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Supplementary Material

Lifespan Changes in Network Structure and Network Topology Dynamics during Rest and Auditory Oddball Performance

Viktor Müller*, Viktor Jirsa, Dionysios Perdikis, Rita Sleimen-Malkoun, Timo von Oertzen, and Ulman Lindenberger

***Correspondence:** Dr. Viktor Müller, Email: vmueller@mpib-berlin.mpg.de

1 Age-related changes in WFC and CFC

Statistical analyses of WFC and CFC of the *ICI* data using a two-way repeated measures ANOVA with a between-subject factor Age (YC, OC, YA, and OA) and a within-subject factors Condition (REC, REO, UOT, and AOT) revealed a significant main effect of Age for both WFC and CFC; whereas main effect of Condition and interaction of factors Age and Condition were significant only for CFC (see Supplementary Table 1 and Fig. 1 for details). The post-hoc Fischer's LSD test for WFC-values showed significantly lower coupling in YC than in other age groups (YC < OC, $P < 0.05$; YC < YA, $P < 0.01$; YC < OA, $P < 0.0001$), while CFC-values were significantly lower in YA than in other age groups (YA < OC, $P < 0.005$; YA < YC, $P < 0.0001$; YA < OA, $P < 0.0001$). The WFC and CFC strength determined within a 10-s epoch using a sliding time window approach showed very similar results (see Supplementary Table 1 and Fig. 1 for details), with an exception that post-hoc tests showed in addition significant differences between OC and OA for both WFC and CFC strengths ($P < 0.05$), whereby the differences between OC and YA were only approximately significant. In accordance with these similarities, Cronbach's alpha test showed high consistency for mean *ICI* values averaged across eight 10-s segments and strengths determined within a 10-s time interval using a sliding time window approach (see Supplementary Table 2 for details).

Supplementary Table 1. ANOVA results for the mean *ICI* values and coupling strengths determined separately for within- and cross-frequency coupling

Factors	F-value	P-value	Partial eta squared
	Mean *ICI* (WFC)		
Age	$F_{3,107} = 5.71$	**P < 0.005**	$\eta^2 = 0.14$
Condition	$F_{3,321} = 0.46$	P = 0.68	$\eta^2 = 0.004$
Age × Condition	$F_{9,321} = 0.97$	P = 0.46	$\eta^2 = 0.03$
	Mean *ICI* (CFC)		
Age	$F_{3,107} = 11.29$	**P < 0.0001**	$\eta^2 = 0.24$
Condition	$F_{3,321} = 91.41$	**P < 0.0001**	$\eta^2 = 0.46$
Age × Condition	$F_{9,321} = 6.87$	**P < 0.0001**	$\eta^2 = 0.16$
	Strength (WFC)		
Age	$F_{3,107} = 6.08$	**P < 0.005**	$\eta^2 = 0.15$
Condition	$F_{3,321} = 2.63$	P = 0.057	$\eta^2 = 0.02$
Age × Condition	$F_{9,321} = 0.59$	P = 0.79	$\eta^2 = 0.02$
	Strength (CFC)		
Age	$F_{3,107} = 8.56$	**P < 0.0001**	$\eta^2 = 0.19$
Condition	$F_{3,321} = 53.41$	**P < 0.0001**	$\eta^2 = 0.33$
Age × Condition	$F_{9,321} = 3.17$	**P < 0.005**	$\eta^2 = 0.08$

WFC, within-frequency coupling; CFC, cross-frequency coupling

Supplementary Table 2. Reliability of coupling strength determined within an epoch as compared to mean ICI measure averaged across the eight different epochs

	Conditions			
Measures	REC	REO	UOT	AOT
	Within-frequency coupling (WFC)			
Cronbach's α	0.986	0.987	0.984	0.987
R	0.973	0.974	0.968	0.973
	Cross-frequency coupling (CFC)			
Cronbach's α	0.942	0.773	0.901	0.895
R	0.891	0.630	0.821	0.809

R, correlation coefficient; WFC, within-frequency coupling; CFC, cross-frequency coupling

Supplementary Table 3. Reliability of network topology measures determined within two different epochs

Measures	*Mean*		*tSD*		*nSD*	
	Cronbach's α	*R*	*Cronbach's α*	*R*	*Cronbach's α*	*R*
S_{in}	0.934	0.877	0.715	0.556	0.852	0.742
S_{out}	0.936	0.879	0.658	0.490	0.835	0.716
CC	0.977	0.956	0.925	0.860	0.906	0.828
CPL	0.906	0.829	0.647	0.479	0.725	0.568
E_{local}	0.901	0.820	0.772	0.629	0.789	0.652
E_{global}	0.900	0.818	0.840	0.724	0.786	0.647

R, correlation coefficient; *tSD,* temporal standard deviation; *nSD,* nodal standard deviation; S_{in}, in-strength; S_{out}, out-strength; *CC*, clustering coefficient; *CPL*, characteristic path length; E_{local}, local efficiency; E_{global}, global efficiency.

Supplementary Table 4. ANCOVA results for the mean (M) and standard deviation (SD) across time and across nodes for the six GTA measures

GTA measures	Factors	F-value	P-value	Partial eta squared
		Mean (M)		
S_{in}	Age	$F_{3,105} = 20.06$	**P < 0.0001**	$\eta^2 = 0.36$
	Age × Condition	$F_{3,105} = 0.25$	P = 0.86	$\eta^2 = 0.01$
S_{out}	Age	$F_{3,105} = 19.38$	**P < 0.0001**	$\eta^2 = 0.36$
	Age × Condition	$F_{3,105} = 0.58$	P = 0.63	$\eta^2 = 0.02$
CC	Age	$F_{3,105} = 4.91$	**P < 0.005**	$\eta^2 = 0.12$
	Age × Condition	$F_{3,105} = 0.96$	P = 0.42	$\eta^2 = 0.03$
CPL	Age	$F_{3,105} = 15.58$	**P < 0.0001**	$\eta^2 = 0.31$
	Age × Condition	$F_{3,105} = 0.52$	P = 0.67	$\eta^2 = 0.02$
E_{local}	Age	$F_{3,105} = 8.35$	**P < 0.0001**	$\eta^2 = 0.19$
	Age × Condition	$F_{3,105} = 0.72$	P = 0.55	$\eta^2 = 0.02$
E_{global}	Age	$F_{3,105} = 15.25$	**P < 0.0001**	$\eta^2 = 0.30$
	Age × Condition	$F_{3,105} = 0.28$	P = 0.84	$\eta^2 = 0.01$
		Standard Deviation across time (tSD)		
S_{in}	Age	$F_{3,105} = 28.80$	**P < 0.0001**	$\eta^2 = 0.45$
	Age × Condition	$F_{3,105} = 1.61$	P = 0.19	$\eta^2 = 0.04$
S_{out}	Age	$F_{3,105} = 13.28$	**P < 0.0001**	$\eta^2 = 0.28$
	Age × Condition	$F_{3,105} = 2.25$	P = 0. 087	$\eta^2 = 0.06$
CC	Age	$F_{3,105} = 3.85$	**P < 0.05**	$\eta^2 = 0.10$
	Age × Condition	$F_{3,105} = 1.90$	P = 0.13	$\eta^2 = 0.05$
CPL	Age	$F_{3,105} = 18.18$	**P < 0.0001**	$\eta^2 = 0.34$
	Age × Condition	$F_{3,105} = 0.96$	P = 0.42	$\eta^2 = 0.03$
E_{local}	Age	$F_{3,105} = 11.85$	**P < 0.0001**	$\eta^2 = 0.25$
	Age × Condition	$F_{3,105} = 1.13$	P < 0.34	$\eta^2 = 0.03$
E_{global}	Age	$F_{3,105} = 27.89$	**P < 0.0001**	$\eta^2 = 0.44$
	Age × Condition	$F_{3,105} = 2.12$	P = 0.10	$\eta^2 = 0.06$
		Standard Deviation across nodes (nSD)		
S_{in}	Age	$F_{3,105} = 5.63$	**P < 0.001**	$\eta^2 = 0.14$
	Age × Condition	$F_{3,105} = 0.35$	P = 0.79	$\eta^2 = 0.01$
S_{out}	Age	$F_{3,105} = 4.78$	**P < 0.005**	$\eta^2 = 0.12$
	Age × Condition	$F_{3,105} = 0.14$	P = 0.94	$\eta^2 = 0.004$
CC	Age	$F_{3,105} = 4.15$	**P < 0.01**	$\eta^2 = 0.11$
	Age × Condition	$F_{3,105} = 0.04$	P = 0.99	$\eta^2 = 0.001$
CPL	Age	$F_{3,105} = 4.49$	**P < 0.005**	$\eta^2 = 0.11$
	Age × Condition	$F_{3,105} = 1.36$	P = 0.26	$\eta^2 = 0.04$
E_{local}	Age	$F_{3,105} = 14.12$	**P < 0.0001**	$\eta^2 = 0.29$
	Age × Condition	$F_{3,105} = 0.19$	P = 0.90	$\eta^2 = 0.01$
E_{global}	Age	$F_{3,105} = 4.64$	**P < 0.005**	$\eta^2 = 0.12$
	Age × Condition	$F_{3,105} = 0.52$	P = 0.67	$\eta^2 = 0.02$

S_{in}, in-strength; S_{out}, out-strength; *CC*, clustering coefficient; *CPL*, characteristic path length; E_{local}, local efficiency; E_{global}, global efficiency.

Supplementary Table 5. ANCOVA results for the temporal and nodal (positive and negative) similarity for the six GTA measures

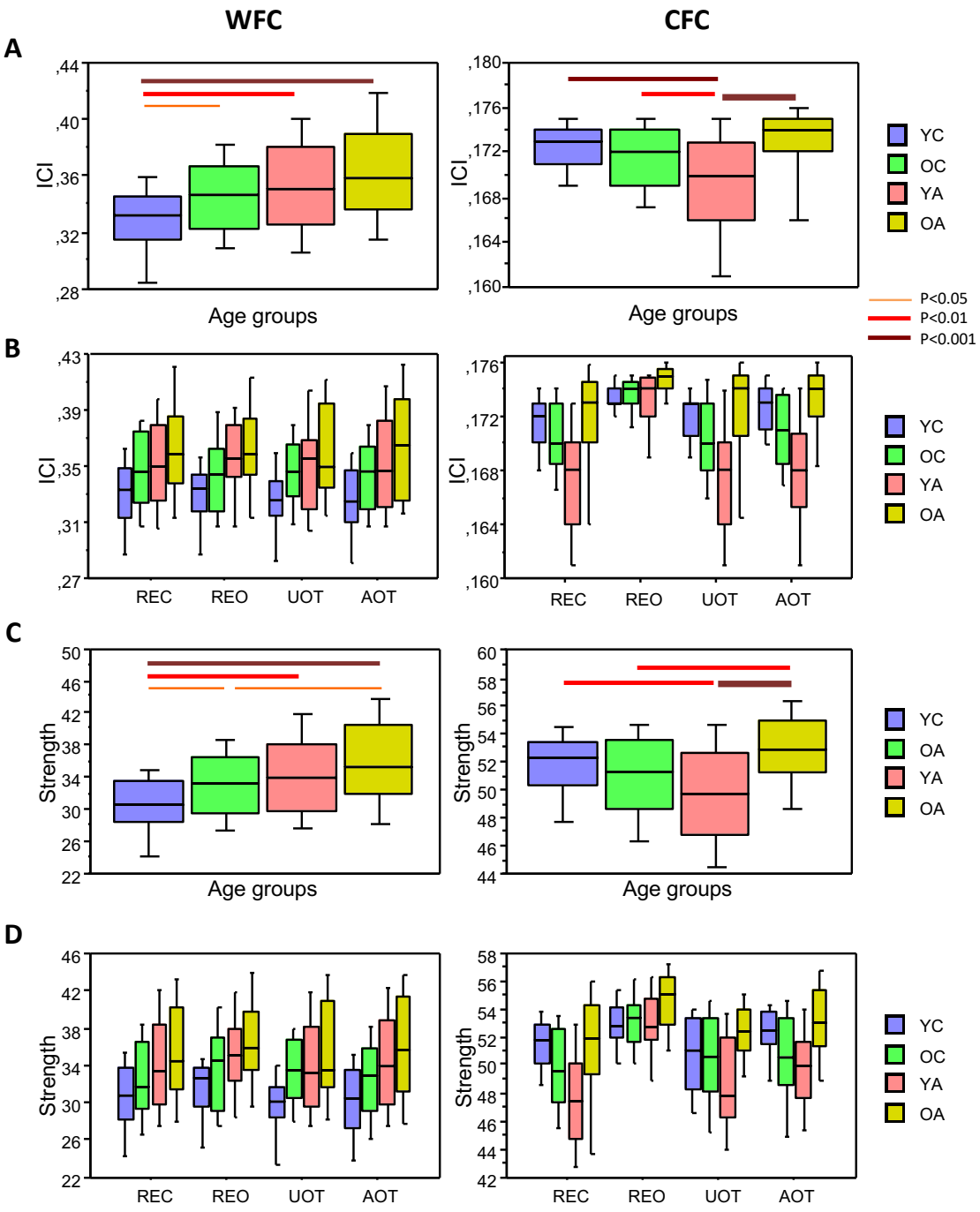
GTA measures	Factors	F-value	P-value	Partial eta squared
		Temporal network similarity		
S_{in}	Age	$F_{3,105} = 5.40$	**P < 0.005**	$\eta^2 = 0.13$
	Age × Condition	$F_{3,105} = 2.12$	P = 0.10	$\eta^2 = 0.06$
S_{out}	Age	$F_{3,105} = 2.79$	**P < 0.05**	$\eta^2 = 0.07$
	Age × Condition	$F_{3,105} = 1.41$	P = 0.25	$\eta^2 = 0.04$
CC	Age	$F_{3,105} = 3.42$	**P < 0.05**	$\eta^2 = 0.09$
	Age × Condition	$F_{3,105} = 3.11$	**P < 0.05**	$\eta^2 = 0.08$
CPL	Age	$F_{3,105} = 20.97$	**P < 0.0001**	$\eta^2 = 0.38$
	Age × Condition	$F_{3,105} = 2.80$	**P < 0.05**	$\eta^2 = 0.07$
E_{local}	Age	$F_{3,105} = 1.30$	P = 0.28	$\eta^2 = 0.04$
	Age × Condition	$F_{3,105} = 0.67$	P = 0.57	$\eta^2 = 0.02$
E_{global}	Age	$F_{3,105} = 3.95$	**P < 0.01**	$\eta^2 = 0.10$
	Age × Condition	$F_{3,105} = 0.87$	P = 0.46	$\eta^2 = 0.02$
		Network similarity across nodes (positive)		
S_{in}	Age	$F_{3,105} = 1.92$	P = 0.13	$\eta^2 = 0.05$
	Age × Condition	$F_{3,105} = 0.31$	P = 0.82	$\eta^2 = 0.01$
S_{out}	Age	$F_{3,105} = 1.97$	P = 0.12	$\eta^2 = 0.05$
	Age × Condition	$F_{3,105} = 0.01$	P = 0.99	$\eta^2 = 0.00$
CC	Age	$F_{3,105} = 1.57$	P = 0.20	$\eta^2 = 0.04$
	Age × Condition	$F_{3,105} = 0.18$	P = 0.91	$\eta^2 = 0.01$
CPL	Age	$F_{3,105} = 0.86$	P = 0.47	$\eta^2 = 0.02$
	Age × Condition	$F_{3,105} = 0.41$	P = 0.75	$\eta^2 = 0.01$
E_{local}	Age	$F_{3,105} = 0.91$	P = 0.44	$\eta^2 = 0.03$
	Age × Condition	$F_{3,105} = 0.11$	P = 0.96	$\eta^2 = 0.003$
E_{global}	Age	$F_{3,105} = 1.67$	P = 0.18	$\eta^2 = 0.05$
	Age × Condition	$F_{3,105} = 0.15$	P = 0.93	$\eta^2 = 0.004$
		Network similarity across nodes (negative)		
S_{in}	Age	$F_{3,105} = 2.09$	P = 0.11	$\eta^2 = 0.06$
	Age × Condition	$F_{3,105} = 1.02$	P = 0.39	$\eta^2 = 0.03$
S_{out}	Age	$F_{3,105} = 1.96$	P = 0.13	$\eta^2 = 0.05$
	Age × Condition	$F_{3,105} = 0.47$	P = 0.71	$\eta^2 = 0.01$
CC	Age	$F_{3,105} = 0.13$	P = 0.94	$\eta^2 = 0.004$
	Age × Condition	$F_{3,105} = 0.93$	P = 0.43	$\eta^2 = 0.03$
CPL	Age	$F_{3,105} = 6.16$	**P < 0.001**	$\eta^2 = 0.15$
	Age × Condition	$F_{3,105} = 0.19$	P = 0.91	$\eta^2 = 0.01$
E_{local}	Age	$F_{3,105} = 3.28$	**P < 0.05**	$\eta^2 = 0.09$
	Age × Condition	$F_{3,105} = 1.70$	P = 0.17	$\eta^2 = 0.05$
E_{global}	Age	$F_{3,105} = 8.54$	**P < 0.0001**	$\eta^2 = 0.20$
	Age × Condition	$F_{3,105} = 0.66$	P = 0.58	$\eta^2 = 0.02$

S_{in}, in-strength; S_{out}, out-strength; *CC*, clustering coefficient; *CPL*, characteristic path length; E_{local}, local efficiency; E_{global}, global efficiency.

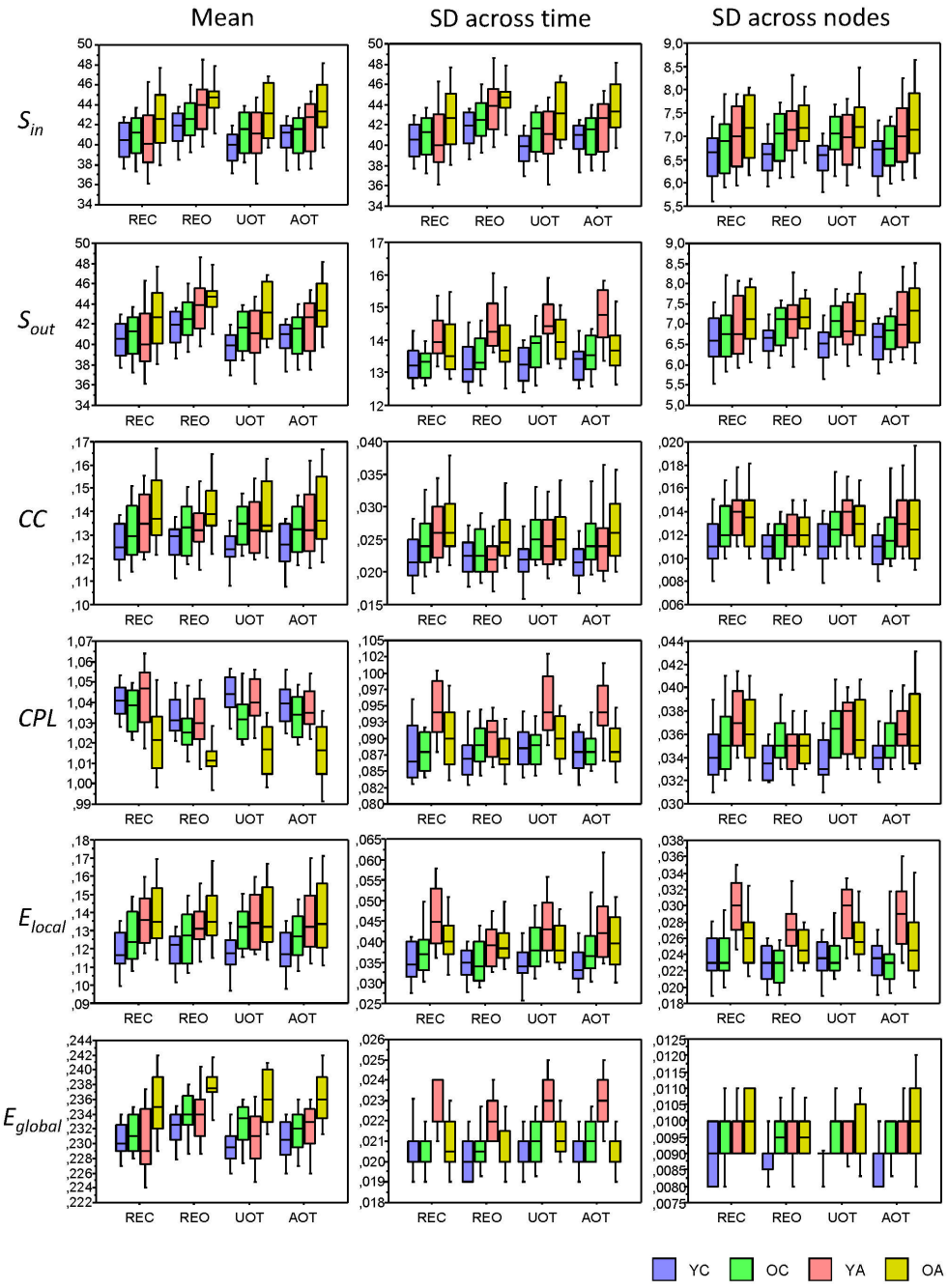
Supplementary Table 6. ANCOVA results for the network complexity and modular organization measures

Measures	Factors	F-value	P-value	Partial eta squared
		Complexity measures		
GE	Age	$F_{3,105} = 11.26$	**P < 0.0001**	$\eta^2 = 0.24$
	Age × Condition	$F_{3,105} = 1.28$	P = 0.28	$\eta^2 = 0.04$
LE	Age	$F_{3,105} = 27.60$	**P < 0.0001**	$\eta^2 = 0.44$
	Age × Condition	$F_{3,105} = 1.89$	P = 0.14	$\eta^2 = 0.05$
C_e	Age	$F_{3,105} = 16.60$	**P < 0.0001**	$\eta^2 = 0.32$
	Age × Condition	$F_{3,105} = 0.62$	P = 0.61	$\eta^2 = 0.02$
C_r	Age	$F_{3,105} = 11.54$	**P < 0.0001**	$\eta^2 = 0.25$
	Age × Condition	$F_{3,105} = 2.37$	P = 0.08	$\eta^2 = 0.06$
OdC	Age	$F_{3,105} = 8.39$	**P < 0.0001**	$\eta^2 = 0.19$
	Age × Condition	$F_{3,105} = 0.42$	P = 0.74	$\eta^2 = 0.01$
PE	Age	$F_{3,105} = 9.91$	**P < 0.0001**	$\eta^2 = 0.22$
	Age × Condition	$F_{3,105} = 1.93$	P = 0.13	$\eta^2 = 0.05$
CDN	Age	$F_{3,105} = 15.99$	**P < 0.0001**	$\eta^2 = 0.31$
	Age × Condition	$F_{3,105} = 0.92$	P = 0.43	$\eta^2 = 0.03$
IDN	Age	$F_{3,105} = 15.84$	**P < 0.0001**	$\eta^2 = 0.31$
	Age × Condition	$F_{3,105} = 1.71$	P = 0.17	$\eta^2 = 0.05$
		Modular organization measures		
Q	Age	$F_{3,105} = 4.36$	**P < 0.01**	$\eta^2 = 0.11$
	Age × Condition	$F_{3,105} = 0.91$	P = 0.44	$\eta^2 = 0.03$
NofM	Age	$F_{3,105} = 10.52$	**P < 0.0001**	$\eta^2 = 0.23$
	Age × Condition	$F_{3,105} = 1.72$	P = 0.17	$\eta^2 = 0.05$
nMI	Age	$F_{3,105} = 26.25$	**P < 0.0001**	$\eta^2 = 0.43$
	Age × Condition	$F_{3,105} = 0.28$	P = 0.84	$\eta^2 = 0.01$
nVI	Age	$F_{3,105} = 8.55$	**P < 0.0001**	$\eta^2 = 0.20$
	Age × Condition	$F_{3,105} = 0.42$	P = 0.74	$\eta^2 = 0.01$

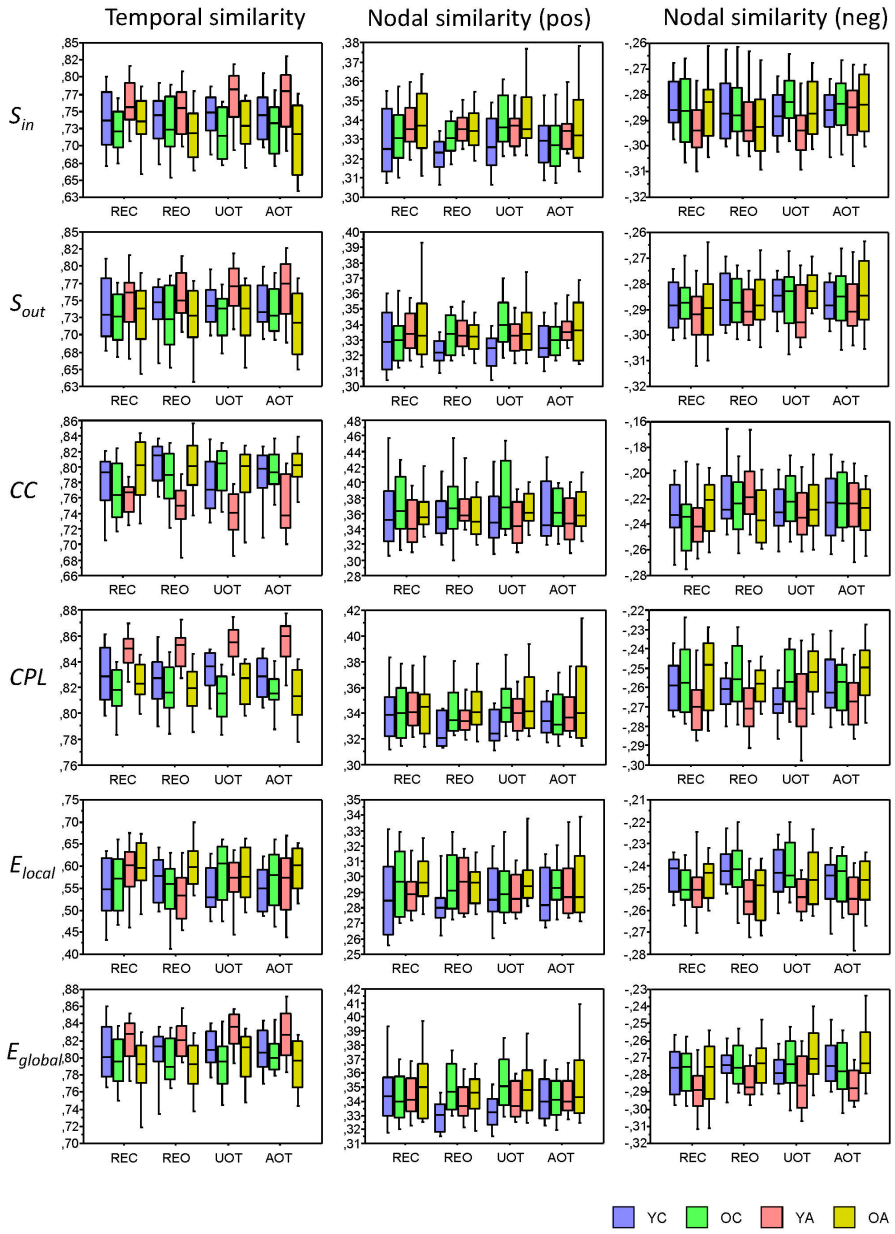
GE, graph energy; *LE*, Laplacian energy; C_e, efficiency complexity; C_r, graph index complexity; *OdC*, offdiagonal complexity; *PE*, partition entropy; *CDN*, correlation dimension of the network; *IDN*, information dimension of the network; *Q*, modularity; *NofM*, number of modules; *nMI* = normalized mutual information; *nVI* = normalized variation of information.



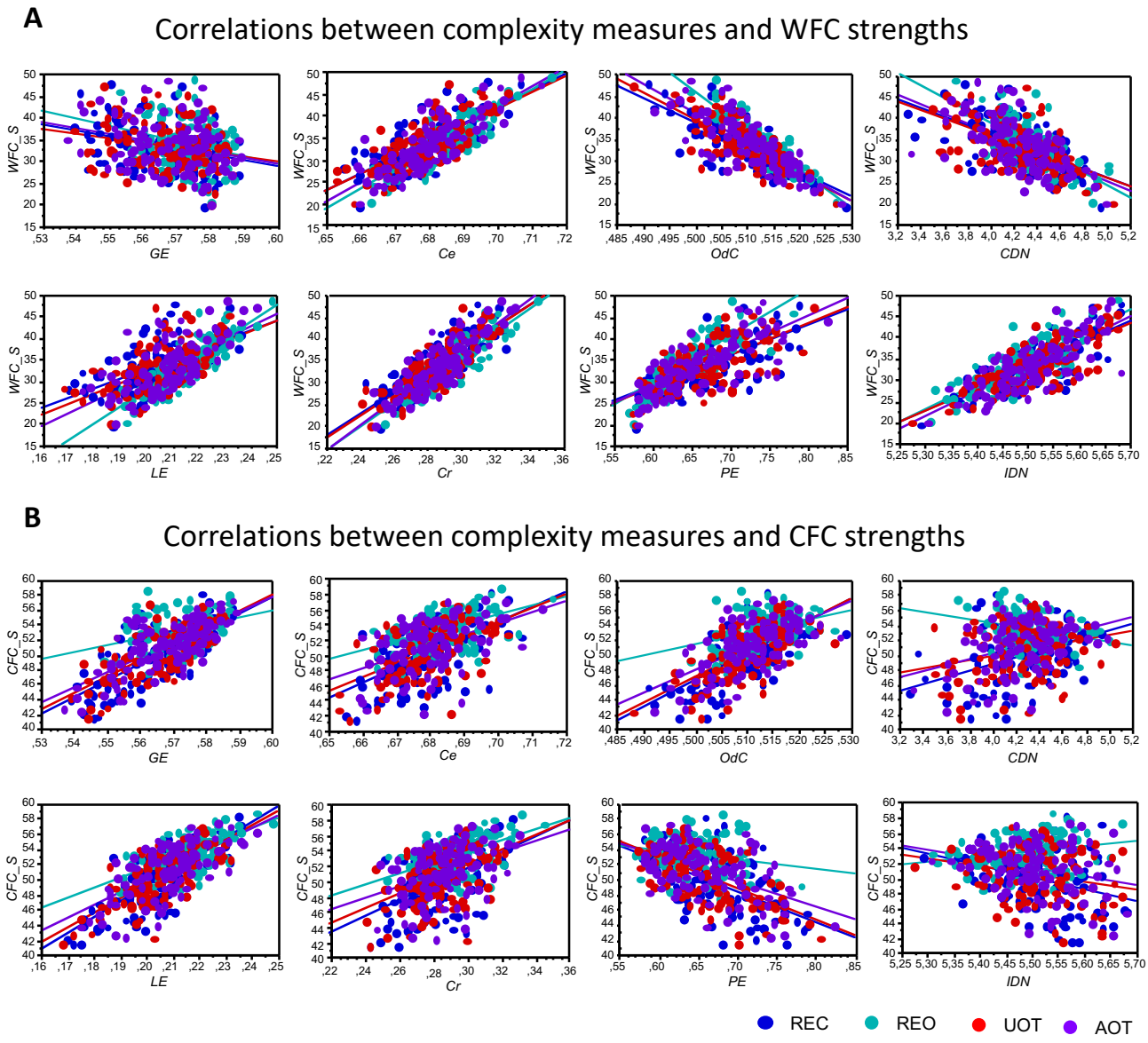
Supplementary Figure 1. ANOVA results for WFC and CFC. (A) Diagrams of mean *ICI* values averaged across eight 10-s segments for WFC (left) and CFC (right) across the lifespan. **(B)** Diagrams of mean *ICI* values for WFC and CFC across the lifespan under the four task conditions. **(C)** Diagrams of WFC and CFC strengths across the lifespan. **(D)** Diagrams of WFC and CFC strengths across the lifespan under the four task conditions. Age groups: YC, younger children; OC, older children; YA, younger adults; OA, older adults. Conditions: REC, rest with eyes closed; REO, rest with eyes open; UOT, unattended oddball task; AOT, attended oddball task.



Supplementary Figure 2. Box plots of the mean and standard deviation (SD) of the six GTA measures across the lifespan under different task conditions. Changes of the mean and SD across time and across nodes for the six GTA measures under the different task conditions. GTA measures: In-Strength (S_{in}), Out-Strength (S_{out}), Clustering Coefficient (*CC*), Characteristic Path Length (*CPL*), Local Efficiency (E_{local}), and Global Efficiency (E_{global}). Age groups: YC, younger children; OC, older children; YA, younger adults; OA, older adults. Conditions: REC, rest with eyes closed; REO, rest with eyes open; UOT, unattended oddball task; AOT, attended oddball task.



Supplementary Figure 3. Box plots of the temporal and nodal similarity of the six GTA measures across the lifespan under different task conditions. Temporal similarity was calculated by Pearson's product correlation between nodes among the 81 consecutive time windows, resulting in an 81 × 81 symmetric matrix. In this matrix, average strength has been determined as a *global temporal similarity index*. Nodal similarity was calculated by Pearson's product correlation between time windows among the 580 consecutive nodes, resulting in a 580 × 580 symmetric matrix. In this matrix, average strength has been determined as a *global nodal similarity index*. Since nodal network similarity contained positive as well as negative values, we calculated two means or average strengths for positive and negative correlation values, respectively. GTA measures: In-Strength (S_{in}), Out-Strength (S_{out}), Clustering Coefficient (*CC*), Characteristic Path Length (*CPL*), Local Efficiency (E_{local}), and Global Efficiency (E_{global}). Age groups: YC, younger children; OC, older children; YA, younger adults; OA, older adults. Conditions: REC, rest with eyes closed; REO, rest with eyes open; UOT, unattended oddball task; AOT, attended oddball task.



Supplementary Figure 4. Correlation plots showing Pearson's product correlations between network complexity measures and WFC and CFC strengths. (A) Correlations between complexity measures and WFC strengths. **(B)** Correlations between complexity measures and CFC strengths. Pearson's product correlations were calculated for each condition separately. Complexity measures: *GE*, graph energy; *LE*, Laplacian energy; C_e, efficiency complexity; C_r, graph index complexity; *OdC*, offdiagonal complexity; *PE*, partition entropy; *CDN*, correlation dimension of the network; *IDN*, information dimension of the network. Conditions: REC, rest with eyes closed; REO, rest with eyes open; UOT, unattended oddball task; AOT, attended oddball task.