

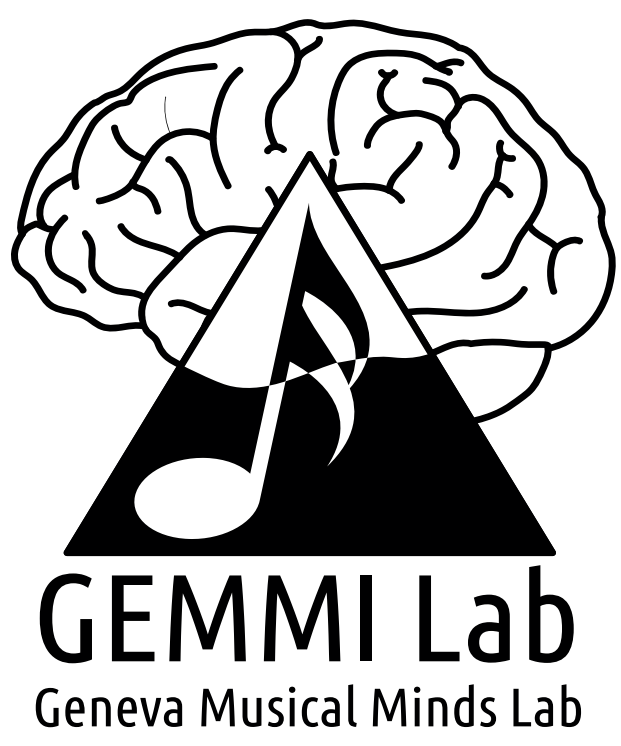


Cognitive enrichment through art

An RCT on the effects of music vs. visual arts group practice on cognitive and brain development of young children: **a study protocol**

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Research question: Can two years of music vs. visual arts group practice boost executive functions and induce structural and functional brain plasticity in young primary school children?

BACKGROUND & RATIONALE

- ▶ Optimal brain stimulation in the early school years: yet to be determined
- ▶ Musical practice vs. other arts in children: stronger transfer to Executive Functions (EF), particularly Working Memory (WM) [1,2,3,4,5,6] **Figure 1**
- ▶ Gap: Lack of large-scale, long-term RCT comparing musical **instrumental** training to other art form & control
- ▶ Ultimate aim: Build data-driven model of brain & EF development (ages 6-8 > 8-10) using machine learning, considering distinct impact of music vs. arts training vs. standard curriculum

METHODS SECTION

Experimental design: stratified RCT

Factors: 1) age, 2) gender, 3) Parents' educational level

Intervention groups (Figure 2)

1. Music practice group (Orchestra in Class, **OC**): n=44
2. Visual Arts group (**VA**): n= 44
3. Culture Group (control group **CG**, cultural outings): n=44

OC & VA interventions over 2 years :
1 x per week 90 minutes + daily homework
CG: 6 cultural outings per year

Measurements at each timepont (Figure 3)

Timepoints: 0-1 year-2 years (**t0-t1-t2**)

1. Extensive demographic battery
2. Behavioral testing (**Table 1**)
3. Neuroimaging (Magnetic Resonance Imaging; **Table 2**)
5. School results
6. Home work reporting (weekly)

Additional measurements

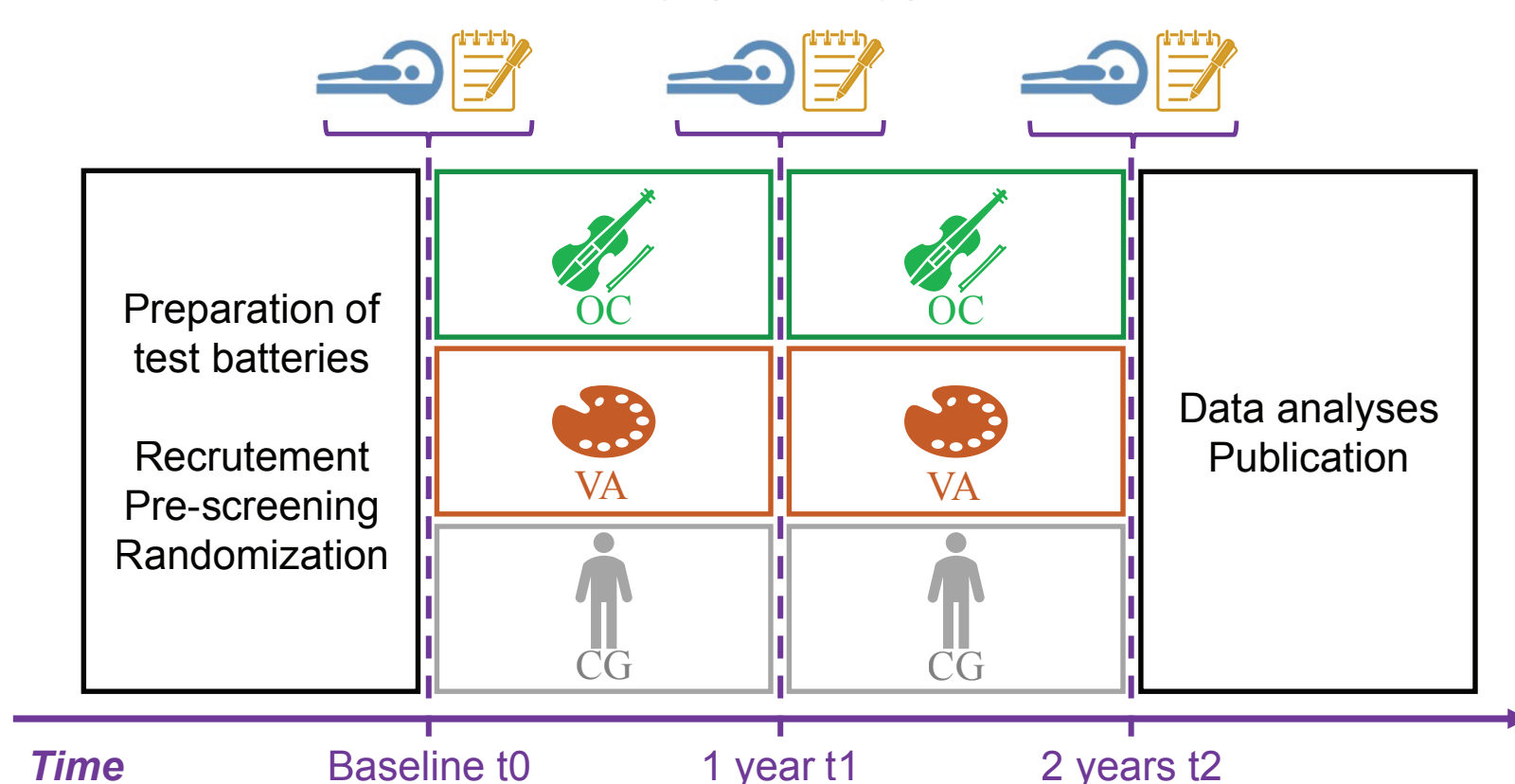


Figure 3: Schema of experimental plan



Figure 2: Left, OC intruments; Right, VA strands

ENDPOINTS

Primary endpoint: Enhance WM and associated brain plasticity in OC & VA vs. Control group (CG)

Secondary endpoints:

- ▶ Reinforce Brain Plasticity OC & VA vs. CG
- ▶ Show associations between brain plasticity and EF development controlling for demographic confounds
- ▶ Build a data-driven model(s) integrating WM, other EF, functional and structural brain development
- ▶ Predict WM change across groups based on a set of brain and behavioral features based on this model
- ▶ Show the relationship between EF changes following interventions and academic achievement

BROADER IMPACT

Contribute to resolving the controversy on the *specific effect* of group musical instrumental practice on EF and its cerebral substrates in young children

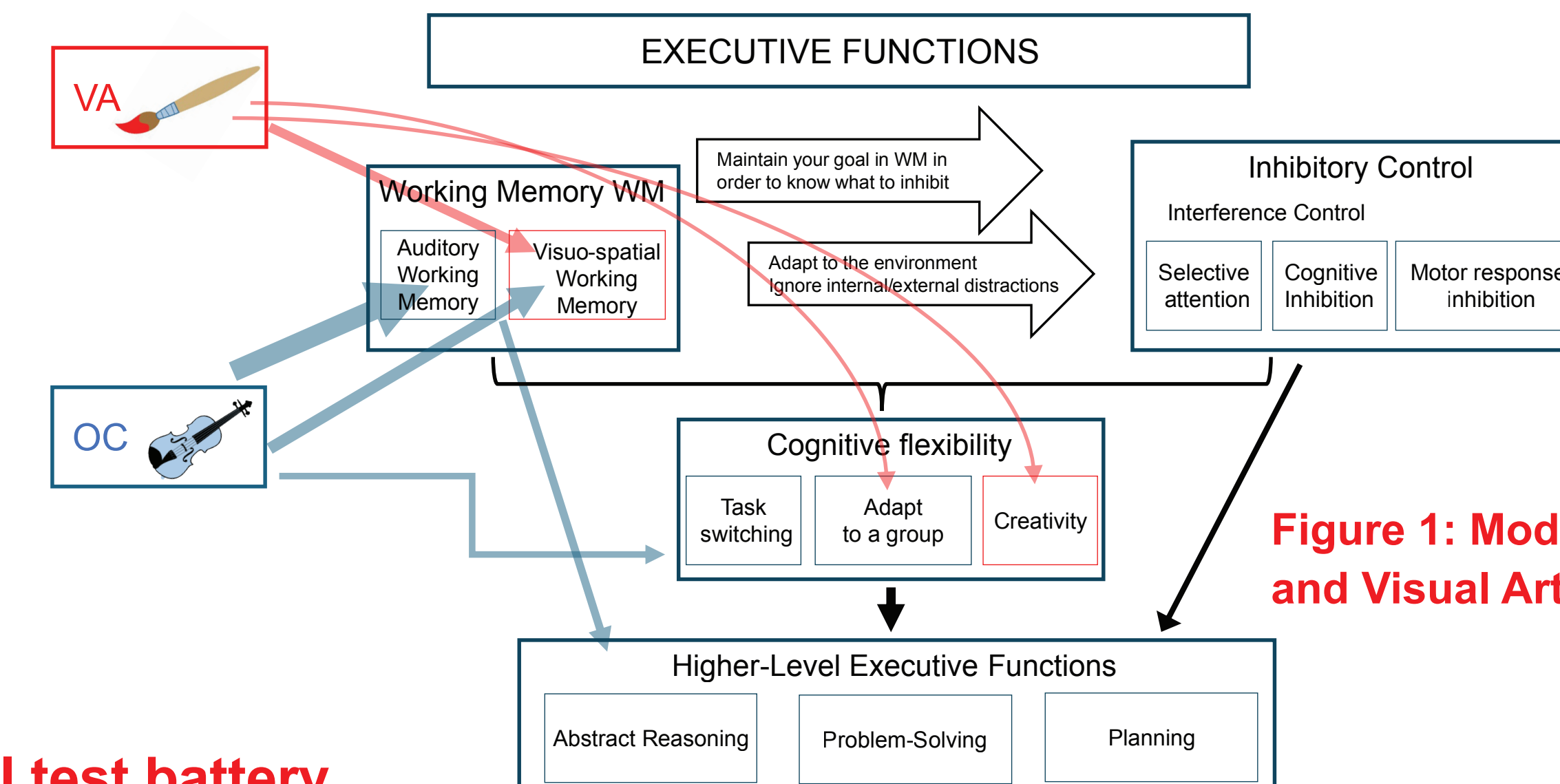


Figure 1: Model of EF in the context of Orchestra in Class (OC) and Visual Arts (VA) interventions, adapted from Diamond, 2013



QR code to Published protocol

Table 1: Behavioral test battery.

COGNITIVE DOMAIN	FUNCTION	NAME OF THE TEST	BRIEF DESCRIPTION	REFERENCES
Music abilities	Rhythm perception	Intermediate Measures of Music Audiation (IMMA)	Pattern comparison: judge if same or different in rhythm RIGHT button for identical patterns, LEFT for different patterns	Gordon, 1984, 2007
Visuo-spatial abilities	1. Visuo-spatial reasoning & praxis 2. Problem solving	Cubes test (WISC-V)	Arranging physical pictured cubes in specific patterns according to a design	Wechsler, 2014
Working memory (fMRI)	Auditory tonal working memory	Pattern comparison (inspired by IMMA)	Compare two 3-note sinus tone patterns 1. Low load condition: RIGHT button for identical patterns, LEFT for different patterns 2. High load condition: RIGHT button for identical patterns, LEFT for different patterns	Adapted from Gordon, 1984, 2007
	Visual-spatial working memory	Visual n-back	6-case spatial matrix containing appealing monster figures-conditions: 0-back, 2-back Right button for matched n-back trial, LEFT button for unmatched n-back trial	Adapted from Vuontela et al., 2003
Memory Systems	Short-term memory	Digit Span Forward (WISC-V)	Repeating series of digit sequences of increasing length aloud	Wechsler, 2014
	Working memory: information manipulation	Digit Span Backward (WISC-V)	Repeating series of digit sequences of increasing length aloud backwards	Wechsler, 2014
Attention	Processing speed	"The Witch" (KITAP)	Specific key for Witch presented in window – respond as quickly and correctly as possible	Zimmermann et al., 2002
	Selective and sustained attention	Ucancellation (child-friendly version of d2 test)	Respond to upright dog (tail left), upside-down monkey (tail right) - ignore similar distractors	Brickenkamp and Zillmer, 1998; Pahor et al., 2022
Auditory selective attention	Speech in noise perception	International Matrix Test	Participants repeat 5 word sentences heard through headphones: first without, then with a white noise background (right ear – left ear – both ears)	Kollmeier et al., 2015
Inhibition	Response inhibition (motor inhibition)	Go/NoGo – "The Bat" (KITAP)	Specific key for bat only - Ignore cat	Zimmermann et al., 2002
	Distractor inhibition (perceptual/cognitive inhibition)	Child-friendly Flanker Task	Left/Right arrow for center fish swimming direction - ignore surrounding fishes (congruent vs. in- congruent swimming direction), as quickly and correctly as possible	Adapted from Rueda et al., 2004
Cognitive control / flexibility (higher EF)	Perceptual switching (simple)	"The dragons' house" (KITAP)	Match button press to dragon color as quickly and correctly as possible – 2 alternating colors	Zimmermann et al., 2002
	Rule switching (complex)	Dimensional Change Card Sort (DCCS)	Sort cards based on changing rules (color, shape) separately and mixed, as quickly and correctly as possible	Adapted from Zelazo, 2006
Reasoning (higher EF)	Abstract/logical	Matrix reasoning (WISC-V)	Inspect incomplete matrix – choose missing piece from 5 options	Wechsler, 2014
	Quantitative/analytical	Figure weight (WISC-V)	Inspect scale with missing weight – select balance option within time limit	Wechsler, 2014
Reasoning Daily life functioning	Executive functions	BRIEF questionnaire	Questionnaire for parents: Daily living assessment of children's executive functions	Baron, 2000; Gioia et al., 2000
	Emotion regulation (affective abilities)	Emotion Regulation Checklist French Version (ERC-vf)	French version of questionnaire concerning children; 24 questions on a 4-point Likert scale measuring 2 factors: emotion regulation & emotional lability	Nader-Grosbois and Mazzone, 2015
	Behavioral and emotional problems	Emotion Regulation Questionnaire for Children & Adolescents (ERQ-CA)	French version of questionnaire for children (self-report); 20 questions on a 5-point Likert scale measuring 2 strategies: cognitive reappraisal and expressive suppression	J. Gosling et al., 2018
		Strengths and Difficulties Questionnaire (SDQ_Fra)	French version of questionnaire concerning children; 25 questions on a 3-point Likert scale measuring 3 factors: internalizing problems, externalizing problems & prosocial tendencies	Goodman et al., 2010
Language	Language Experience and Proficiency	Language Experience and Proficiency Questionnaire (LEAP-Q)	Questionnaire for parents: A self-report questionnaire, assessing language exposure, use, and proficiency in multilingual contexts	Marian et al., 2007
Sleep	Sleep evaluation in children	Sleep Disturbance Scale for Children (SDSC)	A parent-reported questionnaire, evaluating sleep problems in children, including habits and disorders	Bruni et al., 1996
Screen usage	Screen Time and habits	Screen Usage Questionnaire (SUQ)	Questionnaire for parents: A survey measuring children's screen time, device usage patterns, and associated habits	Adapted from Akbayin et al., 2023
Learning and progress	N/A	Multi-media materials	1. Videos (orchestra) – rating on # Likert scales by independent judges 2. Photos and videos (visual arts) – rating on # Likert scales by independent judges	
	N/A	Teacher ratings (Likert scales)	Music: 1. pitch; 2. rhythm; 3. expression; 4. ensemble playing/singing; 5. motivation; 6. overall quality Visual Arts: a. 1. creativity; 2. graphic skill; colors & shapes; 3. attention/concentration; 4. collaboration; 5. motivation; 6. overall quality	
	N/A	Homework	Use an online app to track homework	
	N/A	Aerobic fitness	School gymnastic teachers report aerobic fitness on Likert scale	
Others / Miscellaneous	N/A	Demographic questionnaire	Questionnaire for parents (extensive, including extracurricular activities)	
	N/A	Family Context Questionnaire (FCQ)	A self-report assessing factors such as family relationships, routines, and socio-economic conditions	Adapted from Zortea and Tokumaru, 2010
	N/A	Academic results	Collection of all school grades	

Analyses of behavioral and MRI data:

Step 1: Analyze EF-brain links (particularly WM) at baseline using MANCOVA, GLM, regressions, determining confounders, creating a population brain template [7]

Step 2: Compare EF and brain changes (t1-t0; t2-t0)) between groups and over time using Linear Mixed Models (LMM); test hypotheses linking WM and other EF to brain networks, considering experimental group and demographics

Step 3: Use multivariate data-driven Independent Component Analysis, Partial Least of Squares, and graph-based machine learning (graph neural networks (GNN)) to explore group-level brain-behavior links and individual outcome predictions via GNN models, creating a model of EF development with and without different artistic enrichments [8,9,10,11] (**Figure 4**)

Table 2: Brain magnetic resonance imaging (MRI) test battery.

Resting-state (RS) fMRI	1 EPI run of 8.6 min = 520 volumes, voxel size: 2.5 mm isotropic; 51 slices; FOV: 200x200x120 mm; TR/TE: 1000/30 ms
Task-based fMRI activity	Tonal WM task 1 EPI run of 9.5 min; same sequence as RS Visuo-spatial n-back task 1 EPI run of 9.5 min; same sequence as RS
Grey Matter Morphometry	MPRAGE T1-weighted MRI: duration: 5 min; voxel size: 0.8 mm isotropic; FOV: 230x230x166.4 mm
Structural connectivity	Multishell DWI: duration: 7.5 min; voxel size: 2 mm isotropic; 60 slices, FOV: 208x208x120 mm, TR/TE: 2900/65 ms; b-values: 0/1000/2000 s/mm ² ; 9/30/60 directions

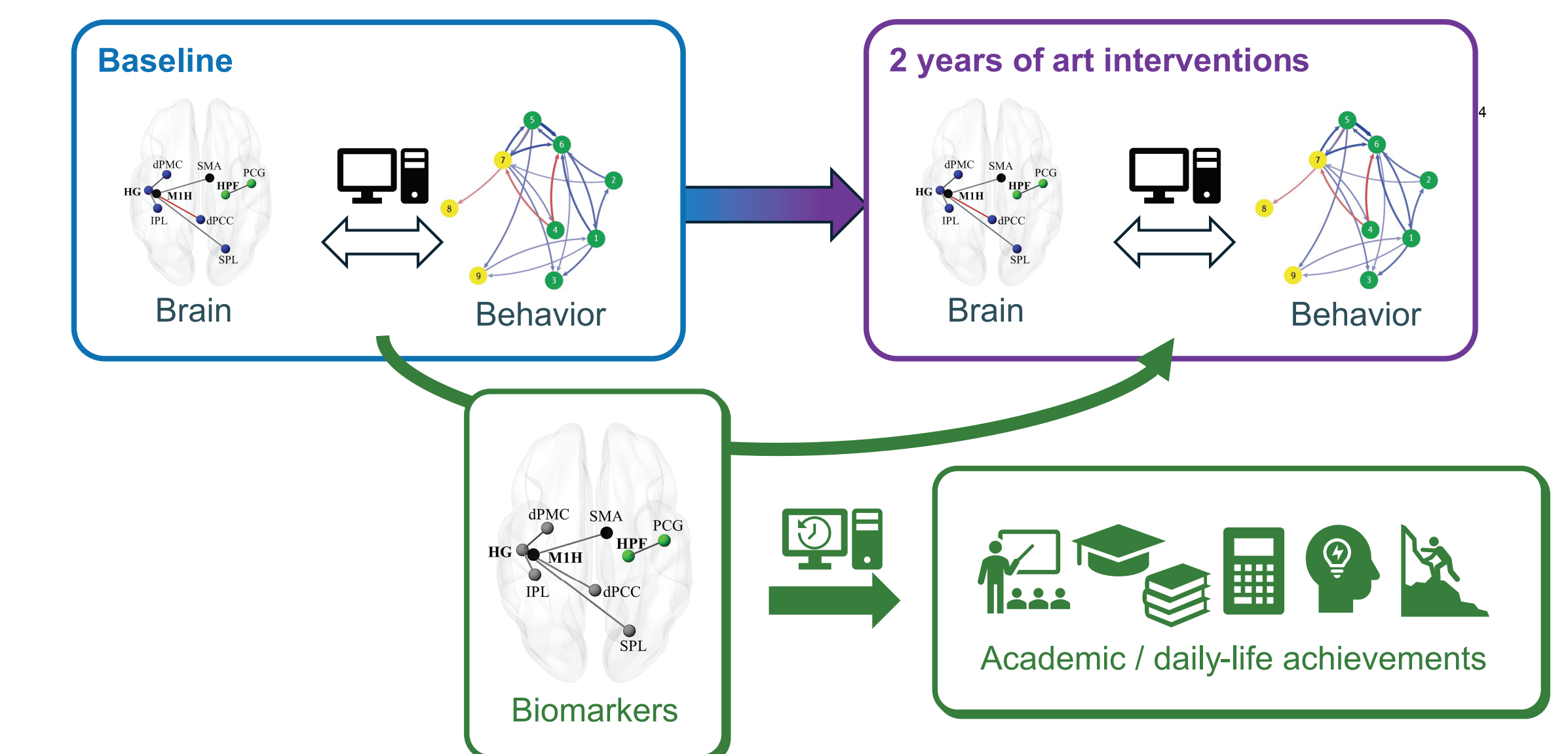


Figure 4: Model of child development with/without artistic enrichment

REFERENCES [1] James et al., 2020; [2] Frischen et al., 2021; [3] Habibi et al., 2018a; [4] Habibi et al., 2018b; [5,6] Schellenberg, 2004, 2006; [7] Marie & Golestani, 2016; [8] Sui et al., 2013; [9] Krishnan et al., 2011; [10] Kebets et al., 2018; [11] Preti et al., 201