Broadening the Construct of Cognitive Flexibility and its Relevance to Academic Achievement and Creativity

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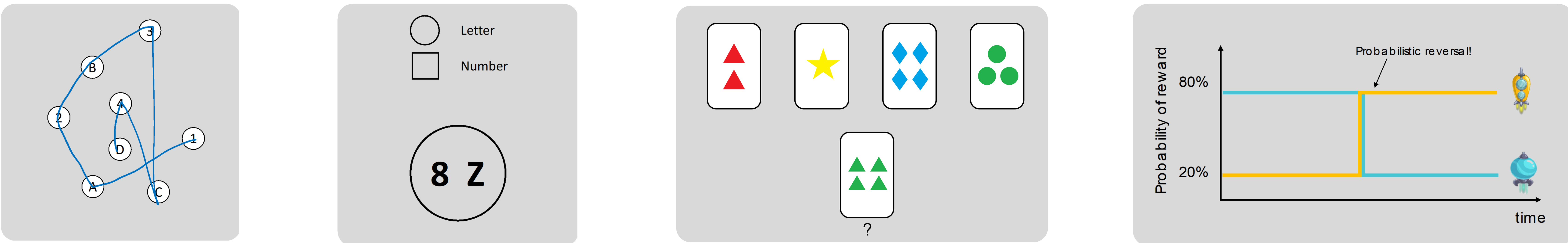
Summary

A broad battery of tests of cognitive flexibility (CF) was administered to a large young adult population, together with tests of working memory, inhibitory control, and verbal fluency to evaluate the construct of CF. Factor analysis confirmed the CF factor, although the extracted factor could not accommodate a test of probabilistic reversal learning. CF was predictive of a measure of verbal creativity based on semantic network analysis and was also associated with an academic index of reading (but not maths) attainment. These findings suggest that a broader application of the CF construct may encourage a renewed focus on CF training for educational purposes.

CF tasks in CLIC Phase 1 Studies



Trail Making Test (TMT): Expected switching between given rules

Task Set Switching (TSS): Random cued switching between given rules

Wisconsin Card Sort Task (WCST): Learn the rules and decide when to switch to a new rule from deterministic feedback

Probabilistic Reversal Learning (PRL): Learn the rules and decide when to switch to a new rule from probabilistic feedback

Fig 1. The Cognitive Flexibility tasks used in the CLIC Phase 1 studies. As highlighted in Friedman & Robbins (2022), CF is a multi-facet construct that is more than switching. The broadened task battery included tasks targeting shifting according to instructions (TMT, TSS), rule-learning and shifting in response to feedback (WCST, IED), and rule learning under uncertainty (PRL).

"Unity-and-Diversity" EF models

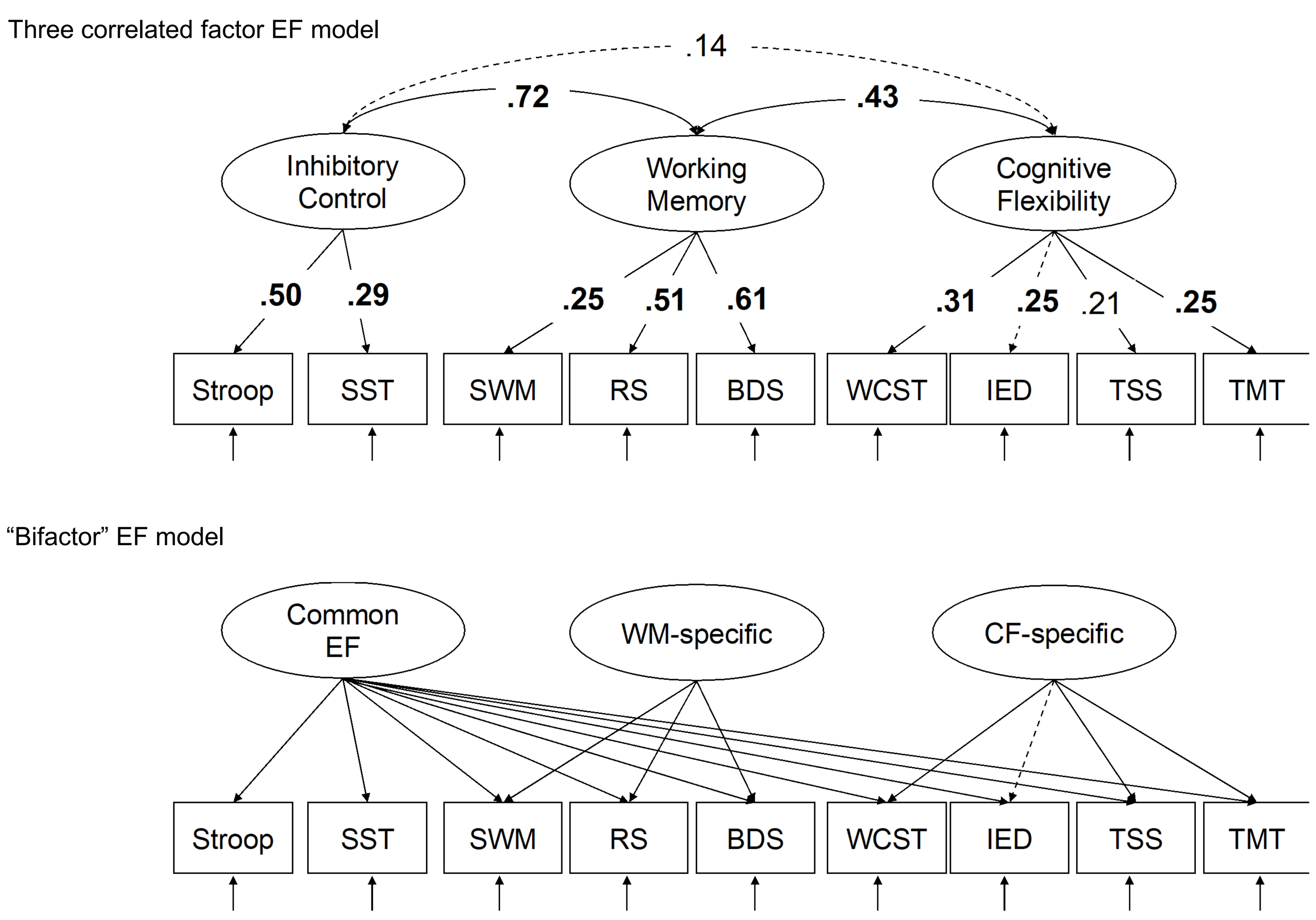


Fig 2. With the broadened CF construct, the CLIC Phase 1 adult data supported the "Unity-and-Diversity" EF conceptualization (Miyake et al., 2000). The three-factor EF model (upper) and "Bifactor" EF model (lower) outperformed the Unitary EF model and independent factors EF model (see Supplementary Materials). Solid lines and bold indices indicate significant relationships, dashed lines indicate insignificant relationships.

CF's relationship with outcomes of interest

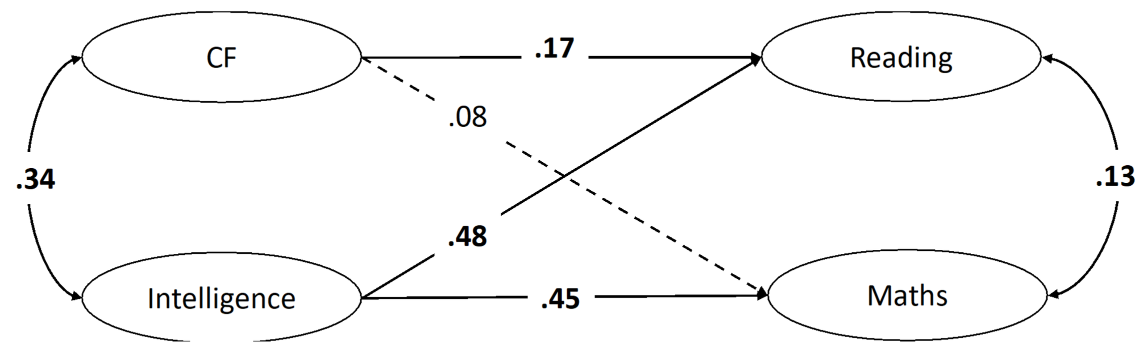


Fig 3. After controlling for intelligence, CF is a significant predictor of Reading scores, but not Maths scores. Solid lines and bold indices indicate significant relationships, dashed lines indicate insignificant relationships

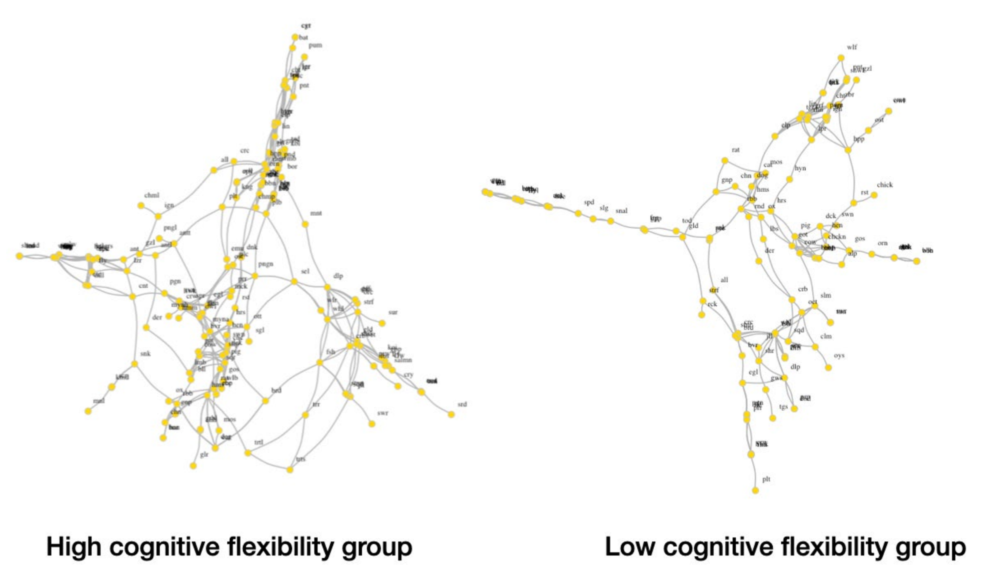


Fig 4. Visualization of group-level semantic networks for the high- and low-CF subsets. Each node represents an animal name, and each connection represents an association between two animal names. The network of the high cognitive flexibility group exhibits greater connectivity (shorter average shortest path length, ASPL) and network flexibility (lower modularity).

Key references

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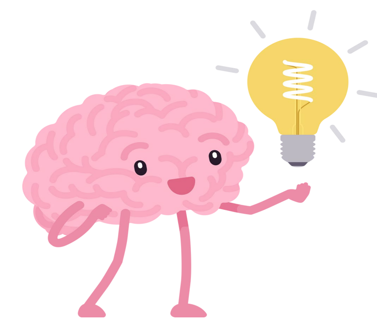
Assessing the Relationship between Creativity and Cognitive Flexibility in Infants

Hoo, N. P.[1], Fu, X.[1], Teo, L. Z.[1], Leong, V.[1,2], and the CLIC Consortium

What is Creativity?

Creativity is our ability to generate ***new, original,*** *and* ***meaningful*** *ideas that are valuable in the current context.*



- ***DIVERGENT*** *thinking: combining information in new ways to generate many different ideas (i.e., thinking outside the box)*
- ***CONVERGENT*** *thinking: organising disparate ideas logically to formulate one novel and effective solution*

Creativity Tasks

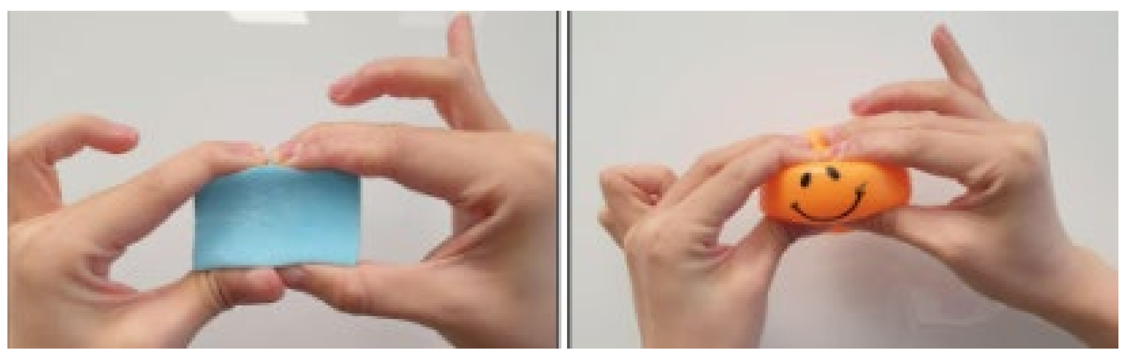
UNUSUAL BOX TEST
- Coming up with original and unique ways to interact with the box

MUSIC PLAY
- Expressing creativity through movement

OBJECT PLAY
- Expressing creativity through actions performed with the toy

EXPLORATORY PLAY
- Creative exploration within a physical environment

Cognitive Flexibility Task



ATTENTION SET SHIFTING TASK
- Assesses the infant's ability to shift their attention from a highly salient dimensional property (shape) of the object to a less salient (compressibility) one

How do we measure Creativity?

Fluency: Number of novel ideas generated in a given period of time
- *Here is an example of the fluency scoring sheet for UBT:*

Actions	Round Hole	Square Room	Stairs	Blocks	Rings	Strings	Edge of Box	Side of Box	Whole Box	No Box
Jump										
Walk										
Hit										1
Touch							1			
Roll			1							
Turn (play)								1		1
Drop		1	1							1
Guide through										
Hold in place			1				1			
Place			1							1
Move over			1							
Pull									1	
Push								1	1	
Squeeze										1
Cover										
Throw against										1
Hang										
Shake										1
Pretend Play										
# New Actions	19									

- *Fluency score: 19*

Originality: Relative novelty of the generated ideas (weighted against the scores of the sample)
- The more unique the action performed, the higher the score, vice versa

Creativity is Positively Associated with Cognitive Flexibility

- Mental flexibility is our ability to shift and adapt to new situations. During childhood, our social environment helps us to develop flexible thinking, which fosters creativity (Arán Filippetti & Krumm, 2020).
- Mental flexibility helps us break out of routines and habits that are no longer beneficial and become open to new opportunities in the environment that lead to creative changes.

Correlation Between Creativity and Shifting Performance

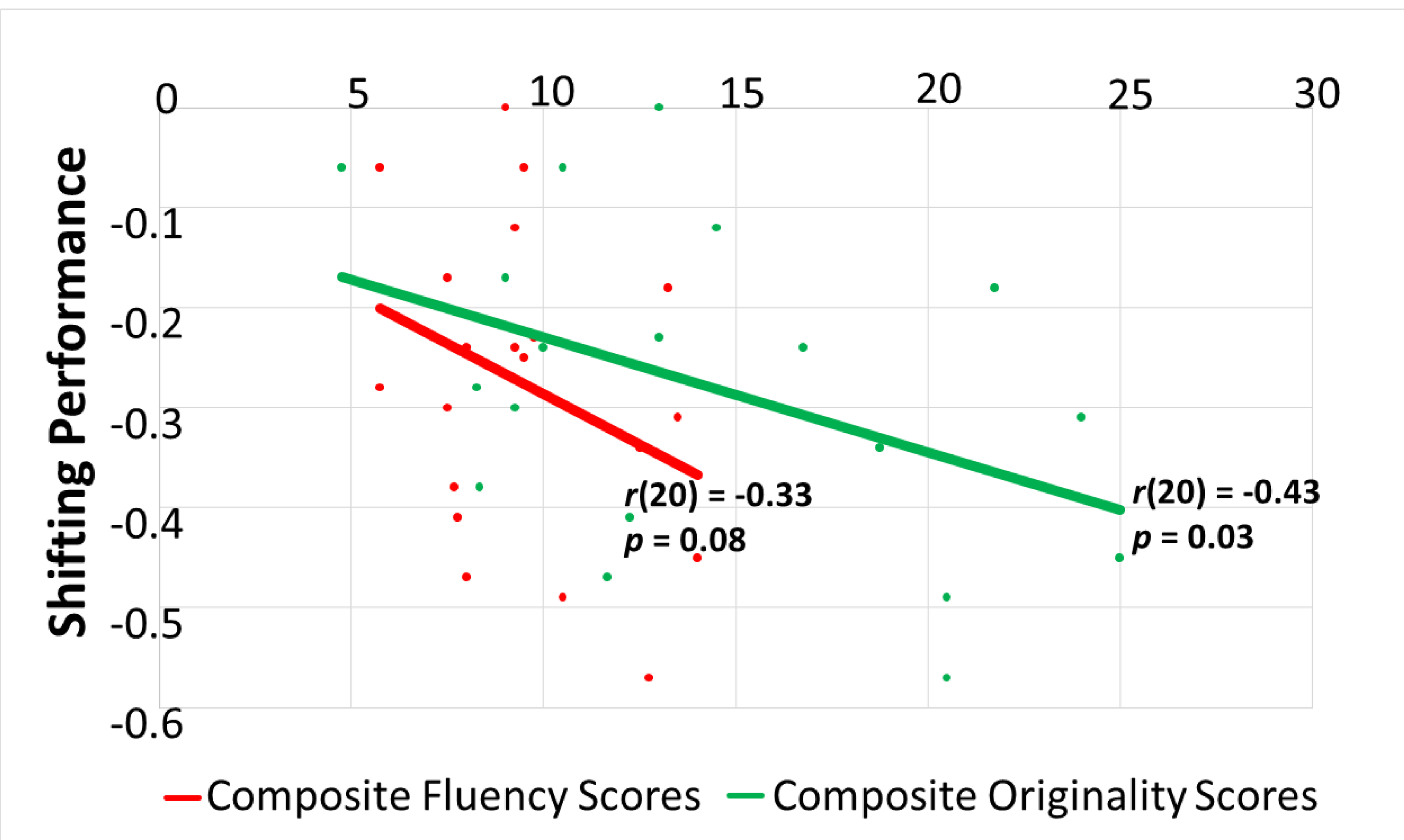


Fig 1. The relationship between creativity (composite fluency scores/composite originality scores) and shifting performance

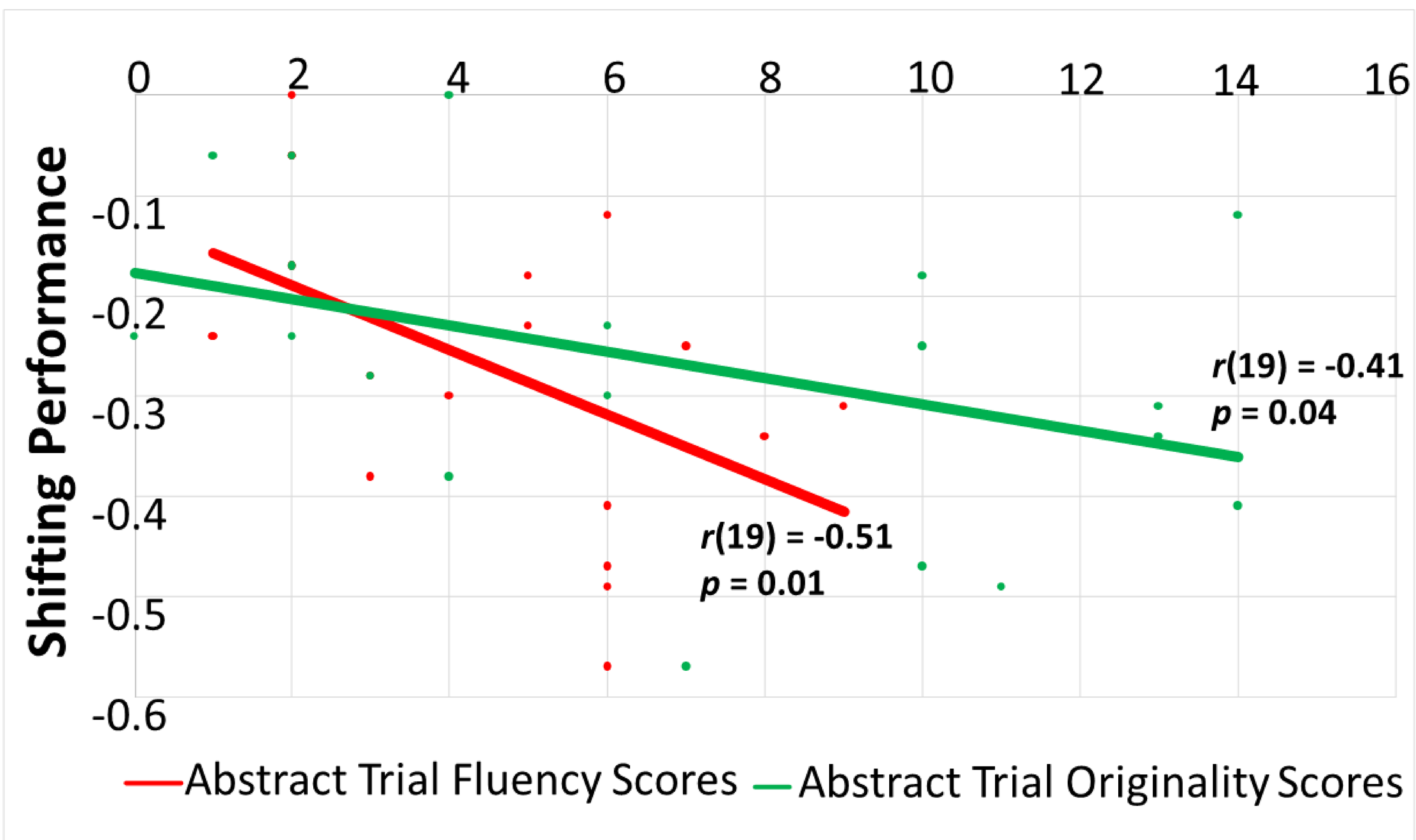


Fig 2. (Looking at Abstract Trial only) The relationship between creativity (fluency scores/originality scores) with shifting performance

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Cognitive Flexibility in Adolescents

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Introduction

What is Cognitive Flexibility?

Cognitive Flexibility (CF) refers to the ability to shift between different tasks or thoughts and adapt to changing circumstances.

CF is one of the main executive functions that helps us to optimise goal-directed behaviors in different situations.

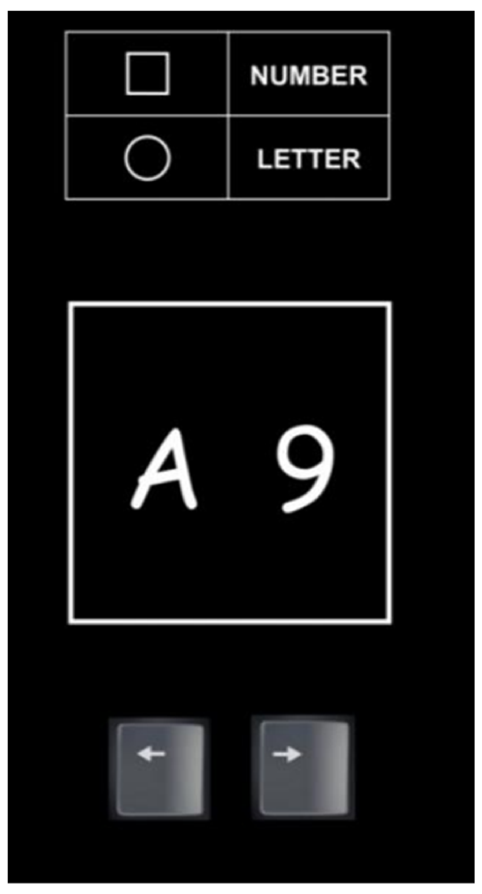
How to measure CF?

At the Centre of Lifelong Learning and Individualised Cognition (CLIC) we measure CF with game-like cognitive tasks.

We use different tasks to probe different aspects of CF such as:

- Responding to different rules
- Switching between concepts

Some tasks we use to measure cognitive flexibility:



Task Set Switching

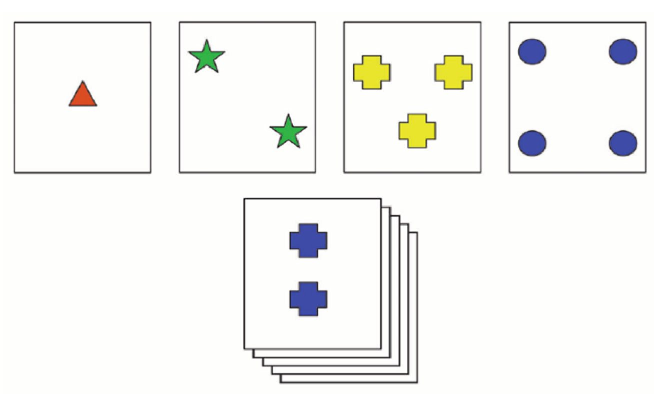
Based on the shape (circle or square), respond to either the letter or number on the screen.

Key measure: Switch cost

Switch Cost: Time loss from switching between paradigms

Wisconsin Card Sorting Task

Sort the cards to the correct deck based on an unknown rule. The rule may change during the game.



Key measure: Number of perseverative errors

Perseverative Error: Errors made due to inability to switch after rule change

We used a total of 5 tasks to measure cognitive flexibility (CF), together with other executive function and creativity tasks.

Our preliminary findings are:

- CF correlates significantly and positively with working memory, fluid intelligence performance on the Ravens Standard Progressive Matrices (RSPM), fluency in a divergent creative thinking task (alternate uses task – AUT), and stochastic performance in a probabilistic reversal learning (PRL) task. It does not correlate significantly with inhibitory skills;
- Hierarchical multiple regression analysis showed that the model that better explains CF variance in adolescents is the one that accounts for the adolescents' performance in RSPM (i.e., fluid intelligence index) and adolescents' stochastic performance in PRL.
- Mediation analysis showed that, in adolescents, CF has a direct effect on fluency performance in AUT (i.e., index of creativity), and this is not mediated by their performance neither in RSPM nor working memory tasks.

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Multilingualism and its Relation to Perceived Social Support and Cooperativeness

Melia, N. V.[1], Feng S.[1], Abraham, A.[1], Chan, Y. N.[1], Lee, L. L.[1], Yap, H. S.[1], Christopoulos, G.[1], Hendriks, H.[2], and the CLIC Consortium

Introduction

Singapore's social life is characterised by a diverse linguistic fabric. We here assess this rich linguistic environment (called "contextual multilingualism") and examine its association with perceived social support and tendency to cooperate.

METHODOLOGY

- The Contextual and Individual Linguistic Diversity Questionnaire (CILD-Q)[1] captures an individual's contextually influenced linguistic experience and includes three subscales:

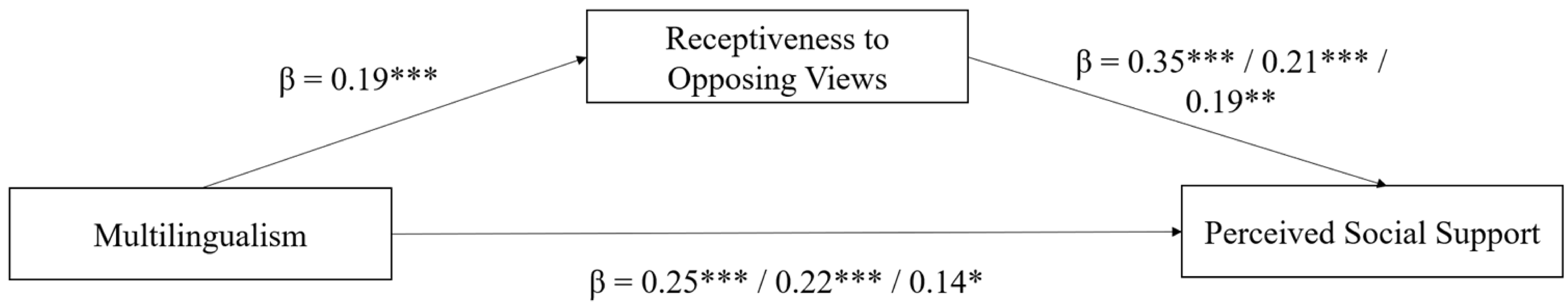
Multilingualism in Context (7 items)	Multilingualism in Practice (7 items)	Linguistic Diversity Promotion (6 items)

- Language entropy[2] captures the day-to-day use of various languages in the individual and takes into account **self-rated proficiency**, **extent of exposure**, **duration**, and **usage frequency** of each language.
- High language entropy indicates a more balanced exposure to multiple languages.

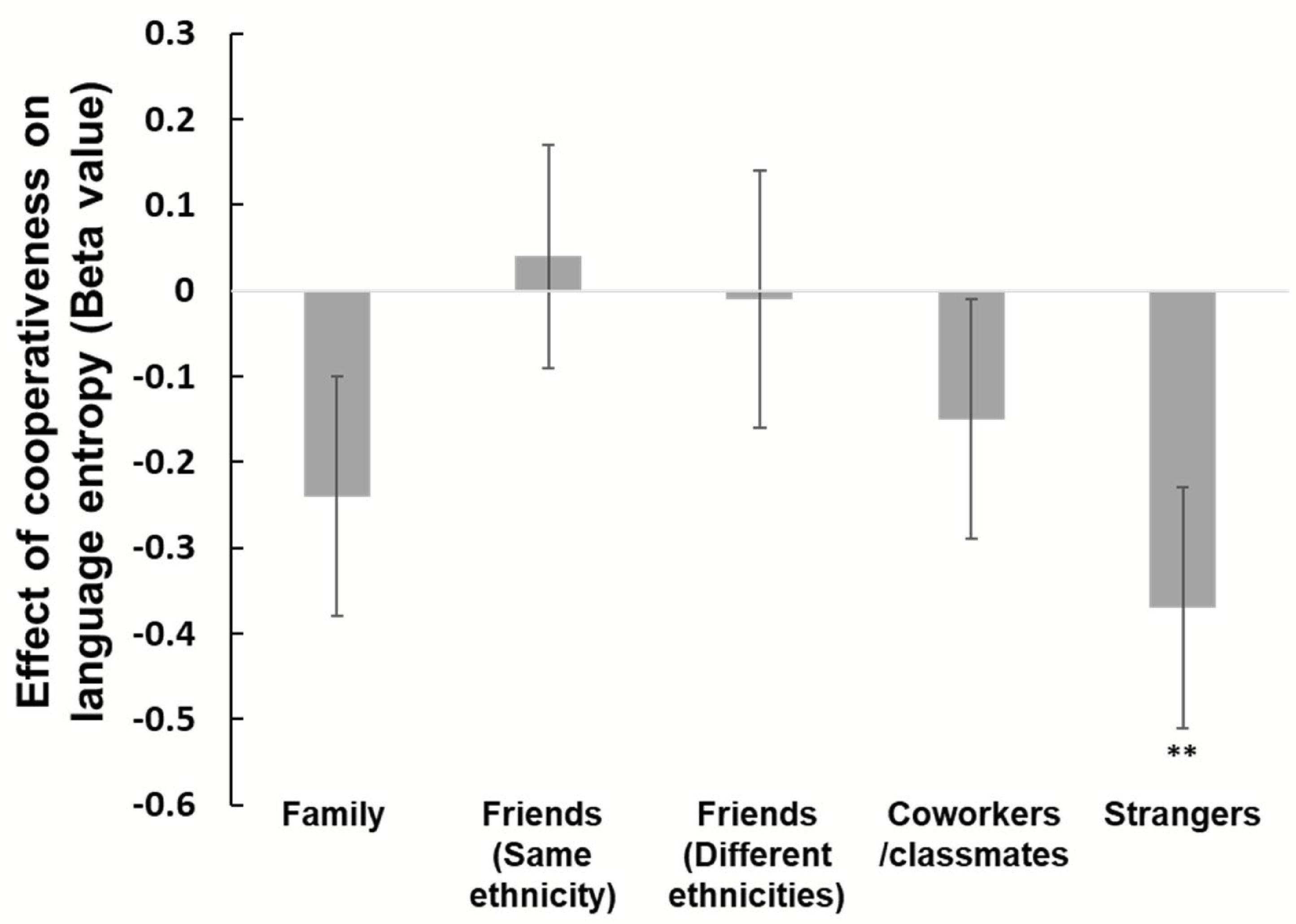
RELATIONSHIP BETWEEN MULTILINGUALISM AND SOCIAL FACTORS

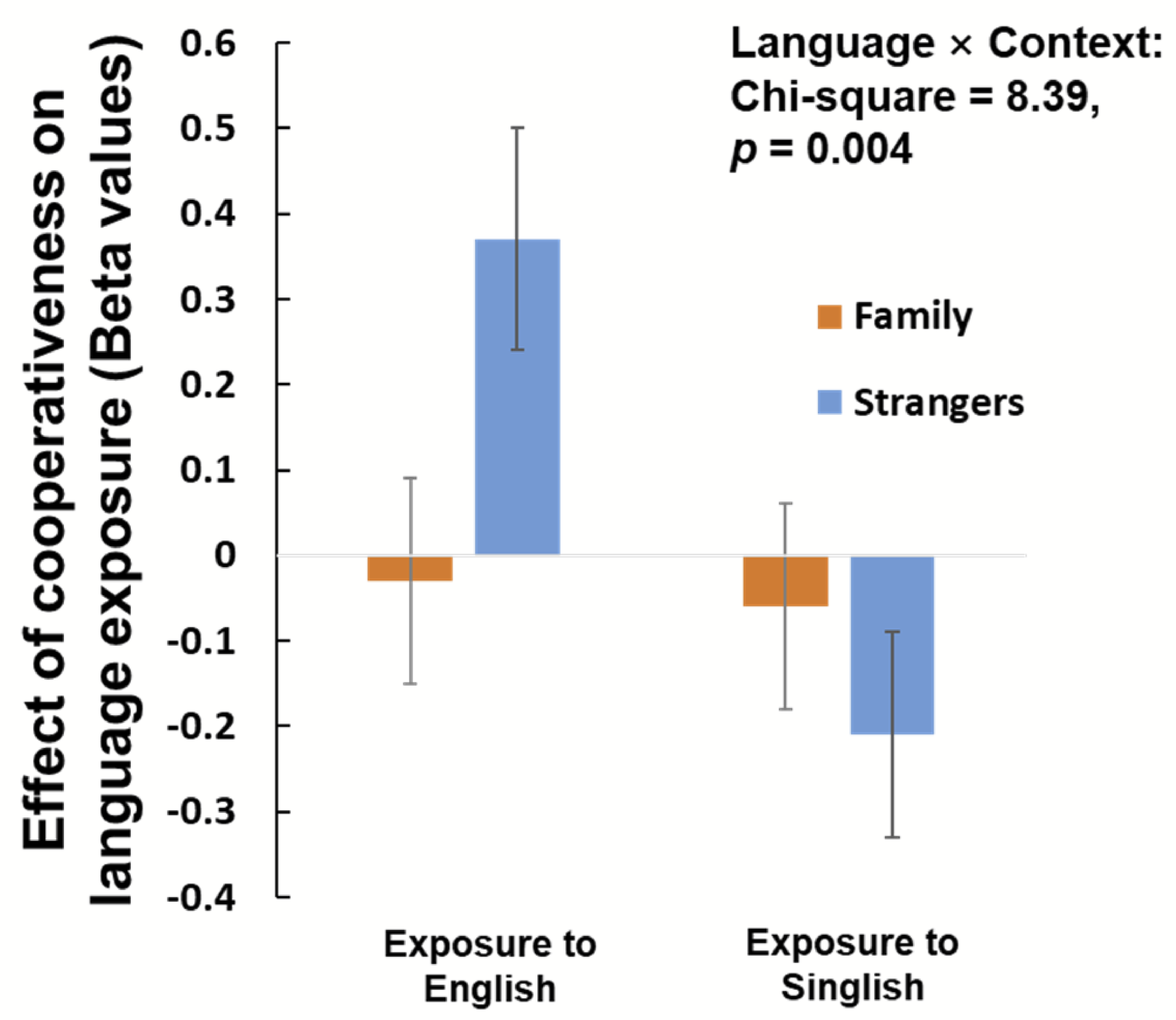
	Multi-lingualism	Social Support (SP)	Social Support (MSPSS)	Social Support (LSN)	Uncertainty (ROV)	Uncertainty (MCEX)
Social Support (SP)	0.31***					
Social Support (MSPSS)	0.22***	0.66***				
Social Support (LSN)	0.14**	0.43***	0.36***			
Uncertainty (ROV)	0.19***	0.39***	0.20***	0.25***		
Uncertainty (MCEX)	0.11*	0.25***	0.18***	0.18***	0.15*	
Uncertainty (NFC)	-0.06	-0.09	0.03	-0.18***	-0.34***	-0.16**

- Multilingualism is positively correlated to tolerance of uncertainty and perceived social support
- There is a significant indirect effect of contextual multilingualism on perceived social support via receptiveness to opposing views.
- However, this is a partial mediation model, suggesting that other factors may contribute to the relationship between contextual multilingualism and perceived social support.



RELATIONSHIP BETWEEN LANGUAGE ENTROPY AND COOPERATIVENESS





- Regression analysis used to test the effect of **cooperativeness**[3] on **language entropy** in different communicative contexts.
- **Cooperativeness** negatively predicts **language entropy when interacting with strangers.**
- This suggests cooperative individuals tend to have a dominant usage of one language when interacting with strangers.

- A second regression analysis used to test the effect of **cooperativeness** on **exposure to different languages** in different contexts.
- Interaction found between **language** (English vs. Singlish) and **communicative context** (Family vs. Strangers).
- This reveals that cooperative individuals tend to use/be exposed to English only when interacting with strangers.

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Ready for a Career Change?

Sam, Y. L.[1], Tong, K.[1], Yap, H. S.[1], Chen, S. H. A.[1], Leong, V.[1,2], Kourtzi, Z.[2], Robbins, T. W.[2], Sahakian, B. J.[2], Hendriks, H.[2], Christopoulos, G.[1], and the CLIC Consortium

Introduction

The increasingly volatile job markets require flexibility from the modern workforce. We examine how Cognitive Flexibility (CF) affects flexible career development & transition. We used both task-based ("objective") and self-assessed ("subjective") measurements of CF to examine its effect on aspects of career-related adaptability, efficacy, and behaviour of young Singaporean adults who have not yet entered the workforce.

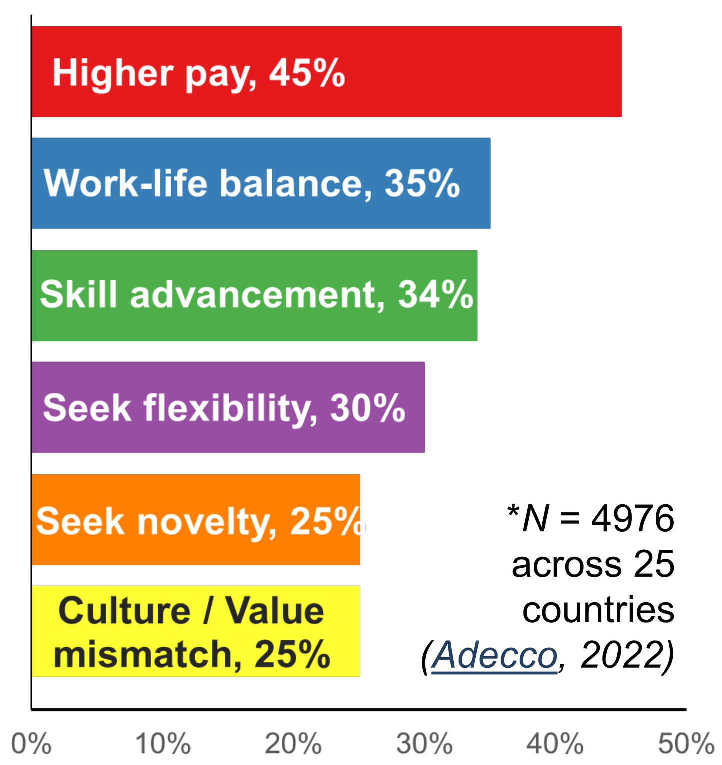
The new career paths in the era of A.I.

90% *of Singaporeans ready for career change* (Oracle, 2021)

Roles that are highly susceptible to automation by AI

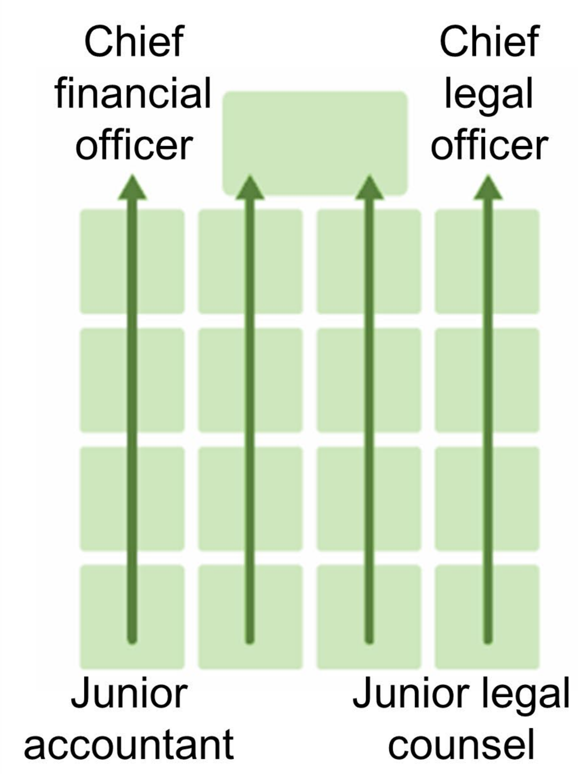
Image credit: Yahoo Finance

Why change jobs in 12 months?*



*N = 4976 across 25 countries (Adecco, 2022)

How do you see yourself progressing in your career?



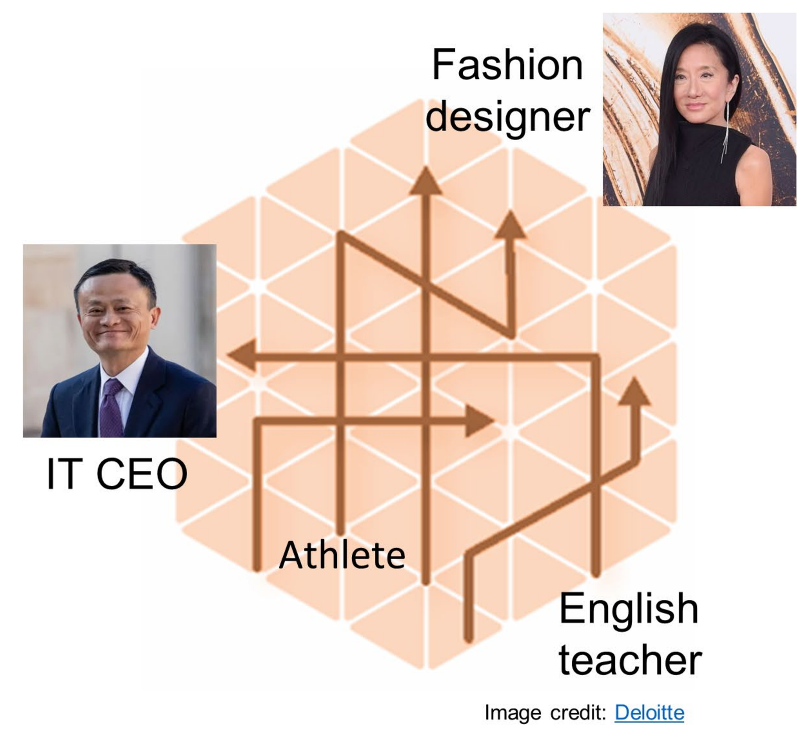
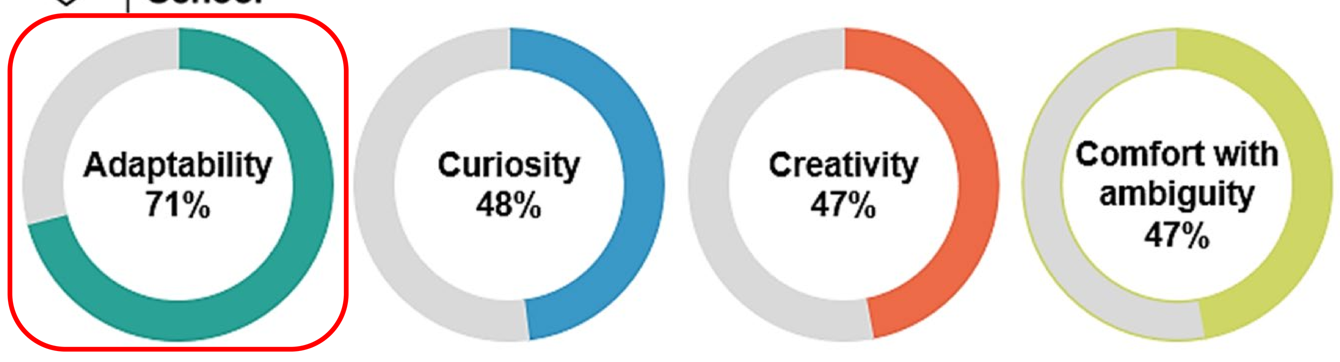


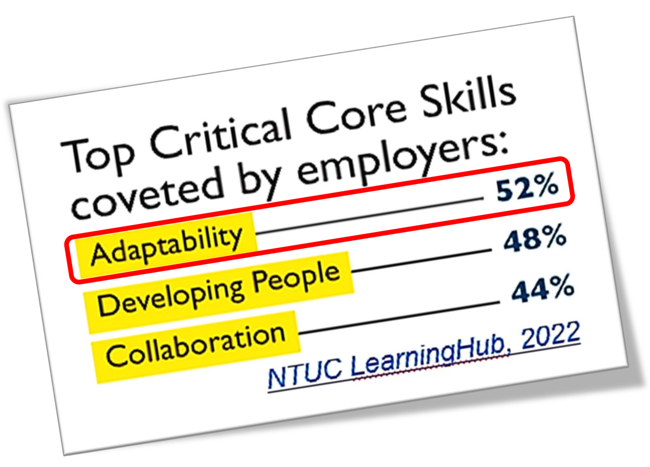
Image credit: Deloitte

Traditional Career **OR** ***New Career***

Are young Singaporeans ready for new (and nearly constant) career transitions?

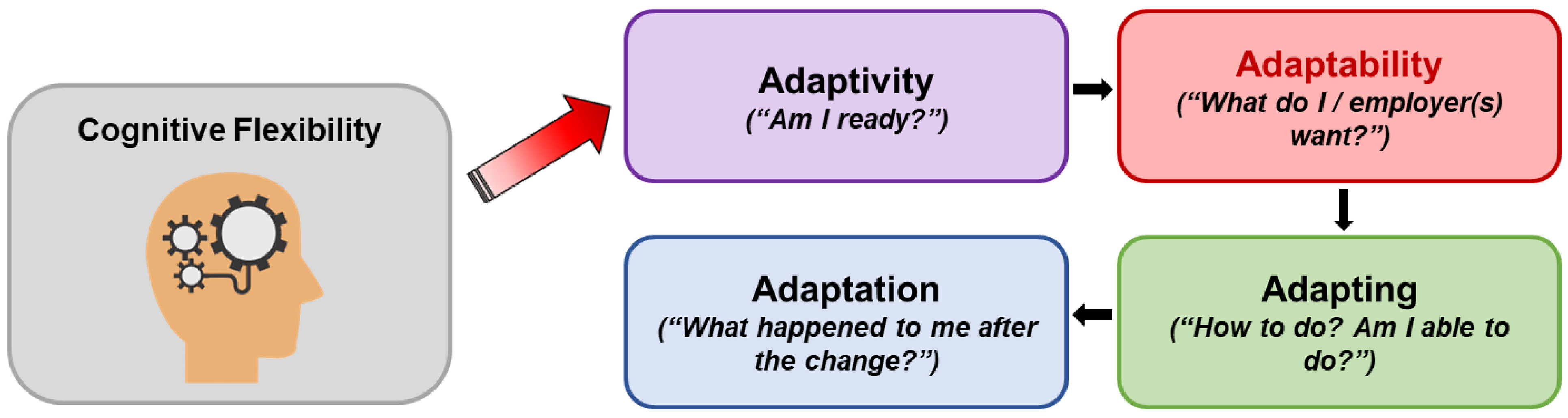
Harvard Business School ***Essential Leadership Skills for the Digital Age***





✓ ***Career Adaptability***: A vital psychosocial competency that influences how individuals cope with transitions and navigate challenges during career growth.

How does Cognitive Flexibility relate to versatile career transitions?



(Savickas & Porfeli's Career Construction Model of Adaptation, 2012)

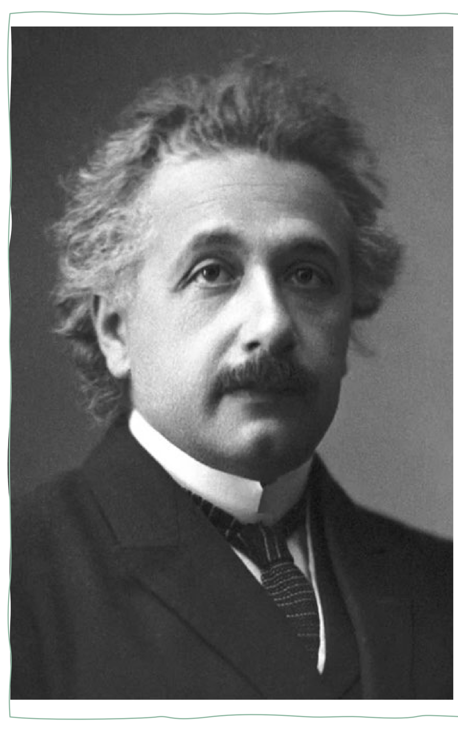
✓ ***Flexibility*** is crucial for developing adaptability and competencies in career decision-making. Individuals who demonstrate greater ***adaptability*** are better equipped to anticipate novel situations and proactively prepare for changes.

"Change is the law of life. And those who look only to the past or present are certain to miss the future."

— *John F Kennedy*

"…lifelong learning will be key. Not just upskilling once and being done with it, but multiple times, to become more adaptable and resilient, well-equipped and confident to face the future."

— *Lawrence Wong*



"A new type of thinking is essential if mankind is to survive and move toward higher levels"

— *Albert Einstein*

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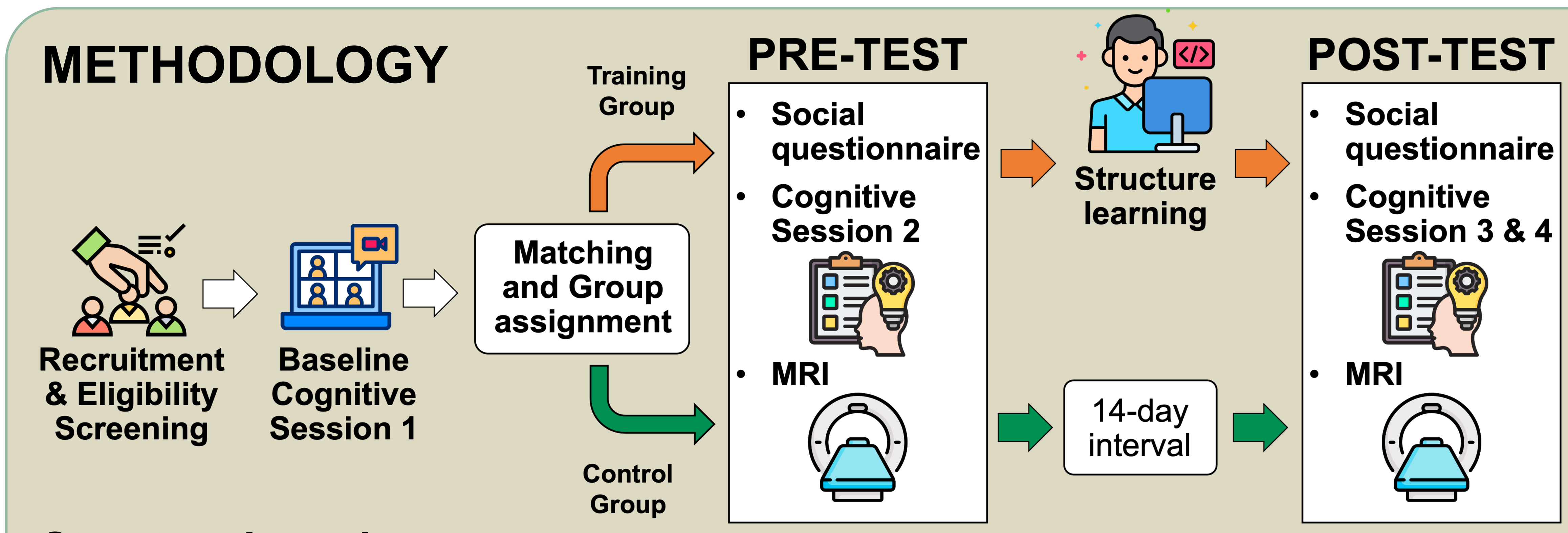
Structure Learning Training and its Potential Impact on Cognitive Flexibility

Koo, E. W. S.[1,2], Koo W. L.[1,2], Shukla, D.[1,2], Tan, J. Y. J.[1,2], Ubrani, M. B.[1,2], Gulyas, B.[1,2], Suckling, J.[2,3], Chen, S. H. A.[1,2], Kourtzi, Z.[2,3], and the CLIC Consortium

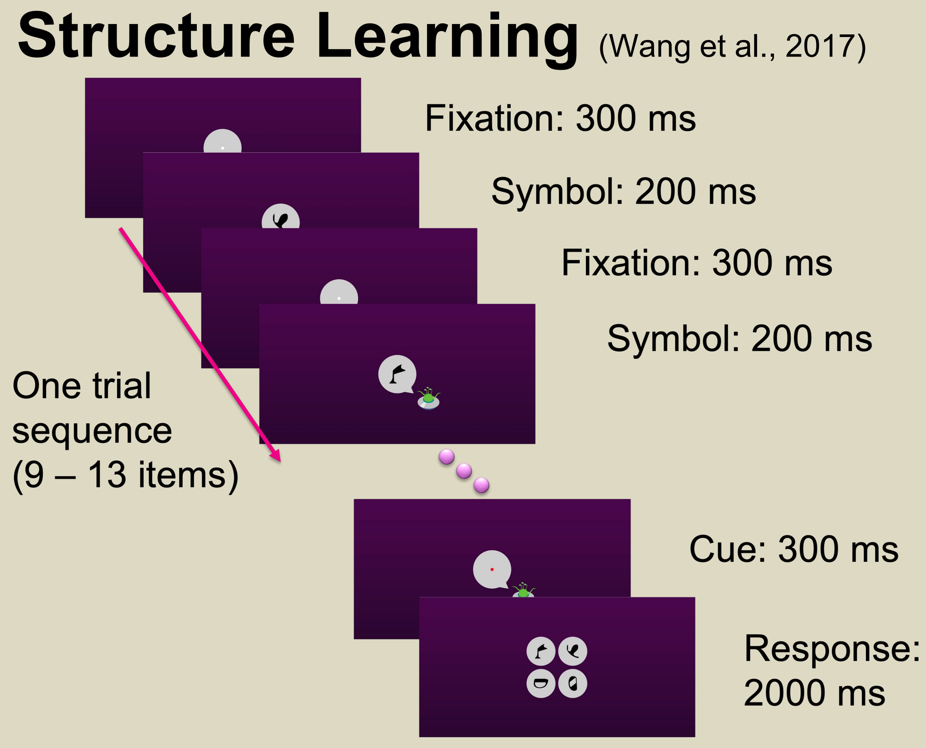
INTRODUCTION

Structure Learning is a task designed for participants to learn stochastically from seeking patterns in stimuli without explicit feedback. In CLIC Work Programme 0.2, we aim to evaluate the impacts of Structure Learning training in enhancing cognitive flexibility and its transferability to other cognitive abilities. A multi-modality approach was adopted, such that cognitive-behavioural, social and neuroimaging data were collected.

METHODOLOGY



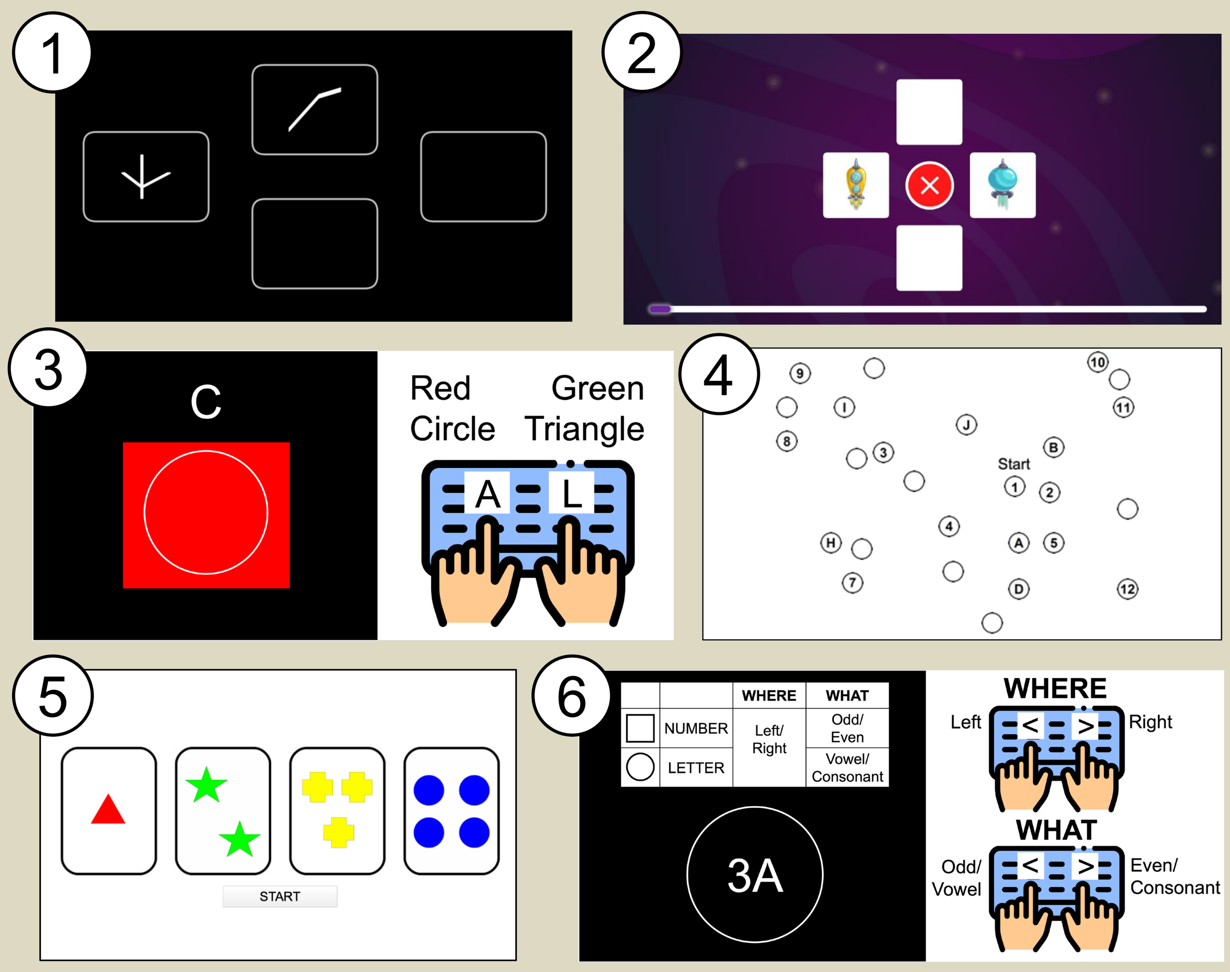
Structure Learning (Wang et al., 2017)



Stage	Stimuli set	Conditions	Session number
Training 1*	A	Level 1 (80/20)	6 ≤ x ≤ 12
Testing 1	B	Level 1 (80/20)	1
Training 2	C	Level 1 (70/30)	12-x
Testing 2 (after Post-MRI)	C	Level 1 (30/70)	1

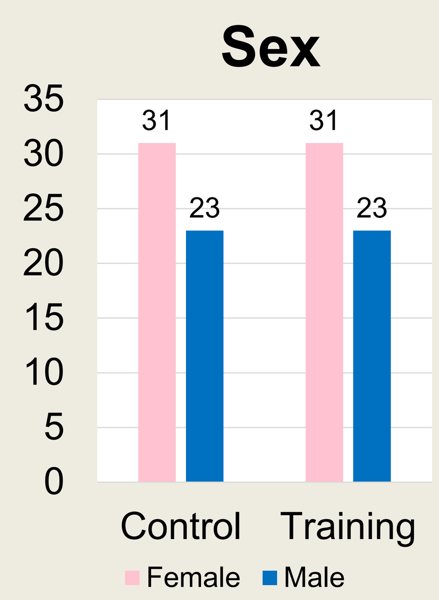
*Progression criterion: At least 75% for mean PI in last two blocks across two consecutive sessions

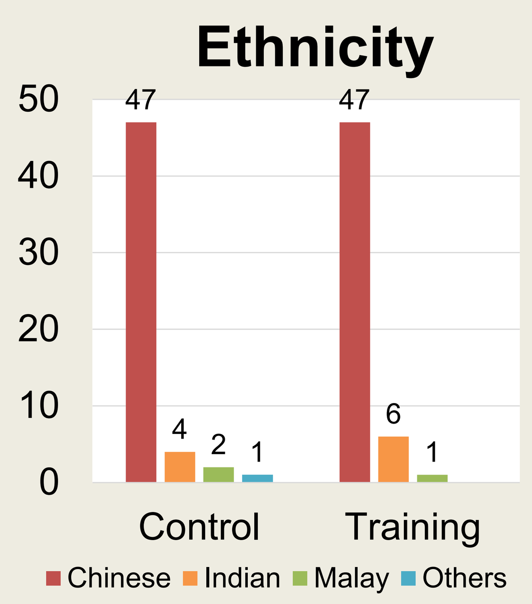
Cognitive Flexibility tasks

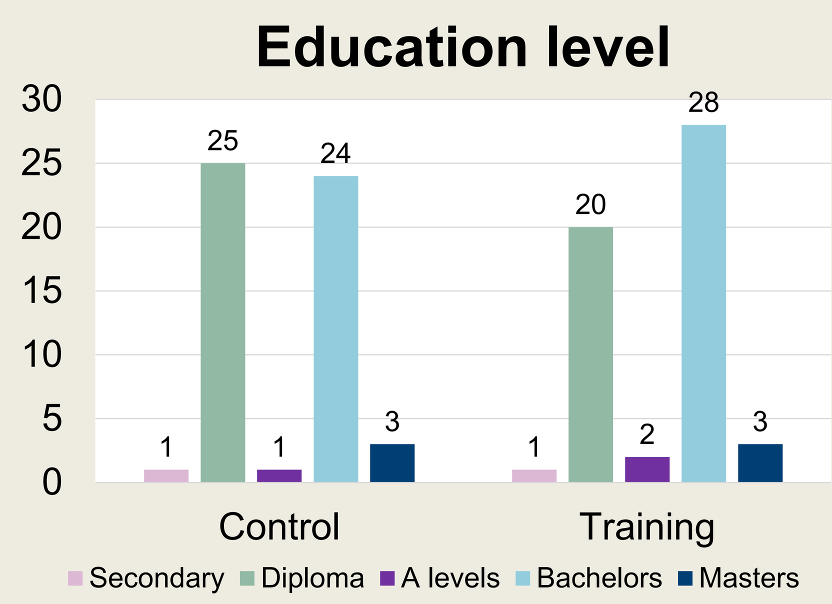


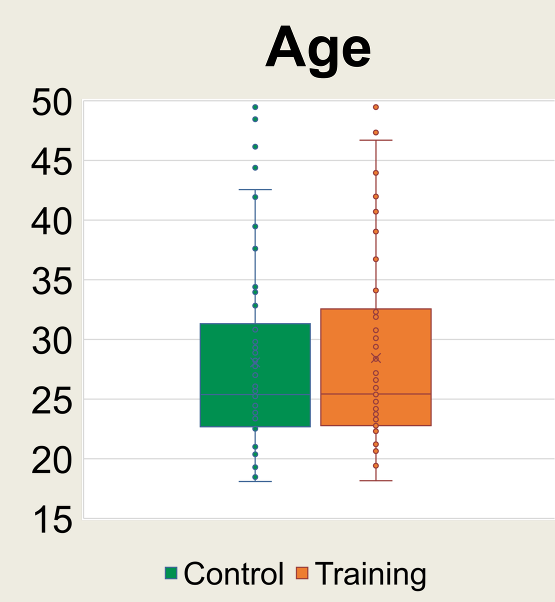
1. Intra-extradimensional task (IED)
2. Probabilistic reversal learning (PRL)
3. Colour shape task (CST)
4. Trail making test (TMT)
5. Wisconsin card sorting task (WCST)
6. Task set switching (What & Where) (TSS)

RESULTS AND DISCUSSION









N = 108 (Control = 54; Training = 54)

- Age range = 18 to 50
- Mean age (SD) = 28.3 (8.03)

- Participants were matched by age, sex, baseline intelligence and cognitive flexibility for each group assignment
- Successfully classified training participants by Learner and Strategy type, with the majority as Learners and Maximisers
- Positive relationship between strategy ICD and inverse temperature parameter for IED and PRL – indicates a possible transfer effect of SL training such that participants who maximised during SL are more likely to choose the option with higher reward in IED and PRL

Key variables of Structure Learning

Performance index (PI) relative: Minimum overlap between participant responses' distribution and symbol distribution within the sequence

Strategy Integral Curve Difference (ICD): Strategy index that places matching and maximizing on a continuous scale
= Integral of exact matching curve - Integral of participant's strategy curve

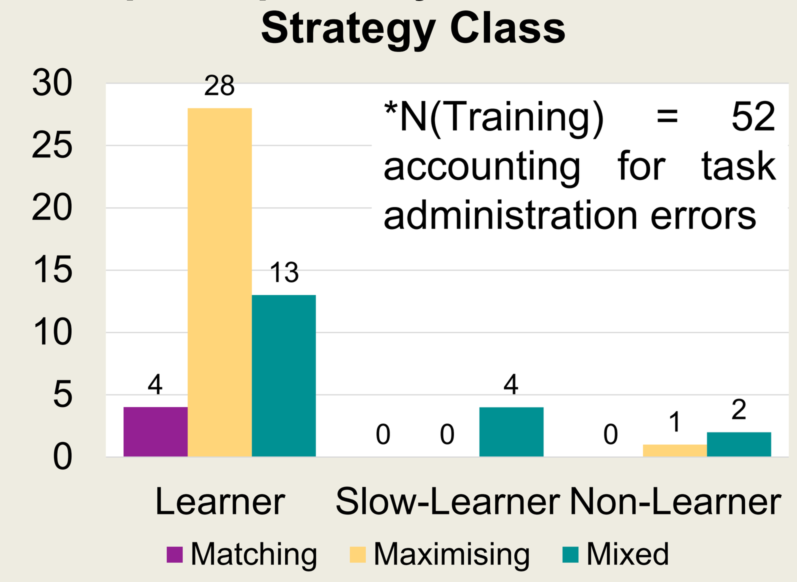
Learner Class

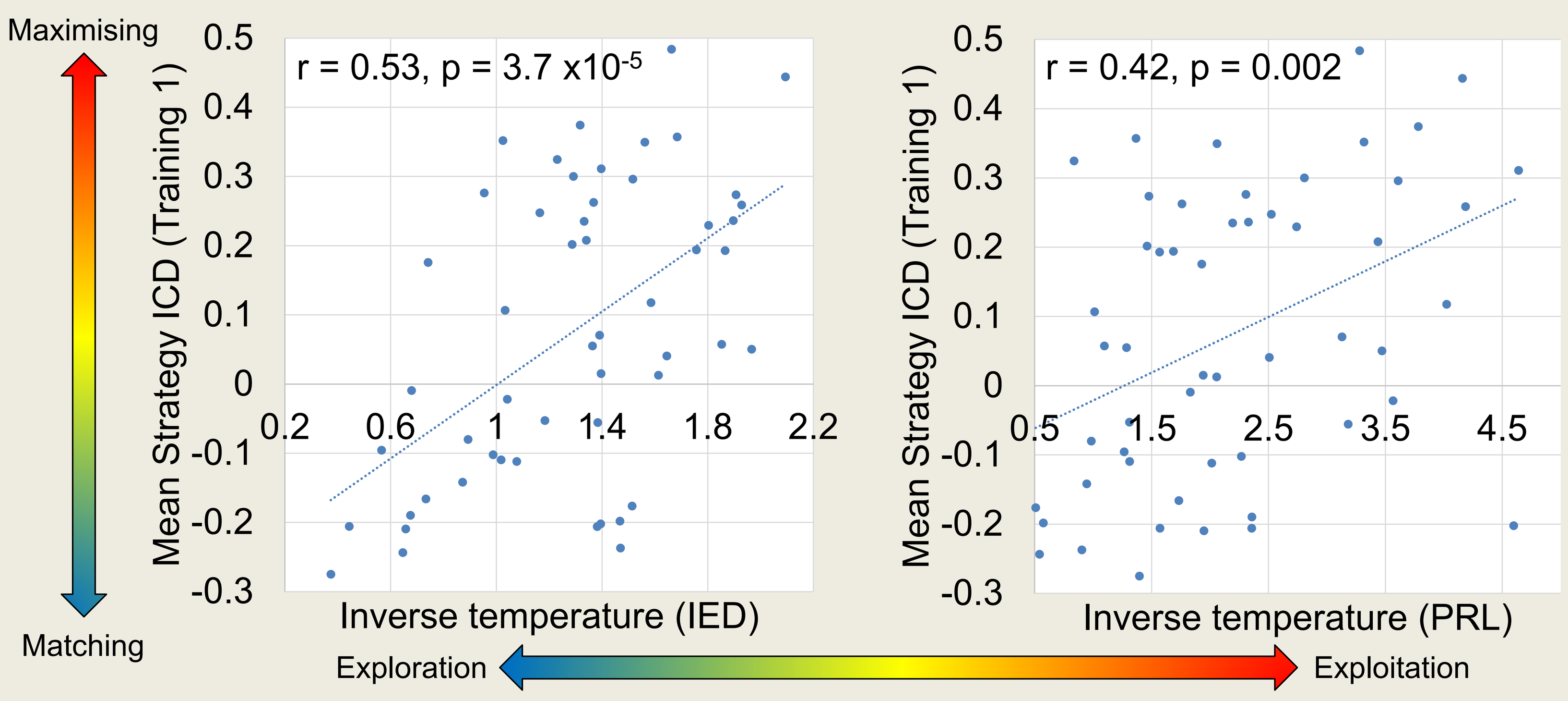
1. Learners: PI relative change > 0 between Session 3/6 and Session 1
2. Non-learners: PI relative change < 0 between Session 3/6 and Session 1
3. Slow-learners: PI relative change differs between S6-S1 and S3-S1

Strategy Class

1. Mixed: ICD ≤ -0.05
2. Matching: -0.05 < ICD < 0.05
3. Towards Maximising: ICD ≥ 0.05

Classification of Training participants by Learner and Strategy Class





References

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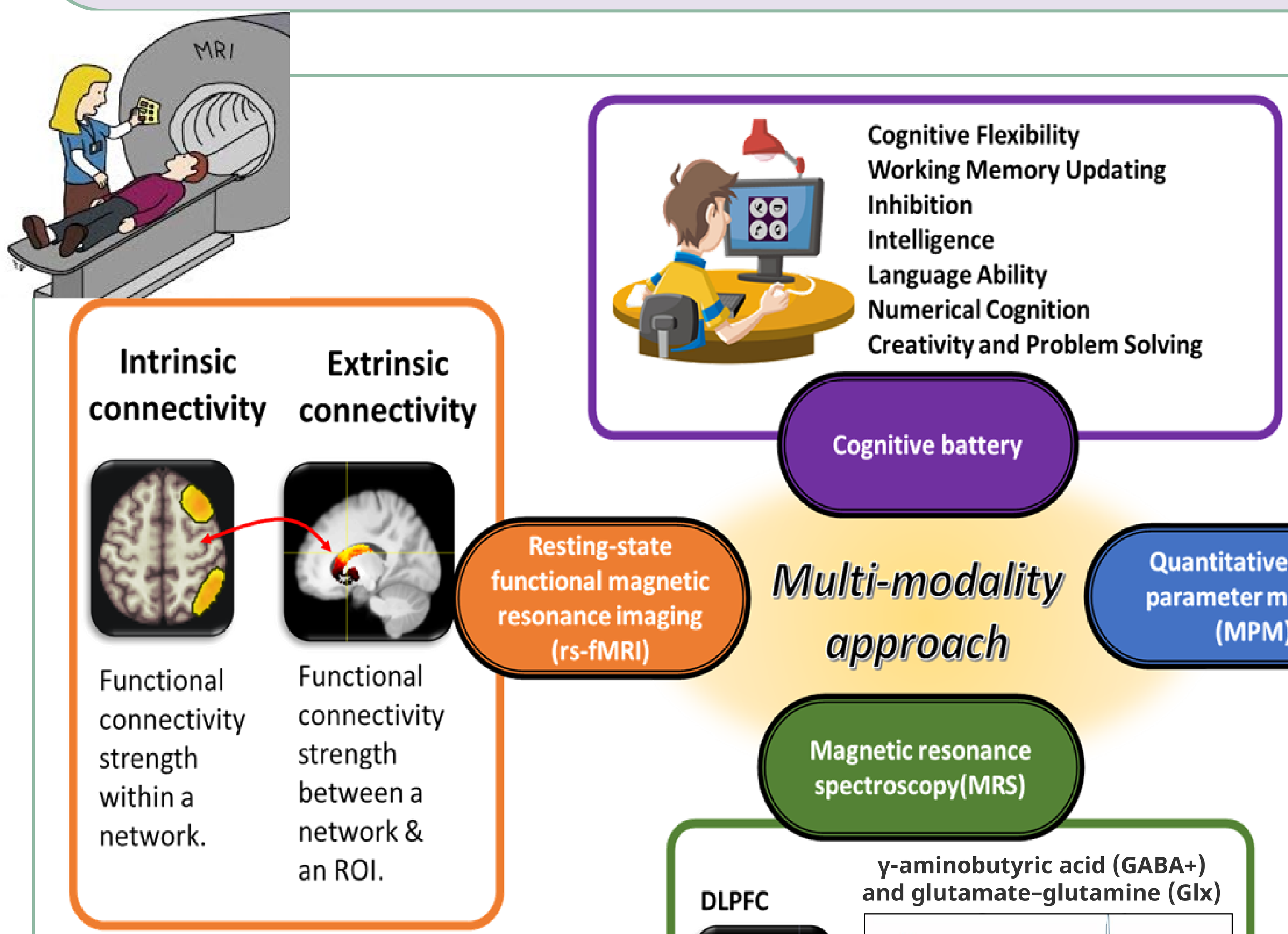
Neurochemical Alterations in Bilateral DLPFC in Response to Structural Learning Training in Healthy Adults

Shukla, D.[1,2], Choo, B. L.[1,2], Hong, M.[1,2], Koo, E. W. S.[1,2], Koo, W. L.[1,2], Liu, C. L.[1,2], Tan, J.[1,2], Ubrani, M. B.[1,2], Gulyas, B.[1,2], Kourtzi, Z.[2,3], Suckling, J.[2,3], Chen, S. H. A.[1,2], and the CLIC Consortium

Introduction

In CLIC work program 0.2, we aim to investigate the impact of structure learning training on individual's cognitive flexibility and its transferability to other cognitive abilities, that pose significant implications in learning. To investigate the effect of training at neural level, we adopted a multimodal imaging approach comprising whole brain functional connectivity patterns, microstructure-myelination and neuro-metabolite concentration in the frontal brain regions.

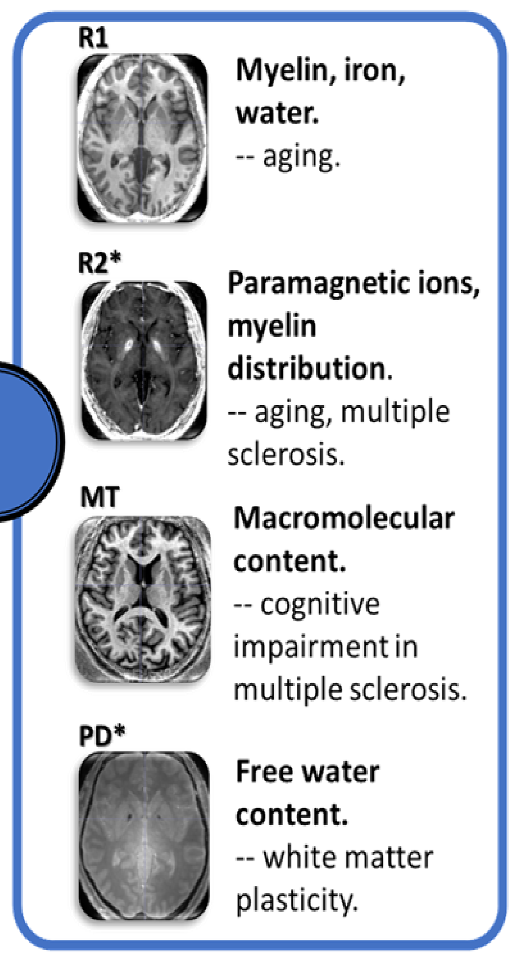
Methodology



Cognitive Flexibility: Executive control network and the midcingulo-insular network [1]

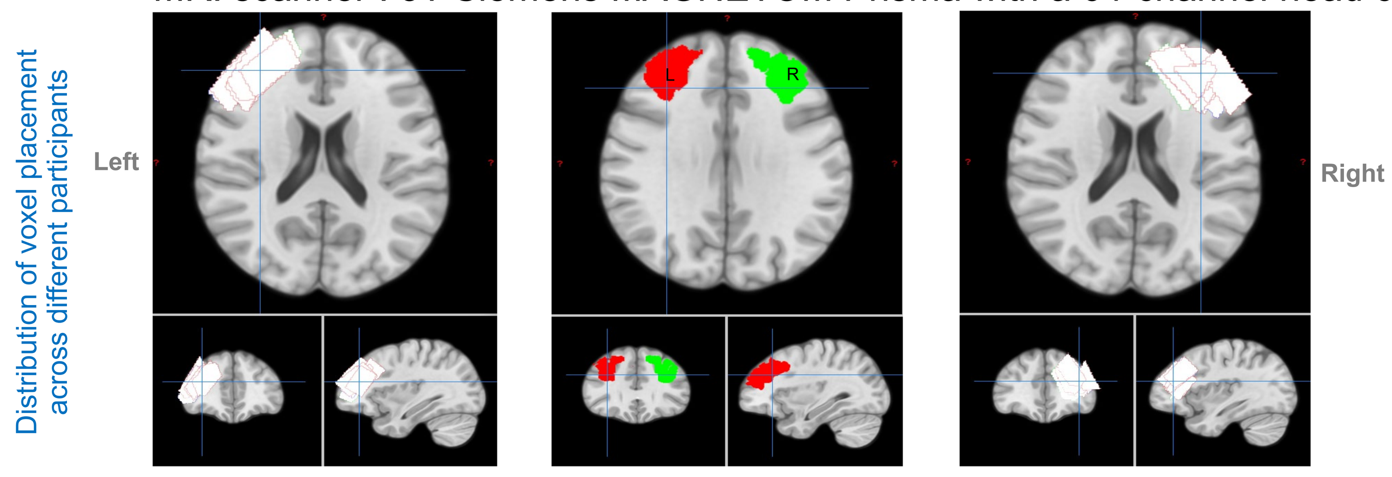
Informed consents for cognitive and both pre- and post-training MRI sessions were obtained

Related cognitive plasticity and learning dependent changes in frontal brain regions

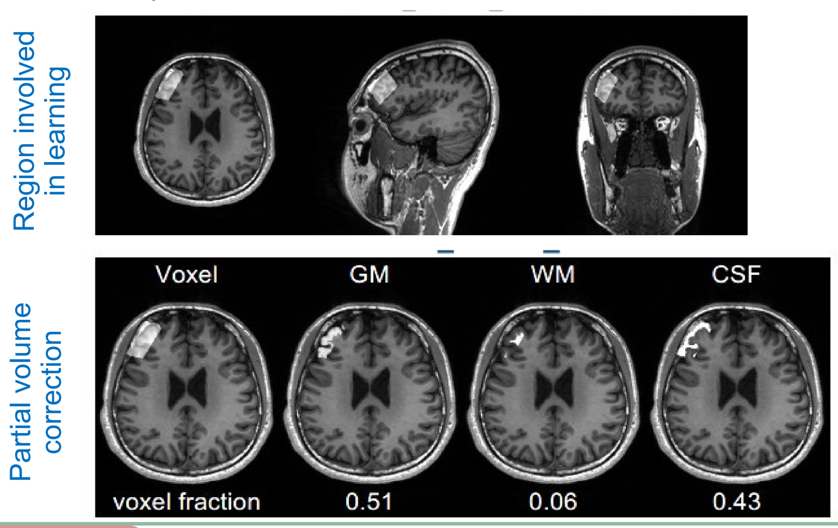


Water diffusion and myelination strongly linked to **learning plasticity**

#Participants: Total 113 (Control:55 ; Training:58)
Age: 28.21±7.89 yrs (18-55 years, right-handed); Gender: 65-F, 48-M
1H-MRS region of interest: R & L-DLPFC; Vox size:30x15x30 mm³
MEGA-Press: TE = 68 ms ; TR = 2000 ms; ON = 1.98 ppm: OFF = 7.5ppm
MRI scanner : 3T Siemens MAGNETOM Prisma with a 64-channel head coil.



Distribution of MRS voxel placement on Left DLPFC | DLPFC Mask as combination of Brodmann Area-46,9 on MNI152 | Distribution of MRS voxel placement on Right DLPFC



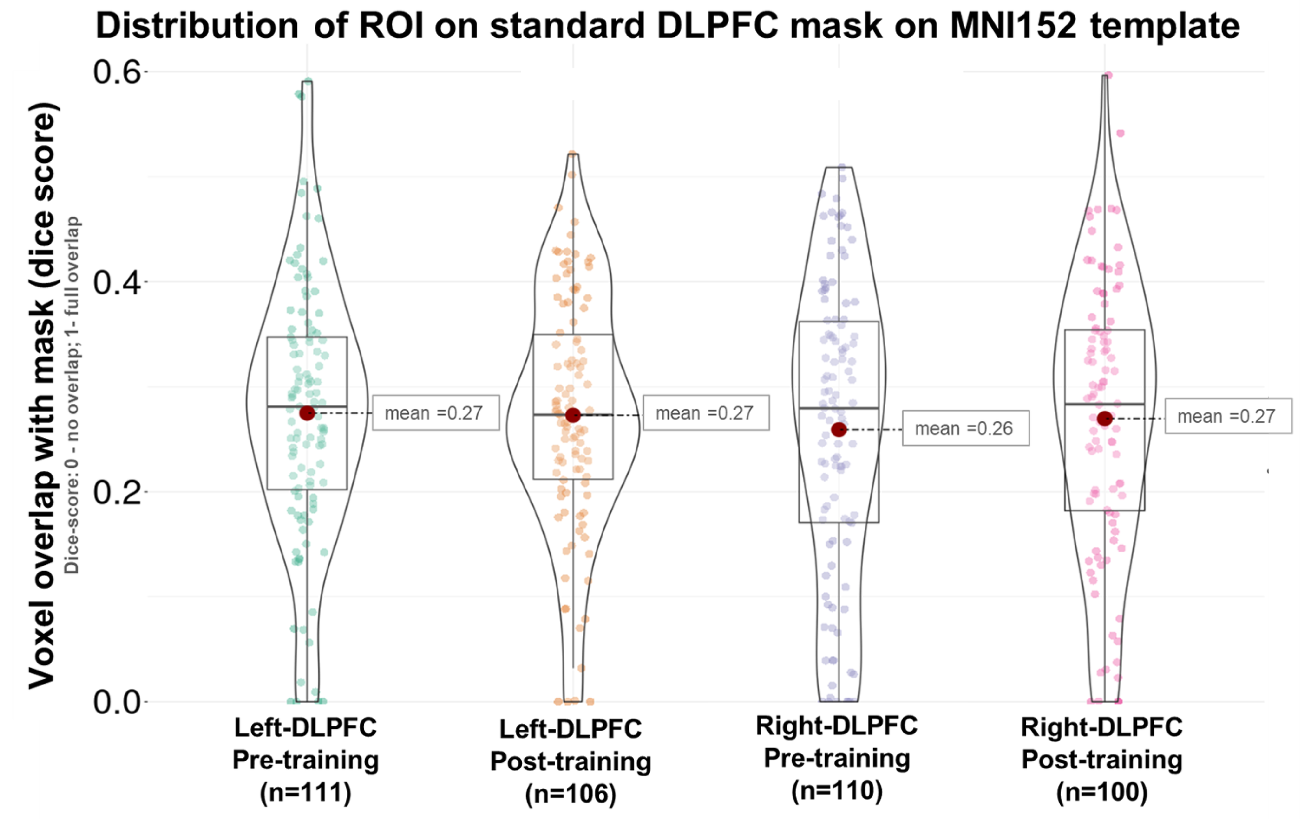
ROLE of GABA/Glx in LEARNING:

- GABA and Glx (neurotransmitters) are *chemical messengers*, work to send messages between neurons.
- GABA: inhibitory neurotransmitter
- Glx: excitatory neurotransmitter
- The neurotransmitter GABA plays an important role in helping the brain consolidate new info.
- The balance between GABA and Glx i.e. inhibitory-excitatory transmission is essential for proper cell membrane stability and neurologic function.
- GABA & Glx can be measured non-invasively using MRS: an advanced neuroimaging technique.

Results & Discussion

Effect of Structural Learning on neuro-metabolites

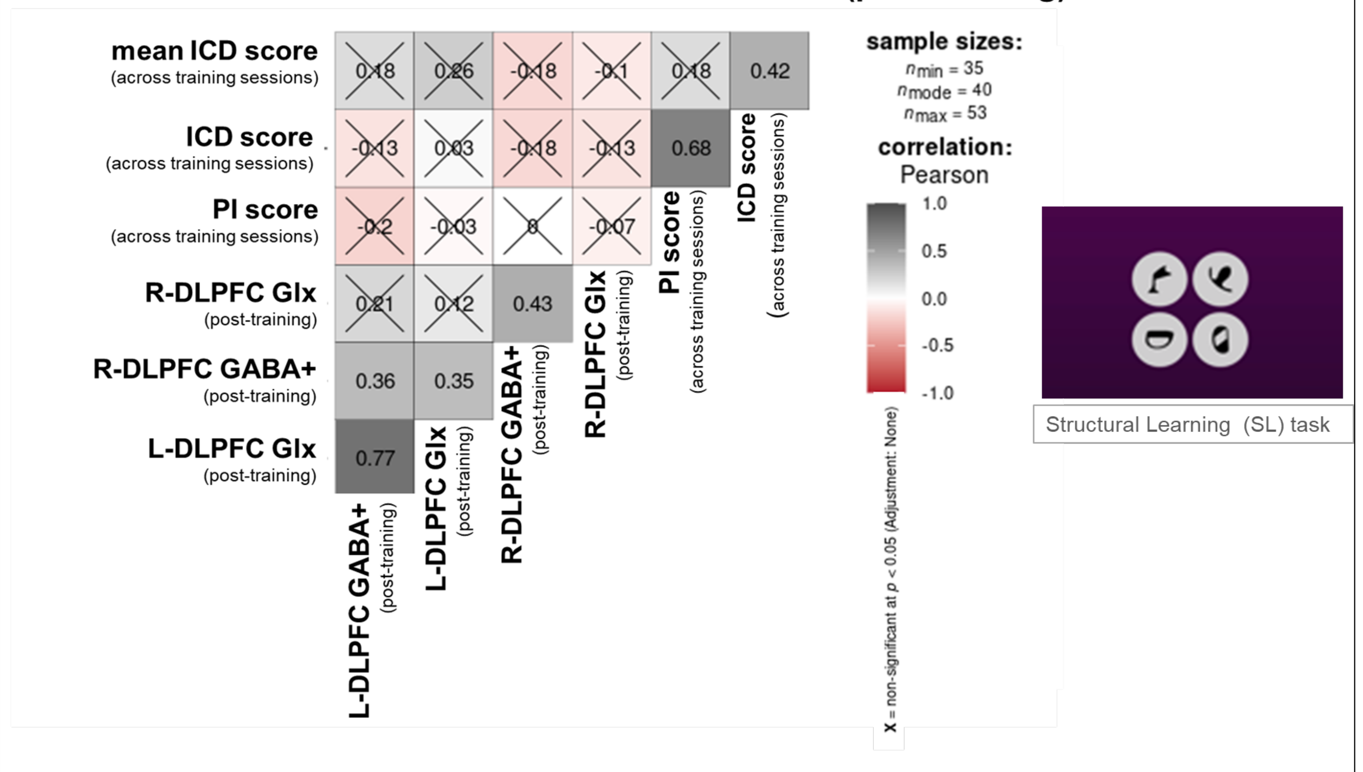
Distribution of ROI on standard DLPFC mask on MNI152 template



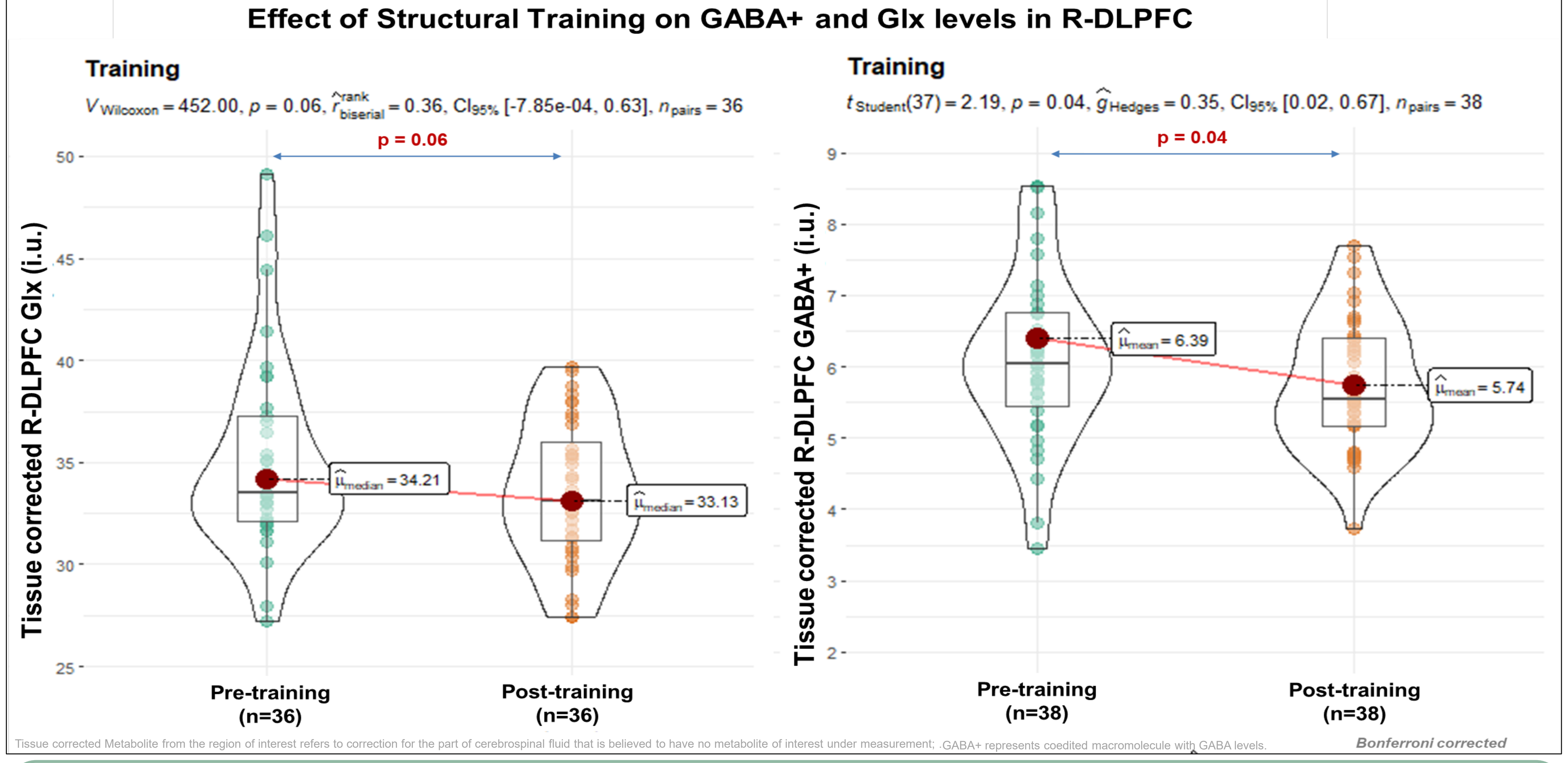
- Each MRS voxel in the left and the right DLPFC are transformed from local space to standard MNI152 space.
- Standard DLPFC mask is designed using combined Brodmann areas BA-46 & BA-9.
- MRS voxel positioning on DLPFC in the Left and Right regions across pre-and post- training sessions did not differ.
- MEGA-PRESS edited MRS spectra for each regions were checked and cleaned for visual artefacts, Cr linewidth in the OFF-spectra, poor fitting and head movement resulting in displaced voxel position during data acquisition.
- Good quality data L-DLPFC(NC= 52; NT=52) & R-DLPFC (NC=52; NT=50) in pre-training session and L-DLPFC (NC=46; NT=48) and R-DLPFC (NC=47; NT=43) in post-training session were used in analysis.

Relation between neuro-metabolites and cognitive scores

Correlation of GABA+ & Glx levels with SL scores (post training)

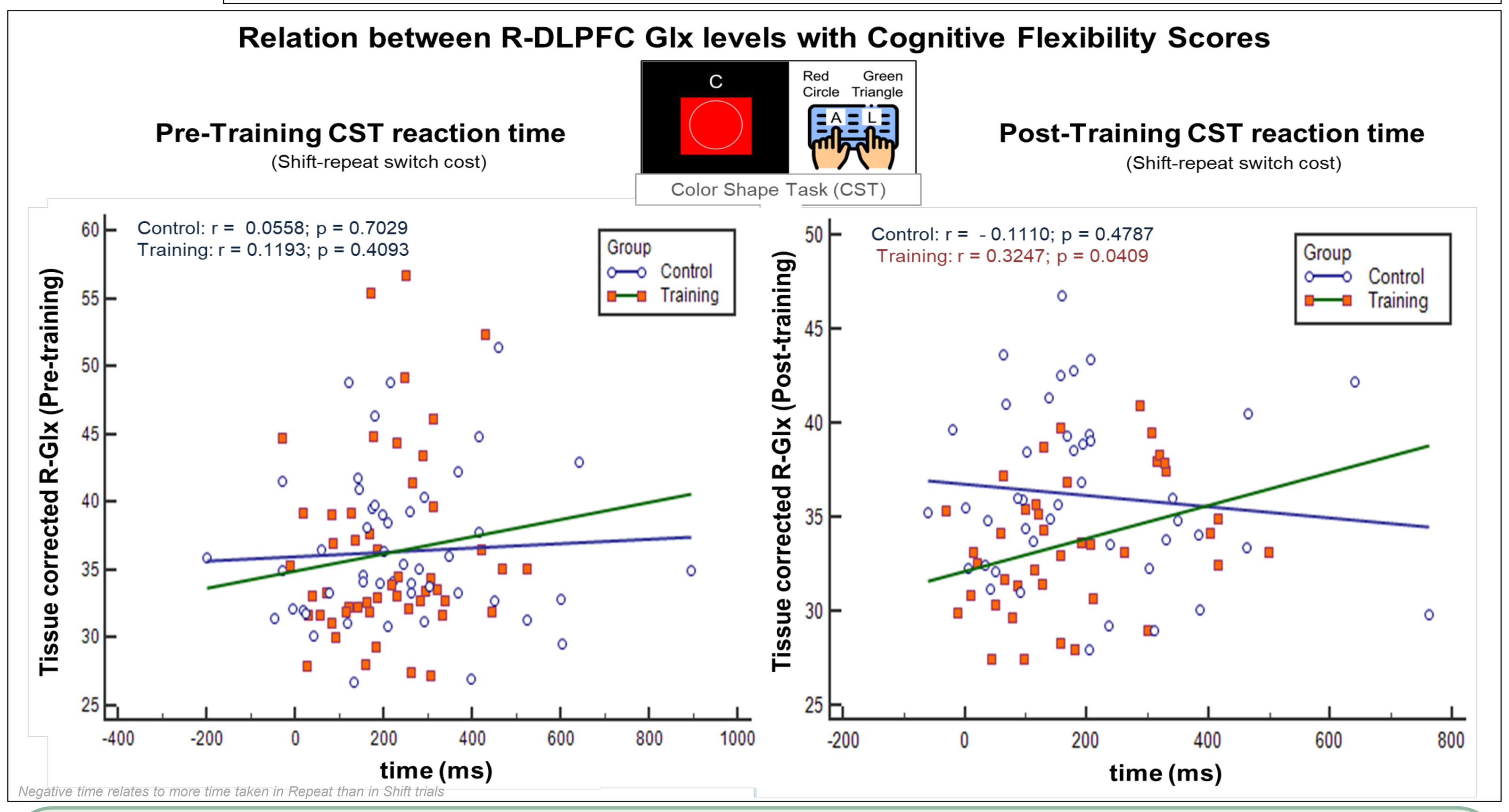


Effect of Structural Training on GABA+ and Glx levels in R-DLPFC



- Off-spectrum Cr linewidth varied across as L-DLPFC (6.23±1.26 Hz) and R-DLPFC (6.37±1.057 Hz).
- Each data group further cleaned for outliers using generalized extreme Studentized deviate) ESD test for statistical analysis.
- Both the training and the control groups observed similar GABA+ and Glx levels in bilateral DPFC in their pre-test before start of two-week structural training.
- Post-test GABA+ in R-DLPFC reduced significantly in the training (p = 0.04 , 5.74±0.922) group, and no changes observed in the control (p = 0.119) group.
- No significant change observed in post-training Glx levels in the R-DLPFC in training (p = 0.062) as well in control (p = 0.468) groups.
- L-DLPFC GABA+ and Glx did not change between pre- and post-training sessions among both the control and training groups.

Relation between R-DLPFC Glx levels with Cognitive Flexibility Scores



- Tissue corrected GABA+ and Glx levels in the both the L- & R-DLPFC did not show any significant correlation with the Structural Learning test scores.
- Post-training R-DLPFC GABA+ positively correlated with both L-DLPFC GABA (r =0.3633; p=0.0271) and Glx (r = 0.3473; p = 0.0281) levels, indicating effect of training with the involvement of bilateral neuro-chemical modulation in learning.
- No significant correlation with R-DLPFC Glx levels in both control and training groups observed with their CST pre-test switch cost in reaction times.
- R-DLPFC Glx in training group correlates positively (r = 0.3247; p = 0.0409) with CST post-test switch cost in reaction time, indicating reduced Glx levels in the R-DLPFC related to shorter reaction time.
- Post-test R-DLPFC GABA in control group correlated negatively with the shift cost reaction time (r = -0.3, p = 0.045) in repeat trials but did not show any relation in training group.

References: [1]. Lucina Q Uddin , Cognitive and behavioral flexibility: neural mechanisms and clinical considerations, 2021 Mar;22(3):167-179. doi: 10.1038/s41583-021-00428-w. Epub 2021 Feb 3.

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