms. Shivani Tanwar[1]
Ph.D. Scholar, School of Behavioral Forensics, National Forensic Sciences University,
Dr. Smita Pandey[2]
Associate Professor, School of Behavioral Forensics, National Forensic Sciences University

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Abstract
The concept of Cognitive Reserve (CR) refers to the brain's ability to maintain function despite damage or pathology, influenced by individual differences in neural and cognitive resources. This study explores the relationship between Cognitive Reserve and Cognitive Flexibility (CF), focusing on the mediating role of education. Using a sample of 120 individuals from Gujarat, India, divided based on their educational attainment (below and above primary education), the study employed various cognitive measures, including the Cognitive Reserve Index Questionnaire (CRIQ) and the Wisconsin Card Sorting Test (WCST), to assess CR and CF, respectively. Statistical analyses revealed significant positive correlations between CR and CF, CR and education, and education and CF. The mediation analysis confirmed that education significantly mediates the relationship between CR and CF, highlighting its critical role in enhancing cognitive reserve and flexibility.

Keywords- Cognitive Reserve, Cognitive flexibility, Educational attainment.

Introduction

Cognitive Reserve is the brain's ability to maintain optimal functioning despite brain damage or pathology, influenced by individual differences in neural and cognitive resources. It allows healthy and cognitively impaired adults to compensate for cognitive decline, focusing on mental flexibility and efficiency. This reserve can be manipulated by Education, occupation, leisure activities, and social engagement. Cognitive Reserve predicts brain pathology outcomes and mediates between pathology and cognitive decline symptoms. It involves robustness of cognitive functions against pathology and ability to use alternative functions. (Stern 2002).

The Reserve Hypothesis suggests that cognitive reserve, similar to brain reserve, is the "software" of cognitive paradigms that can sustain disruption and operate effectively. It suggests that individuals with more reserve process tasks more efficiently than those with less reserve. The hypothesis explores individual variability in cognitive information processing, mental tasks, and neurodegenerative disease coping, influencing the severity of clinical symptoms after the

threshold of their appearance. The reserve hypothesis consists of two models: passive and active. The passive model, also known as "Brain Reserve," refers to the that brain size positively influences competence to navigate pathology without clinical impairment while the active model, "cognitive reserve," take life experiences like Education and stimulating activities protect individuals from brain damage or pathology by decreasing memory decline(see Stern, 2002, 2006, 2009).The passive model, also known as cerebral reserve, refers to the brain's ability to withstand brain damage before disease symptoms appear. It suggests that individuals with larger brain volumes or more neurons can withstand greater brain insults than those with smaller brain volumes. However, testing this hypothesis requires rare measures like baseline data. (Katzman, 1993 & Mortimer 1981). The Threshold Model, as reviewed by (Satz 1993), focuses on Brain Reserve Capacity (BRC), a hypothetical construct that acknowledges individual differences and critical thresholds. If synapses are depleted above a threshold, initial symptoms of dementia may appear, but severe symptoms can lead to Alzheimer's disease diagnosis. Cognitive differences in reserve capacity affect the expression of clinical symptoms, with individuals with more reserve experiencing severe synapse loss before symptoms appear. The model suggests that reserve is between pathology and clinical outcomes.

Proxies of Cognitive Reserve

Cognitive Reserve(CR) is a modifiable factor that can enhance cognitive function in aging both normal and pathological (Stern, 2002; Scarmeas and Stern, 2004; Soldan et al., 2020). It can be improved through cognitively, mentally, and physically stimulating activities. Factors like, Education, occupation complexity, premorbid intelligence quotient and hobbies can measure CR. (Reed et al., 2010; Jones et al., 2011; Clare et al., 2017,).There are three factors that are considered the proxies of Cognitive Reserve which is Education, Occupation and leisure activities (Nucci et al., 2011).**Education** significantly impacts cognitive decline in age-related individuals. Lower Education levels lead to declines in functional systems, memory, and verbal skills, while higher Education levels increase conceptualizing ability and processing abilities, which delay the onset of neurodegenerative illnesses. Education levels are independently associated with higher dementia prevalence, implying the brain's ability to tolerate gradual insults and compensate for pathology through optimal use of existing cognitive networks. Formal Education significantly influences the full functionality and autonomy of the elderly, as well as their Cognitive Reserve and cognitive capacity. (Stern et al.,1994; Stern 2009, Bessi et al., 2018; Mazzeo et al., 2019;) Reading and writing skills, primarily acquired from formal Education, are crucial for cognitive extension and cognitive reserve, preserving functional autonomy and preventing aging-related cognitive decline. (Scarmeas and Stern 2003, 2006; Ardila et al., 2010; Pettigrew and Soldan, 2019;) **Occupation** refers to non-formal Education acquired through professional experiences, which develops specialized skills over time, it can influence fluid reasoning and optimal cognitive performance in the future, independent of factors like Education and intellect, Complex work can motivate individuals to perform better, encouraging neuronal plasticity. Occupation acts as a protective role on higher cognitive functioning, such as intellect, by analysing the complexity of tasks.

The Cognitive Reserve hypothesis suggests that **leisure activities** can enhance Cognitive Reserve and enhance cognitive resilience against brain injury. (Stern, 2002), Leisure activities, including intellectual, social, and physical activities, can increase CR separately or synergically. These studies use various instruments to record various types, numbers, target periods, and frequencies, indicating that adult experiences can affect reserve.(Wilson et al., 2002, Scarmeas et

al., Crowe et al., 2003, Solé-Padullés et al., 2009) Cognitively stimulating activities, such as information seeking or processing, have been linked to maintaining higher cognitive function during healthy aging and reducing the risk of Alzheimer's disease.

Cognitive flexibility (CF) is a key aspect of Executive Function (EF) that aids in new flexibility by allowing individuals to shift their cognitive set, thought, or attention to respond to different situations. This ability to produce diverse ideas, consider response alternatives, modify behaviour and cognition in response to changing environmental demands is more common in older adults compared to younger adults. Cognitive flexibility refers to an individual's ability to adapt cognitive processing strategies to new and unexpected environmental conditions (Cañas et al. 2003). It involves Cognitive Flexibility from experiences, adapting cognitive processing strategies, and navigating problem space. However, flexibility doesn't always occur, and cognitive inflexibility occurs when an individual fails to adapt to changes. Research on this topic offers explanations for this phenomenon. Cognitive flexibility is a crucial skill that requires attentional control and the ability to adapt to changing situations. It involves recognizing environmental conditions and rearranging actions to address new task demands. It also involves how individuals represent their knowledge about a task and potential strategies. Spiro and Jehng's (1990) Cognitive Flexibility Theory suggest that people who represent tasks from multiple perspectives can easily interpret environmental changes, making them more cognitively flexible. This allows them to quickly restructure their knowledge and adapt their responses to changing situational demands.

Mediating Role of Education

Education has been shown to have a protective effect against dementia and Alzheimer's Disease (AD). Research indicates that higher Education levels reduce the risk of developing dementia. Education boosts cognitive reserve, preventing the onset of clinical expression of neurodegenerative illnesses by maintaining global cognitive efficiency (Carret et al., 2003). Education also increases synaptic density and promotes intellectual and creative activity, leading to lifelong neuronal activity. This positive impact on cerebral growth and cognitive processes is due to Education, providing resilience to cerebral lesions (Friedland and Katzman (1993).

Education may serve as a protective factor against cognitive decline in later life, as higher levels of Education are linked to functional independence and cognitive test performance in non-demented elderly individuals. Studies have shown a crossover between lower levels of Education and the risk of developing Alzheimer's Disease. This suggests that Education provides a "reserve" capacity, allowing individuals to resist the harmful effects of aging and disease on brain function. However, greater Education may be associated with severe age-related changes in brain structure, such as parenchymal atrophy and increased CSF volume. This hypothesis is supported by studies of patients with Alzheimer's Disease. (C.offey et al., 1999)

According to a study conducted by Farfel et.al. (2013), even few years of Education can contribute to the CR of an individual. They conducted a neuropathological exam using immune histochemistry along with a structured interview, a clinical dementia rated scale in 675 people and multivariate linear regression models were conducted to determine the Education level and CR.Lopez et.al. (2014) conducted a Magnetoencephalography while performing a memory task (Sternberg's task) on healthy elderly people where the results showed that people with low level of Education and occupational attainment showed greater connectivity while performing the task which suggests that they need more efforts while doing a task. People with low CR need great effort and show more connectivity while performing any cognitive function. More efforts while

performing a task suggest that it was much more difficult for the people with low Educational levels to do that task and also, they have low CR levels.

Education level can also help in the potential risks of operative ailments. In a metanalysis study by Feinkohl& Winterer (2017), they suggested that patients with better Education are at reduced risk of post-operative cognitive dysfunction as compare to patients with low levels of Education or no Education; which further indicated towards better Cognitive reserve.

Reserve is a theoretical construct that explains individual differences in cognitive performance associated with neuropathological changes in various disorders (Satz, Cole, Hardy, &Rassovsky, 2010; Stern, 2009; Whalley, Deary, Appleton, & Starr, 2004). It is applicable to a broad array of clinical disorders (Sachdev & Valenzuela, 2009) and describes variability across persons in the relationship of pathologic changes with disease expression (Satz, 1993; Studenski et al., 2006). Two models of reserve pertaining to cognitive functioning are brain and cognitive. Brain reserve is passive, evoked by a critical level of brain capacity, while Cognitive Reserve is active, involving greater efficiencies in pre-existing cognitive processes or alternative processes(Stern, 2009).

The concept of CR has evolved significantly in the literature on normal and pathological aging, despite theoretical pitfalls and methodological controversies. Challenges include the lack of an operational definition, clarification of neural bases, relationship between brain and CR, and factors affecting brain reserve. A consensus report aims to clarify CR terminology by claiming "resilience" as an umbrella concept encompassing multiple reserve-related concepts. (Álvares-Pereira et al., 2022).

Cognitive Reserve is the brain's ability to cope with brain damage caused by aging or disease by recruiting pre-existing cognitive processing networks. (Scarmeas & Stern, 2003; Stern, 2012), It is influenced by life experiences and genetic characteristics (Puccioni&Vallesi, 2012b). Standard proxies for measuring Cognitive Reserveinclude Educational attainment, occupation, and leisure activities (Nucci, Mapelli, & Mondini, 2011). Also, assumed that more Education, cognitively demanding work, and leisure involvement may help retain cognitive function in older adults, as these factors are considered indicators of cognitive reserve. (Arbuckle,Gold, & Andres, 1986; Hall et al., 2009; Jefferson et al., 2011; Opdebeeck, Martyr, & Clare, 2016).

A study by Ansiau et al. found a significant correlation between cognitive performance, attention tests, memory, and processing speed, but did not establish a causal relationship between stimulating work environment and cognitive stimulation. Richards et al. suggest that cognitive capabilities can be influenced by various factors, including work complexity, which can measure Cognitive Reserve and add variance to later cognitive functions. Baldivia and Beuno found that work-level complexity enhances executive planning performance, regardless of cofounding variables. These findings highlight the importance of considering various influencing factors in cognitive development.

The relationship between leisure activities and cognitive function varies depending on the type of activity, but inconsistent results have been found in older adults. (Hughes, 2010; Kuster et al., & 2016; Stern & Munn, 2010). However, cognitive leisure activities have been linked to a lower risk of vascular cognitive impairment and a lower risk of dementia (Verghese, Wang, Katz, Sanders, & Lipton, 2009), though not social, physical, or recreational activities. Physical activities are among the most protective factors against cognitive decline, as demonstrated through meta-analytic (Lovden, Xu, & Wang, 2013) and longitudinal approaches (Ku, Stevinson, & Chen, 2012). These inconsistencies can be partly attributed to categorizing each leisure

activity differently or collapsing all content into one category called "leisure activity."(e.g. Lee, Kim, & Back, 2009, Park et al., 2018)

Studies in past have provided general information on the relationship between leisure activities and cognitive function, yet it is more important to examine these associations individually. Each leisure activity has unique characteristics and some of the studies have demonstrated the relationship between each activity and cognitive function. Reading books, solving puzzles, playing games and engaging in computer or craft activities have been found to decrease the likelihood of mild cognitive impairment, while social activities are marginally significant. (Gedaet al., 2011, Park et al., 2018)

The inconsistent results suggest a moderating factor between leisure activities and cognitive function, possibly Education. Education is associated with higher cognitive function and lower dementia risk. (Marioni, Hout, Valenzuela, Brayne, & Matthews, 2012; Meng & D'Arcy, 2012; Sattler et al., 2012). There are three factors that are considered the proxies of Cognitive Reserve which is Education, Occupation and leisure activities (Nucci et al.,2011) Only Education has been related to Gray and white matter volume, highlighting its widespread impact on brain function (Foubert-Samier et al., 2012).(Park et al., 2018)

Cross sectional Studies Indicates the relationship between cognitive decline and occupation, which a can be controversial (Bonaiuto,1995) Occupation type may predict dementia but failed to show such association (callahan,1996) while other researches focused on the possible relationship between the social and leisure activity, PAQUID data has shown regular participation in activities like travelling, odd jobs, knitting or gardening is linked to lower risk of subsequent dementia, while decreased physical activity is more likely to develop AD (Fabrigoule et al., 1995 Kondo, Niino, and Shido 1994).

A study of Cognitive Reserve(CR) in super agers examines the cognitive profile of elderly individuals 80 years or older, known as Super Agers, who exhibit exceptional performance in cognitive tests, including episodic memory capacity comparable to the average in their 50s and 60s, and superior memory capacity despite age. Super Agers have brains with less atrophy, a higher density anterior cingulate cortex, Significant amount of Von Economos Neurons increased functionality and lower AD incidence compared to cognitively normal older adults. The anatomical-structure showing daily life functionality, preserving mental capacity for coherent decisions with autonomic cognitive function. Cognitive Reserve is a key factor in preventing cognitive decline, Super Agers exhibit superior cognitive tasks compared to their age group due to their developed reserves and greater neuroplasticity throughout their life. (Balduino et al., 2019). Cognitive flexibility is a crucial aspect of EF, enabling individuals to adapt their cognitive set, thought, or attention to different situations (Eslinger and Grattan, 1993, Rende, 2000), thereby facilitating new Cognitive Flexibility and enabling them to, consider alternative responses, and modify behaviour and cognition in response to changing environmental demands as well as generate diverse ideas. (Rende, 2000)

Methodology

Aim

To determine the relation between Cognitive reserve and Cognitive flexibility and to identify the mediating role of Education levels in People having education below primary level and above primary level.

Hypothesis

H_{01}- There is no significant relation between Cognitive reserve score (T_CRIQ) and cognitive flexibility (Learning to learn concept) of an individual.

H_{02}- There is no significant relation between Cognitive reserve score and educational levels (Edu).

H_{03}- There is no significant relation between education and cognitive flexibility.

H_{04}- Education levels have no mediation effects between Cognitive reserve score and Cognitive flexibility.

Sampling Technique

Convenient Sampling technique has been utilized to extract out the sample from various villages and colleges of Gujarat state. 120 out of 135 people completed the test.

Sampling size - Sample consisted of 120 people out of which 60 were having education below primary level and 60 were having education above primary levels that is 8^{Th} Standard as per national education policy of India.

Sampling Inclusion Criteria – People of age range 18 years to 75 years

Sampling exclusion Criteria-

- People below 18 years of age
- People above 75 years of age
- People having any type of mental, neurological or visual dysfunction.

Ethical Consideration

- Proper consent was taken from the participants. For people who were not able to read and sign, they were well informed about the test.
- Confidentiality of the subjects were maintained during the process of data collection, scoring and analysis.

Data Collection Procedure and tools

Data were collected from 120 individuals, divided into Above primary education (60) and below primary Education (60) groups.

Various cognitive measures, including CRIQ scores, WCST scores were recorded. The CRIQ scores were used to assess cognitive reserve, while the "learning to Learn" ability in the WCST was used as a measure of cognitive flexibility.

Statistical Analysis

To analyze the data PROCESS macro for SPSS (Version 4.2) developed by Andrew F. Hayes (Hayes, 2022) has been utilized.

Pearson Correlation has been conducted to determine the correlation as mentioned in first 3 null hypotheis. Mediation analysis and linear regression has been done in order to test 4^{th} hypothesis.

Results and Discussion

Results

Table 1 depicting the correlation between TCRIQ & CF Showing a significant positive correlation at 0.01 level with R= 0.795, Hence Null Hypothesis H_{01} rejected.

		Total CRIQ	**Cognitive flexibility**
Total CRIQ	Pearson Correlation	1	.795**
	Sig. (2-tailed)		.000
	N	120	120

Cognitive Flexibility	Pearson correlation	.795**	1
	Sig. (2-tailed)	.000	
	N	120	120

***. Correlation is significant at the 0.01 level (2 tailed).*

Table 1- Correlation between TCRIQ & Cognitive flexibility (CF)

Table 2 depicting the correlation between TCRIQ & Education Showing a significant positive correlation at 0.01 level with R= 0.741, Hence Null Hypothesis H_{02} rejected.

		Total CRIQ	**Education**
Total CRIQ	Pearson Correlation	1	.741**
	Sig. (2-tailed)		.000
	N	120	120
Education	Pearson correlation	.741**	1
	Sig. (2-tailed)	.000	
	N	120	120

***. Correlation is significant at the 0.01 level (2-tailed).*

Table 2- Correlation between TCRIQ & Education

Table 3 depicting the correlation between Cognitive Flexibility & Education Showing a significant positive correlation at 0.01 level with R= 0.859, Hence Null Hypothesis H_{03} rejected.

		Education	**Cognitive Flexibility**
Education	Pearson Correlation	1	.859**
	Sig. (2-tailed)		.000
	N	120	120
Cognitive Flexibility	Pearson correlation	.859**	1
	Sig. (2-tailed)	.000	
	N	120	120

***. Correlation is significant at the 0.01 level (2-tailed).*

Table 3- Correlation between CF & Education

Mediation analysis

Model Summary:

Table 4 shows the model summary for Education as the mediator. The independent variable T_CRIQ explains 55.00% of the variance in Education (R^2 = 0.5500), which is statistically significant ($F(1, 117) = 142.9753$, $p < 0.0001$).

R	**R-sq**	**MSE**	**F**	**df1**	**df2**	**p**
0.7416	0.5500	14.4192	142.9753	1	117	0.0000

Table 4. Model Summary for Education as Mediator

Coefficients:

- The coefficient for T_CRIQ is 0.1209 (SE = 0.0101), indicating a significant positive effect of T_CRIQ on Edu ($t=12.0008, p<0.0001$).
- The intercept is -24.3608 (SE = 2.8650), which is also significant ($t=-8.5029, p<0.0001$).

Variable	Coefficient	SE	t	p	LLCI	ULCI
Constant	-24.1011	2.8650	-8.5029	0.0000	-30.0343	-18.6873
T_CRIQ	0.1209	0.0101	12.008	0.0000	0.1009	0.1408

Table 5. Coefficients for Education as Mediator

Learning as the Dependent Variable

Model Summary for Learning:

- The predictors (T_CRIQ and Edu) explain 79.31% of the variance in Learning (R2=0.7931) which is statistically significant (F(2,117)=224.2505,p<0.0001

R	R-sq	MSE	F	df1	df2	p
0.8906	0.7931	2.1029	224.2505	2	117	0.0000

Table 6. Model Summary for Learning as Dependent Variable

Coefficients for Learning:

- Both T_CRIQ (β=0.0321 SE = 0.0057, t=5.6177,p<0.0001 and Edu (β=0.3339, SE = 0.0350, t=9.5381,p<0.0001) have significant positive effects on Learning.
- The intercept is -12.1150 (SE = 1.3837), which is also significant (t=−8.7554,p<0.0001t = -8.7554, p < 0.0001).

Variable	Coefficient	SE	t	p	LLCI	ULCI
Constant	-12.1150	1.3837	-8.7554	0.0000	-14.8554	-9.3746
T_CRIQ	0.0321	0.0057	5.6177	0.0000	0.0208	0.0434
Education	0.3339	0.0350	9.5381	0.0000	0.2646	0.4033

Table 7. Coefficients for Learning as Dependent Variable

DirectEffect:

Table 8 shows the direct effect of T_CRIQ on Learning. The coefficient is 0.0321 (SE = 0.0057), indicating a significant positive direct effect (t = 5.5817, p < 0.0001).

Effect	SE	t	p	LLCI	ULCI
0.0321	0.0057	5.6177	0.0001	0.0207	0.0434

Table 8. Direct Effect of T_CRIQ on Learning

IndirectEffect:

Table 9 presents the indirect effect of T_CRIQ on Learning through Edu. The indirect effect is 0.0404, Bootstrap=0.0056 with a 95% confidence interval of [0.0299, 0.0522], indicating significance as the interval does not contain zero.

Effect Type	Effect	SE	t	p	LLCI	ULCI
total	0.0724	0.0051	14.243	0.00	0.0624	0.0825
Direct	0.0321	0.0057	5.6177	0.00	0.0208	0.0434
Indirect	0.0404	0.0056	NA	NA	0.0299	0.0522

Table 9. Indirect Effects of T_CRIQ on Learning through Education

Concluding from the mediation analysis results, There is both direct and indirect effect of Cognitive reserve on cognitive flexibility and Education plays a significant mediating role with R=0.741 at 0.01 level of significance.

Discussion

This study aimed to determine the relationship between Cognitive Reserve (CR) and Cognitive Flexibility (CF) and to identify the mediating role of education in individuals with different

levels of educational attainment. The findings reveal a significant positive correlation between CR and CF,correlation at 0.01 level with R= 0.795, Hence Null Hypothesis H_{01} rejected.
Which is consistent with previous research suggesting that higher cognitive reserve contributes to better cognitive flexibility and vice versa.
The study's results align with Stern's (2009) hypothesis that cognitive reserve enables individuals to process tasks more efficiently, thereby maintaining cognitive function despite brain pathology. This efficiency likely extends to cognitive flexibility, which involves adapting cognitive processing strategies to new and unexpected environmental conditions. There is also a significant positive correlation between TCRIQ & Education Showing a significant positive correlation at 0.01 level with R= 0.741, Hence Null Hypothesis H_{02} rejected which indicates that if the cognitive reserve is enhanced, there can be more educational attainment possibility and vice versa.
Education emerged as a significant mediator in the relationship between CR and CF. Higher levels of education were associated with increased cognitive reserve and flexibility, supporting the notion that educational attainment can enhance cognitive resilience. The study indicated that Cognitive Flexibility & Education is Showing a significant positive correlation at 0.01 level with R= 0.859, Hence Null Hypothesis H_{03} rejected, Which is indicative of the fact that educational attainment is also collaborative towards better cognitive flexibility along with the cognitive reserve. These findings corroborates the work of Scarmeas and Stern (2003), who noted that formal education significantly influences cognitive reserve by providing the brain with more resources to cope with damage.
Moreover, the study's mediation analysis confirmed that education explains a substantial portion of the variance in cognitive flexibility,asThere is both direct and indirect effect of Cognitive reserve on cognitive flexibility and Education plays a significant mediating role with R=0.741 at 0.01 level of significance. Indicating that educational experiences directly and indirectly contributes to developing and maintaining cognitive reserve. This is in line with studies by Valenzuela and Sachdev (2006), which highlighted the role of education in promoting neural plasticity and cognitive reserve. All these results are indicating towards the importance of educational attainment and its role in catalyzing the effects of cognitive reserve in enhancement of executive functioning specially cognitive flexibility. These results are suggestible that the educational attainment can actually be responsible for better executive functioning and enhancing the resilience of an individual.

Conclusion

The present study underscores the crucial role of education in enhancing Cognitive Reserve (CR) and Cognitive Flexibility (CF), demonstrating that higher educational attainment positively impacts these cognitive domains. The findings suggest that educational interventions could be a valuable strategy for mitigating cognitive decline and promoting cognitive health in aging populations. Future research should further explore the mechanisms through which education influences cognitive reserve and flexibility, considering other potential mediating factors such as occupational complexity and engagement in cognitively stimulating activities. These insights can inform the development of targeted cognitive training programs aimed at enhancing cognitive reserve and flexibility, ultimately contributing to better cognitive outcomes in older adults.

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