

Table S1. Candidate set of generalized linear models used for AIC-based model selection to examine the associations between metal exposure and executive function outcomes.

Model Approach	Model Formula	Description
Baseline model	EFs ~ BM (intercept-only or age or HC)	No EFs is affected by Heavy Metal (HM) or their interaction
Models with one metal	EFs ~ BM + Pb	EFS is affected by a single metal
	EFs ~ BM + Hg	
	EFs ~ BM + Cu	
	EFs ~ BM + Zn	
Model with additive effect of non-essential metals	EFs ~ BM + Pb + Hg	EFS is affected by non-essential metals, but not by their interaction
Model with additive effect of essential metals	EFs ~ BM + Cu + Zn	EFS is affected by essential metals, but not by their interaction
Model with additive effect of all metals	EFs ~ BM + Pb + Hg + Cu + Zn	EFS is affected by all HMs, but not by their interaction
Models with interaction between non-essential and essential metals (additive or antagonistic effect)	EFs ~ BM + Pb*Hg	The aim is to evaluate the interaction (additive or antagonistic) relationship between essential and non-essential metals on EFS
	EFs ~ BM + Pb*Cu	
	EFs ~ BM + Pb*Zn	
	EFs ~ BM + Hg*Cu	
	EFs ~ BM + Hg*Zn	
	EFs ~ BM + Cu*Zn	
Models with interaction between non-essential and essential metals, plus effects of other metals	EFs ~ BM + Pb*Hg + Cu + Zn	The goal is to evaluate both pathways: an additive or antagonistic interaction between metals and the extra effect of other metals
	EFs ~ BM + Pb*Cu + Hg + Zn	
	EFs ~ BM + Pb*Zn + Hg + Cu	
	EFs ~ BM + Hg*Cu + Pb + Zn	
	EFs ~ BM + Hg*Zn + Pb + Cu	
	EFs ~ null + Cu*Zn + Pb + Hg	

Note: The dependent variable (EFs) refers to one of six separate cognitive scores derived from the BANFE-3: the standardized total score (STS), anterior prefrontal cortex (aPFC) subscore, orbitomedial cortex (OMC) subscore, dorsolateral prefrontal cortex (DLPFC) subscore, working memory domain (WM-DLPFC), and executive function domain (EF-DLPFC). All candidate models differ in the inclusion of essential HMs (Cu, Zn) and toxic HMs (Pb, Hg), evaluating either their individual main effects, additive combinations, or interactive effects on the outcomes. BM: Baseline Model (representing outcome-specific biological covariates: intercept-only, age, or head circumference [HC]).

Table S2. Comparison of candidate baseline models (GLM.nb) for girls (n = 28) and boys (n = 25) across distinct EFs outcome.

Task Score	Girls (n = 28)					Boys (n = 25)				
	Predictor	AIC	Δ AIC	AICw	logLik	Predictor	AIC	Δ AIC	AICw	logLik
STS	1	240.79	0	0.451	-118.4	age	218.89	0	0.667	-106.44
	age	241.14	0.34	0.38	-117.57	1	220.93	2.04	0.24	-108.46
	HC	242.76	1.96	0.169	-118.38	HC	222.82	3.94	0.093	-108.41
aPFC	1	231.6	0	0.453	-113.8	1	226.66	0	0.561	-111.33
	age	232.1	0.5	0.353	-113.05	age	228.41	1.76	0.233	-111.21
	HC	233.3	1.7	0.194	-113.65	HC	228.66	2	0.206	-111.33
OMC	age	238.5	0	0.918	-116.25	age	227.42	0	0.994	-110.71
	1	243.97	5.47	0.059	-119.99	1	238.35	10.93	0.004	-117.17
	HC	245.9	7.4	0.023	-119.95	HC	240.35	12.93	0.002	-117.17
DLPFC	1	239.25	0	0.426	-117.62	age	217.11	0	0.546	-105.55
	age	239.3	0.05	0.416	-116.65	1	218.14	1.03	0.326	-107.07
	HC	241.24	1.99	0.158	-117.62	HC	220.01	2.9	0.128	-107
WM-DLPFC	age	192.06	0	0.964	-93.03	age	174.49	0	0.528	-84.24
	1	199.25	7.19	0.026	-97.63	HC	175.45	0.96	0.326	-84.73
	HC	201.21	9.15	0.01	-97.6	1	177.06	2.57	0.146	-86.53
EF-DLPFC	HC	246.34	0	0.586	-120.17	1	222.5	0	0.447	-109.25
	age	247.92	1.58	0.266	-120.96	HC	223.08	0.58	0.334	-108.54
	1	249.08	2.74	0.149	-122.54	age	223.93	1.43	0.218	-108.97

Note: Predictor '1' represents the intercept-only model. HC: Head Circumference; Δ AIC difference relative to the baseline model with the lowest absolute AIC value (Δ AIC = 0). Cognitive outcomes derived from the BANFE-3: STS (standardized total score), aPFC (anterior prefrontal cortex), OMC (orbitomedial cortex), DLPFC (dorsolateral prefrontal cortex), WM-DLPFC (working memory domain), and EF-DLPFC (executive function domain).

Table S3. Full information-theoretic model selection containing all candidate generalized linear models for girls and boys across distinct EF outcomes.

Task Score	Girls (n = 28)						Boys (n = 25)					
	Model	Predictor	AIC	ΔAIC	AICw	logLik	Model	Predictor	AIC	ΔAIC	AICw	logLik
STS	1	1	240.79	0	0.228	-118.4	11	age + pb * zn	218.11	0	0.252	-103.05
	2	1 + pb	242.12	1.33	0.118	-118.06	1	age	218.89	0.78	0.171	-106.44
	4	1 + cu	242.21	1.41	0.113	-118.1	3	age + hg	220.48	2.38	0.077	-106.24
	5	1 + zn	242.36	1.57	0.104	-118.18	10	age + pb * cu	220.49	2.39	0.077	-104.25
	3	1 + hg	242.79	1.99	0.084	-118.39	2	age + pb	220.53	2.42	0.075	-106.26
	9	1 + pb * hg	243.87	3.08	0.049	-116.94	4	age + cu	220.7	2.59	0.069	-106.35
	6	1 + pb + hg	243.91	3.12	0.048	-117.95	5	age + zn	220.74	2.63	0.068	-106.37
	7	1 + cu + zn	243.98	3.19	0.046	-117.99	17	age + pb * zn + hg + cu	221.65	3.54	0.043	-102.83
	14	1 + cu * zn	244.08	3.28	0.044	-117.04	6	age + pb + hg	222.09	3.98	0.035	-106.04
	11	1 + pb * zn	244.3	3.51	0.039	-117.15	7	age + cu + zn	222.43	4.32	0.029	-106.21
	13	1 + hg * zn	244.33	3.54	0.039	-117.17	13	age + hg * zn	222.8	4.69	0.024	-105.4
	10	1 + pb * cu	245.31	4.52	0.024	-117.66	12	age + hg * cu	223.73	5.63	0.015	-105.87
	12	1 + hg * cu	246.15	5.35	0.016	-118.07	9	age + pb * hg	223.8	5.7	0.015	-105.9
	15	1 + pb * hg + cu + zn	246.75	5.95	0.012	-116.37	14	age + cu * zn	224.22	6.11	0.012	-106.11
	19	1 + hg * zn + pb + cu	247.36	6.57	0.009	-116.68	16	age + pb * cu + hg + zn	224.24	6.13	0.012	-104.12
	8	1 + pb + hg + cu + zn	247.38	6.58	0.008	-117.69	8	age + pb + hg + cu + zn	224.96	6.85	0.008	-105.48
	20	1 + cu * zn + pb + hg	247.97	7.17	0.006	-116.98	19	age + hg * zn + pb + cu	225.38	7.27	0.007	-104.69
	17	1 + pb * zn + hg + cu	248.02	7.22	0.006	-117.01	20	age + cu * zn + pb + hg	226.13	8.03	0.005	-105.07
	16	1 + pb * cu + hg + zn	249.02	8.22	0.004	-117.51	18	age + hg * cu + pb + zn	226.43	8.32	0.004	-105.22
	18	1 + hg * cu + pb + zn	249.37	8.58	0.003	-117.69	15	age + pb * hg + cu + zn	226.8	8.69	0.003	-105.4
aPFC subscore	13	1 + hg * zn	226.73	0	0.495	-108.37	19	1 + hg * zn + pb + cu	225.03	0	0.173	-105.51
	19	1 + hg * zn + pb + cu	229.42	2.68	0.13	-107.71	4	1 + cu	226.44	1.41	0.086	-110.22
	5	1 + zn	230.66	3.93	0.069	-112.33	7	1 + cu + zn	226.57	1.54	0.08	-109.29
	2	1 + pb	231.35	4.62	0.049	-112.67	1	1	226.66	1.63	0.077	-111.33
	1	1	231.6	4.86	0.044	-113.8	8	1 + pb + hg + cu + zn	226.84	1.81	0.07	-107.42
	3	1 + hg	232.02	5.29	0.035	-113.01	3	1 + hg	227.2	2.17	0.058	-110.6
	7	1 + cu + zn	232.17	5.43	0.033	-112.08	17	1 + pb * zn + hg + cu	227.46	2.43	0.051	-106.73
	11	1 + pb * zn	232.32	5.59	0.03	-111.16	10	1 + pb * cu	227.63	2.6	0.047	-108.82
	6	1 + pb + hg	232.83	6.1	0.023	-112.42	5	1 + zn	227.97	2.94	0.04	-110.98
	4	1 + cu	233.55	6.82	0.016	-113.78	11	1 + pb * zn	228.05	3.02	0.038	-109.02
	14	1 + cu * zn	234.12	7.39	0.012	-112.06	12	1 + hg * cu	228.12	3.09	0.037	-109.06
	8	1 + pb + hg + cu + zn	234.2	7.46	0.012	-111.1	20	1 + cu * zn + pb + hg	228.3	3.28	0.034	-107.15
	9	1 + pb * hg	234.32	7.58	0.011	-112.16	18	1 + hg * cu + pb + zn	228.5	3.47	0.03	-107.25
	10	1 + pb * cu	234.81	8.08	0.009	-112.41	15	1 + pb * hg + cu + zn	228.51	3.49	0.03	-107.26
	12	1 + hg * cu	235.56	8.83	0.006	-112.78	14	1 + cu * zn	228.54	3.51	0.03	-109.27
	15	1 + pb * hg + cu + zn	235.58	8.84	0.006	-110.79	2	1 + pb	228.55	3.52	0.03	-111.28
	17	1 + pb * zn + hg + cu	235.97	9.24	0.005	-110.99	13	1 + hg * zn	228.61	3.58	0.029	-109.31
	20	1 + cu * zn + pb + hg	236	9.27	0.005	-111	16	1 + pb * cu + hg + zn	228.67	3.64	0.028	-107.33
	18	1 + hg * cu + pb + zn	236.1	9.37	0.005	-111.05	6	1 + pb + hg	229.06	4.03	0.023	-110.53
	16	1 + pb * cu + hg + zn	236.14	9.4	0.004	-111.07	9	1 + pb * hg	231.06	6.03	0.008	-110.53
OMC subscore	19	age + hg * zn + pb + cu	235.6	0	0.382	-109.8	6	age + pb + hg	226.79	0	0.117	-108.39
	1	age	238.5	2.9	0.09	-116.25	3	age + hg	226.84	0.05	0.114	-109.42
	18	age + hg * cu + pb + zn	238.75	3.15	0.079	-111.38	5	age + zn	226.89	0.1	0.111	-109.44
	4	age + cu	239.51	3.91	0.054	-115.75	11	age + pb * zn	227.31	0.52	0.09	-107.65
	13	age + hg * zn	239.63	4.03	0.051	-113.82	1	age	227.42	0.64	0.085	-110.71
	5	age + zn	239.9	4.3	0.045	-115.95	2	age + pb	227.67	0.88	0.075	-109.83
	2	age + pb	239.99	4.39	0.043	-115.99	4	age + cu	227.88	1.09	0.068	-109.94
	3	age + hg	240.05	4.44	0.041	-116.02	7	age + cu + zn	228.16	1.37	0.059	-109.08
	7	age + cu + zn	240.28	4.68	0.037	-115.14	9	age + pb * hg	228.78	2	0.043	-108.39
	8	age + pb + hg + cu + zn	240.63	5.03	0.031	-113.32	17	age + pb * zn + hg + cu	228.97	2.18	0.039	-106.48
	6	age + pb + hg	241.03	5.43	0.025	-115.52	12	age + hg * cu	229.16	2.37	0.036	-108.58

	10	age + pb * cu	241.7	6.1	0.018	-114.85	13	age + hg * zn	229.31	2.52	0.033	-108.65
	12	age + hg * cu	241.88	6.28	0.017	-114.94	14	age + cu * zn	229.6	2.81	0.029	-108.8
	14	age + cu * zn	242.11	6.51	0.015	-115.05	8	age + pb + hg + cu + zn	229.84	3.05	0.025	-107.92
	9	age + pb * hg	242.15	6.55	0.014	-115.08	16	age + pb * cu + hg + zn	230.56	3.78	0.018	-107.28
	15	age + pb * hg + cu + zn	242.4	6.8	0.013	-113.2	10	age + pb * cu	230.94	4.15	0.015	-109.47
	20	age + cu * zn + pb + hg	242.45	6.85	0.012	-113.23	20	age + cu * zn + pb + hg	231.35	4.56	0.012	-107.67
	16	age + pb * cu + hg + zn	242.56	6.96	0.012	-113.28	18	age + hg * cu + pb + zn	231.58	4.8	0.011	-107.79
	17	age + pb * zn + hg + cu	242.6	7	0.012	-113.3	19	age + hg * zn + pb + cu	231.69	4.9	0.01	-107.85
	11	age + pb * zn	242.88	7.28	0.01	-115.44	15	age + pb * hg + cu + zn	231.82	5.03	0.009	-107.91
DLPFC subscore	1	1	239.25	0	0.178	-117.62	11	age + pb * zn	216.96	0	0.163	-102.48
	4	1 + cu	239.76	0.51	0.138	-116.88	1	age	217.11	0.15	0.151	-105.55
	2	1 + pb	240.59	1.35	0.091	-117.3	3	age + hg	217.87	0.91	0.103	-104.94
	14	1 + cu * zn	240.69	1.44	0.087	-115.34	10	age + pb * cu	218.22	1.25	0.087	-103.11
	5	1 + zn	240.93	1.68	0.077	-117.46	2	age + pb	218.33	1.37	0.082	-105.17
	11	1 + pb * zn	240.93	1.69	0.077	-115.47	5	age + zn	218.56	1.59	0.073	-105.28
	3	1 + hg	241.22	1.97	0.067	-117.61	6	age + pb + hg	218.96	2	0.06	-104.48
	7	1 + cu + zn	241.7	2.45	0.052	-116.85	4	age + cu	219.11	2.15	0.056	-105.55
	9	1 + pb * hg	241.78	2.53	0.05	-115.89	17	age + pb * zn + hg + cu	219.64	2.67	0.043	-101.82
	6	1 + pb + hg	242.29	3.04	0.039	-117.14	13	age + hg * zn	219.77	2.8	0.04	-103.88
	13	1 + hg * zn	243.01	3.76	0.027	-116.51	7	age + cu + zn	220.51	3.55	0.028	-105.25
	15	1 + pb * hg + cu + zn	243.39	4.14	0.022	-114.7	9	age + pb * hg	220.61	3.64	0.026	-104.3
	12	1 + hg * cu	243.42	4.17	0.022	-116.71	12	age + hg * cu	221.27	4.31	0.019	-104.64
	10	1 + pb * cu	243.48	4.23	0.022	-116.74	16	age + pb * cu + hg + zn	221.32	4.36	0.018	-102.66
	17	1 + pb * zn + hg + cu	244.25	5	0.015	-115.13	8	age + pb + hg + cu + zn	222.28	5.31	0.011	-104.14
	20	1 + cu * zn + pb + hg	244.34	5.09	0.014	-115.17	14	age + cu * zn	222.32	5.36	0.011	-105.16
	8	1 + pb + hg + cu + zn	245.34	6.09	0.008	-116.67	19	age + hg * zn + pb + cu	222.37	5.41	0.011	-103.19
	19	1 + hg * zn + pb + cu	245.67	6.42	0.007	-115.84	20	age + cu * zn + pb + hg	223.55	6.58	0.006	-103.77
	18	1 + hg * cu + pb + zn	247.21	7.96	0.003	-116.61	18	age + hg * cu + pb + zn	223.63	6.67	0.006	-103.81
	16	1 + pb * cu + hg + zn	247.28	8.03	0.003	-116.64	15	age + pb * hg + cu + zn	223.99	7.03	0.005	-104
Working memory (DLPFC)	13	age + hg * zn	188.77	0	0.553	-88.39	3	age + hg	170.43	0	0.258	-81.22
	1	age	192.06	3.28	0.107	-93.03	6	age + pb + hg	170.88	0.45	0.206	-80.44
	19	age + hg * zn + pb + cu	192.55	3.78	0.084	-88.28	13	age + hg * zn	172.81	2.38	0.078	-80.41
	3	age + hg	194	5.22	0.041	-93	9	age + pb * hg	172.88	2.45	0.076	-80.44
	2	age + pb	194.01	5.23	0.04	-93	5	age + zn	173.35	2.92	0.06	-82.68
	4	age + cu	194.03	5.26	0.04	-93.02	8	age + pb + hg + cu + zn	173.79	3.36	0.048	-79.9
	5	age + zn	194.05	5.28	0.04	-93.03	12	age + hg * cu	174.18	3.75	0.04	-81.09
	9	age + pb * hg	195.66	6.89	0.018	-91.83	1	age	174.49	4.06	0.034	-84.24
	11	age + pb * zn	195.81	7.03	0.016	-91.9	20	age + cu * zn + pb + hg	175.11	4.67	0.025	-79.55
	6	age + pb + hg	195.97	7.2	0.015	-92.99	7	age + cu + zn	175.33	4.9	0.022	-82.66
	7	age + cu + zn	196.01	7.24	0.015	-93.01	2	age + pb	175.37	4.94	0.022	-83.68
	12	age + hg * cu	196.97	8.2	0.009	-92.49	19	age + hg * zn + pb + cu	175.52	5.09	0.02	-79.76
	14	age + cu * zn	197.7	8.93	0.006	-92.85	17	age + pb * zn + hg + cu	175.74	5.31	0.018	-79.87
	10	age + pb * cu	198	9.22	0.005	-93	15	age + pb * hg + cu + zn	175.78	5.34	0.018	-79.89
	15	age + pb * hg + cu + zn	199.18	10.4	0.003	-91.59	18	age + hg * cu + pb + zn	175.78	5.35	0.018	-79.89
	17	age + pb * zn + hg + cu	199.78	11.01	0.002	-91.89	16	age + pb * cu + hg + zn	175.79	5.36	0.018	-79.9
	8	age + pb + hg + cu + zn	199.95	11.17	0.002	-92.97	4	age + cu	176.13	5.7	0.015	-84.07
	18	age + hg * cu + pb + zn	200.68	11.91	0.001	-92.34	14	age + cu * zn	176.71	6.28	0.011	-82.36
	20	age + cu * zn + pb + hg	201.63	12.86	0.001	-92.82	11	age + pb * zn	176.74	6.31	0.011	-82.37
	16	age + pb * cu + hg + zn	201.94	13.17	0.001	-92.97	10	age + pb * cu	179	8.57	0.004	-83.5
Executive Function (DLPFC)	3	HC + hg	245.07	0	0.196	-118.54	1	1	222.5	0	0.245	-109.25
	1	HC	246.34	1.27	0.104	-120.17	5	1 + zn	224.06	1.56	0.112	-109.03
	9	HC + pb * hg	246.67	1.6	0.088	-117.34	2	1 + pb	224.14	1.64	0.108	-109.07
	5	HC + zn	246.73	1.66	0.086	-119.36	4	1 + cu	224.28	1.79	0.1	-109.14
	6	HC + pb + hg	246.88	1.81	0.079	-118.44	3	1 + hg	224.47	1.97	0.091	-109.24
	2	HC + pb	247.02	1.95	0.074	-119.51	11	1 + pb * zn	225.05	2.55	0.068	-107.53
	10	HC + pb * cu	247.2	2.13	0.068	-117.6	13	1 + hg * zn	225.45	2.95	0.056	-107.72
	13	HC + hg * zn	247.36	2.28	0.063	-117.68	7	1 + cu + zn	225.61	3.11	0.052	-108.81
	4	HC + cu	248.29	3.22	0.039	-120.15	6	1 + pb + hg	226.1	3.61	0.04	-109.05

7	HC + cu + zn	248.41	3.34	0.037	-119.21	10	1 + pb * cu	227.18	4.68	0.024	-108.59
12	HC + hg * cu	248.97	3.9	0.028	-118.48	14	1 + cu * zn	227.59	5.09	0.019	-108.79
16	HC + pb * cu + hg + zn	249.11	4.04	0.026	-116.55	19	1 + hg * zn + pb + cu	227.75	5.25	0.018	-106.88
15	HC + pb * hg + cu + zn	249.25	4.18	0.024	-116.63	9	1 + pb * hg	228.06	5.56	0.015	-109.03
11	HC + pb * zn	249.37	4.3	0.023	-118.69	12	1 + hg * cu	228.23	5.73	0.014	-109.12
8	HC + pb + hg + cu + zn	249.62	4.55	0.02	-117.81	8	1 + pb + hg + cu + zn	228.74	6.24	0.011	-108.37
14	HC + cu * zn	250.39	5.32	0.014	-119.19	17	1 + pb * zn + hg + cu	228.97	6.47	0.01	-107.49
19	HC + hg * zn + pb + cu	251.13	6.06	0.009	-117.57	20	1 + cu * zn + pb + hg	230.46	7.96	0.005	-108.23
20	HC + cu * zn + pb + hg	251.51	6.44	0.008	-117.76	16	1 + pb * cu + hg + zn	230.62	8.12	0.004	-108.31
17	HC + pb * zn + hg + cu	251.55	6.48	0.008	-117.77	15	1 + pb * hg + cu + zn	230.73	8.23	0.004	-108.36
18	HC + hg * cu + pb + zn	251.62	6.55	0.007	-117.81	18	1 + hg * cu + pb + zn	230.74	8.24	0.004	-108.37

Note: Models selected as the most parsimonious among those with $\Delta AIC < 2$ are highlighted in bold. Models were fitted using a Negative Binomial distribution (GLM.nb) to evaluate all hypothesis-driven combinations of essential and toxic HMs. For each executive function score and sex, models are ranked by their Akaike Information Criterion (AIC) values. The table presents the model index number, specific predictors, absolute AIC, AIC difference relative to the top-ranked model (ΔAIC), Akaike weight (AICw), and log-likelihood (logLik). The numbers in the 'Model' column correspond to the sequential order in which the specific research hypotheses were formulated and tested. Predictor '1' represents the intercept-only baseline model. Interaction terms are denoted by asterisks (*). Executive function outcomes derived from the BANFE-3: STS (standardized total score), aPFC (anterior prefrontal cortex), OMC (orbitomedial cortex), DLPFC (dorsolateral prefrontal cortex), WM-DLPFC (working memory domain), and EF-DLPFC (executive function domain)..