

Supplementary Material

Changes in Brain Structure and Function in a Multisport Cohort of Retired Female and Male Athletes, Many Years after Suffering a Concussion: Implications for Neuroplasticity and Neurodegenerative Disease Pathogenesis

Supplementary Table 1. Results of the Bayesian logit model of brain volume differences between athletes and controls.

Parameter	Mean	SD	Q2.5	Q97.5	95% CI excl. 0
Intercept	9.47	2.68	4.34	14.88	*
LateralVentricles	-0.33	0.22	-0.77	0.11	
ThirdFourthFifthVentricles	-0.32	0.22	-0.76	0.11	
NAC	-0.48	0.43	-1.34	0.36	
Amyg	-0.28	0.42	-1.11	0.53	
Caudate	0.85	0.37	0.13	1.60	*
Hippocampus	-1.33	0.42	-2.17	-0.53	*
Pallidum	0.05	0.36	-0.64	0.76	
Putamen	-0.13	0.44	-1.00	0.73	
Thalamus	-0.60	0.34	-1.29	0.06	
ACgG	0.02	0.35	-0.67	0.71	
Ins	0.27	0.24	-0.20	0.75	
AOrG	0.44	0.45	-0.43	1.32	
AnG	-0.46	0.42	-1.29	0.35	
Calc	-0.16	0.40	-0.93	0.61	
FO	0.15	0.42	-0.68	0.98	
FRP	-0.39	0.31	-1.00	0.21	
FuG	-0.41	0.48	-1.35	0.55	
GRe	-0.17	0.42	-1.00	0.66	
IOG	-0.82	0.47	-1.75	0.08	
ITG	0.81	0.45	-0.06	1.71	
LiG	0.02	0.43	-0.82	0.86	
LORG	0.81	0.39	0.04	1.59	*
MCgG	0.34	0.33	-0.29	1.00	
MFC	0.23	0.42	-0.60	1.06	
MFG	-1.36	0.45	-2.25	-0.50	*
MOG	0.98	0.40	0.21	1.77	*
MORG	0.96	0.48	0.03	1.93	*
MPoG	0.68	0.35	0.01	1.37	*
MPrG	-0.42	0.36	-1.14	0.28	
MSFG	-0.07	0.41	-0.88	0.73	
MTG	0.41	0.40	-0.37	1.21	
OCP	-0.59	0.38	-1.36	0.14	
OFuG	0.37	0.44	-0.50	1.24	

Parameter	Mean	SD	Q2.5	Q97.5	95% CI excl. 0
IFG	-0.69	0.25	-1.20	-0.22	*
PCgG	0.62	0.41	-0.18	1.44	
PCu	-0.41	0.40	-1.20	0.36	
Hi&CollateralSulcus	2.34	0.52	1.34	3.38	*
PoG	0.57	0.40	-0.21	1.36	
POrG	-0.10	0.40	-0.89	0.67	
PrG	0.27	0.41	-0.51	1.08	
SFG	0.50	0.39	-0.30	1.25	
SMC	-0.68	0.44	-1.55	0.17	
SMG	-0.96	0.36	-1.69	-0.27	*
SOG	0.67	0.40	-0.12	1.46	
SPL	-0.64	0.33	-1.29	0.01	
STG	0.28	0.42	-0.54	1.10	
TMP	-0.91	0.38	-1.67	-0.17	*
TTG	0.82	0.34	0.17	1.49	*
Age2	0.00	0.00	0.00	0.00	
Gender	-0.35	0.79	-1.91	1.20	

Table depicts mean posterior estimate, standard deviation (SD), 95% credible interval, with asterisk demonstrating if the credible interval of the posterior estimate did not cross zero and hence was significant. Athletes are treated as the positive class with positive posterior estimates signifying increased volumes in the athletes, and reciprocally negative values signifying decreased volumes. Amyg., amygdala; ACgG, anterior cingulate gyrus; AOrG, anterior orbital gyrus; AnG, angular gyrus; Calc, calcarine cortex; FO, frontal operculum; FRP, frontal pole; FuG, occipital fusiform gyrus; GRe, gyrus rectus; Hi, hippocampal [sulcus]; Ins, insula; IFG, inferior frontal gyrus; IOG, inferior occipital gyrus; ITG, inferior temporal gyrus; LiG, lingual gyrus; LOrg, lateral orbital gyrus; MCgG, middle cingulate gyrus; MFC, medial frontal cortex; MFG, middle frontal gyrus; MOG, middle occipital gyrus; MOrG, medial orbital gyrus; MPoG, postcentral gyrus medial segment; MPrG, precentral gyrus medial segment; MSFG, superior frontal gyrus medial segment; MTG, middle temporal gyrus; NAc, nucleus accumbens; OCP, occipital pole; OFuG, occipital fusiform gyrus; PCgG, posterior cingulate gyrus; PCu, precuneus; PoG, postcentral gyrus; POrG, posterior orbital gyrus; PrG, precentral gyrus; SFG, superior frontal gyrus; SMC, supplementary motor cortex; SMG, supramarginal gyrus; SOG, superior occipital gyrus; SPL, superior parietal lobule; STG, superior temporal gyrus; TMP, temporal pole; TTG, transverse temporal gyrus.

Supplementary Table 2. Results of the Bayesian logit model of brain volume differences between athletes and controls, with concussion supplemented as a covariate of no interest.

Parameter	Mean	SD	Q2.5	Q97.5	95% CI excl. 0
Intercept	-1.58	5.20	-11.84	8.60	
LateralVentricles	-0.18	0.42	-1.00	0.64	
ThirdFourthFifthVentricles	-0.72	0.48	-1.66	0.20	
NAc	-0.01	0.71	-1.41	1.39	
Amyg	-0.01	0.72	-1.42	1.39	
Caudate	0.83	0.64	-0.41	2.09	
Hippocampus	-0.40	0.77	-1.92	1.11	
Pallidum	0.02	0.71	-1.37	1.41	
Putamen	-0.93	0.71	-2.31	0.45	
Thalamus	-0.52	0.72	-1.93	0.89	
ACgG	0.70	0.68	-0.62	2.04	
Ins	0.32	0.53	-0.72	1.38	
AOrG	0.16	0.76	-1.34	1.65	
AnG	-0.42	0.77	-1.94	1.08	
Calc	-0.24	0.72	-1.66	1.18	
FO	-0.05	0.71	-1.45	1.34	
FRP	-0.49	0.61	-1.70	0.68	
FuG	0.66	0.73	-0.76	2.09	
GRe	-1.09	0.70	-2.48	0.28	
IOG	-0.31	0.75	-1.79	1.16	
ITG	0.78	0.77	-0.74	2.29	
LiG	-0.25	0.73	-1.68	1.17	
LOrg	0.28	0.73	-1.16	1.73	
MCgG	0.24	0.65	-1.02	1.51	
MFC	0.27	0.66	-1.03	1.56	
MFG	-0.67	0.76	-2.16	0.80	
MOG	0.62	0.70	-0.75	1.99	
MOrG	0.45	0.76	-1.05	1.94	
MPoG	0.21	0.59	-0.93	1.39	
MPrG	-0.54	0.65	-1.83	0.71	
MSFG	0.36	0.71	-1.03	1.75	
MTG	0.02	0.72	-1.40	1.43	
OCP	-0.96	0.64	-2.23	0.27	
OFuG	-0.52	0.76	-2.01	0.98	
IFG	-0.29	0.44	-1.16	0.58	
PCgG	0.39	0.73	-1.03	1.81	
PCu	-0.49	0.64	-1.77	0.74	
Hi&CollateralSulcus	0.83	0.82	-0.77	2.45	
PoG	0.05	0.74	-1.41	1.51	
POrG	0.39	0.70	-0.98	1.77	
PrG	0.19	0.70	-1.19	1.56	
SFG	0.17	0.69	-1.24	1.48	
SMC	-0.08	0.69	-1.44	1.27	

SMG	-0.51	0.64	-1.78	0.74	
SOG	0.83	0.73	-0.58	2.26	
SPL	0.07	0.62	-1.13	1.28	
STG	0.07	0.71	-1.32	1.46	
TMP	-0.28	0.65	-1.57	0.98	
TTG	0.65	0.66	-0.63	1.94	
Age2	0.00	0.00	0.00	0.00	
Gender	-0.15	0.96	-2.02	1.72	
Concussion	3.97	0.68	2.71	5.38	*

Table depicts mean posterior estimate, standard deviation (SD), 95% credible interval, with asterisk demonstrating if the credible interval of the posterior estimate did not cross zero and hence was significant. Athletes are treated as the positive class with positive posterior estimates signifying increased volumes in the athletes, and reciprocally negative values signifying decreased volumes. Amyg., amygdala; ACgG, anterior cingulate gyrus; AOrG, anterior orbital gyrus; AnG, angular gyrus; Calc, calcarine cortex; FO, frontal operculum; FRP, frontal pole; FuG, occipital fusiform gyrus; GRe, gyrus rectus; Hi, hippocampal [sulcus]; Ins, insula; IFG, inferior frontal gyrus; IOG, inferior occipital gyrus; ITG, inferior temporal gyrus; LiG, lingual gyrus; LOrg, lateral orbital gyrus; MCgG, middle cingulate gyrus; MFC, medial frontal cortex; MFG, middle frontal gyrus; MOG, middle occipital gyrus; MOrG, medial orbital gyrus; MPoG, postcentral gyrus medial segment; MPrG, precentral gyrus medial segment; MSFG, superior frontal gyrus medial segment; MTG, middle temporal gyrus; NAc, nucleus accumbens; OCP, occipital pole; OFuG, occipital fusiform gyrus; PCgG, posterior cingulate gyrus; PCu, precuneus; PoG, postcentral gyrus; POrG, posterior orbital gyrus; PrG, precentral gyrus; SFG, superior frontal gyrus; SMC, supplementary motor cortex; SMG, supramarginal gyrus; SOG, superior occipital gyrus; SPL, superior parietal lobule; STG, superior temporal gyrus; TMP, temporal pole; TTG, transverse temporal gyrus.

Supplementary Table 3. Results of the Bayesian regression model of concussion as a function of gender interacting with brain volumetric changes.

Bayesian Poisson ridge regression

Number of obs = 107

Number of vars = 99

MCMC Samples = 100000

MCMC Burnin = 50000

MCMC Thinning = 5

Overdispersion = 1.002

Pseudo R2 = 0.5794

WAIC = 364.48

Parameter	mean(Coef)	std(Coef)	[95% Cred.	Interval]	tStat	Rank	ESS
GenderM:SPL	-0.54935	0.10344	-0.75994	-0.35867	-5.311	1	** 121
GenderM:PCu	-0.30912	0.08787	-0.47891	-0.13037	-3.518	2	** 133
GenderM:FuG	-0.34664	0.10907	-0.56355	-0.12721	-3.178	3	** 96
GenderM:PoG	0.34854	0.10219	0.13614	0.54132	3.411	4	** 138
GenderM:ThirdFourthFifthVentricles	0.29229	0.06895	0.15191	0.42356	4.239	5	** 169
GenderM	0.86718	0.32083	0.24796	1.48399	2.703	6	** 90
GenderM:AnG	-0.29519	0.09349	-0.48323	-0.12117	-3.157	6	** 114
GenderM:OCP	-0.25019	0.08077	-0.42035	-0.10292	-3.098	8	** 122
GenderM:NAc	0.23363	0.09211	0.05485	0.41981	2.537	9	** 89
MOG	0.20917	0.07573	0.07705	0.36814	2.762	10	** 115
GenderM:LateralVentricles	-0.12812	0.05049	-0.23179	-0.0306	-2.538	11	** 131
PCu	0.1662	0.0744	0.02184	0.31664	2.234	12	** 116
GenderM:MFG	-0.21585	0.09504	-0.39534	-0.02829	-2.271	12	** 121
GenderM:SMG	0.21901	0.08282	0.06435	0.38767	2.644	12	** 112
MTG	-0.16217	0.07417	-0.31838	-0.0217	-2.186	15	** 101
GenderM:MOG	-0.23986	0.10887	-0.46836	-0.04586	-2.203	15	** 106
GenderM:OFuG	-0.23122	0.0828	-0.40446	-0.07877	-2.793	15	** 247
ITG	0.16009	0.08023	0.01061	0.32345	1.995	18	** 110
PrG	0.14965	0.06299	0.02884	0.27637	2.376	18	** 138

GenderM:Caudate	0.1811	0.07965	0.02596	0.33945	2.274	20	**	103
GenderM:IOG	0.20715	0.10121	0.01069	0.42128	2.047	21	**	182
MSFG	-0.15211	0.08443	-0.32986	0.00461	-1.802	22	*	78
GenderM:Ins	-0.09982	0.05097	-0.20722	-0.00363	-1.958	22	**	108
GenderM:MOrg	0.20013	0.10588	0.00566	0.41811	1.89	24	**	120
GenderM:MTG	0.1592	0.087	-0.01057	0.33409	1.83	24	*	78
GenderM:Age	-0.00013	0.00008	-0.00029	0.00002	-1.626	26	*	82
`Hi&CollateralSulcus`	0.12778	0.07307	-0.01445	0.26483	1.749	27	*	169
PORG	-0.11941	0.06967	-0.25617	0.01993	-1.714	27	*	132
GenderM:Pallidum	0.14195	0.08836	-0.03598	0.31653	1.607	29	*	144
SMG	-0.11382	0.06074	-0.23125	0.00641	-1.874	30	*	124
FRP	0.106	0.06293	-0.01945	0.22465	1.684	31	*	114
MPrG	-0.10365	0.06561	-0.23161	0.03413	-1.58	32	*	105
GenderM:GRe	-0.15773	0.09273	-0.33986	0.01851	-1.701	32	*	98
Putamen	0.10102	0.06966	-0.03465	0.2428	1.45	34	*	138
Calc	-0.09092	0.05624	-0.20519	0.01388	-1.617	35	*	126
IOG	0.11541	0.08487	-0.05697	0.28564	1.36	35	*	125
LOrg	-0.11118	0.07688	-0.2672	0.03352	-1.446	35	*	120
GenderM:Calc	-0.12133	0.07306	-0.26179	0.02538	-1.661	35	*	99
LiG	0.09827	0.07304	-0.0382	0.24683	1.345	39	*	142
GenderM:Thalamus	-0.10675	0.07921	-0.26684	0.04711	-1.348	39	*	187
GenderM:AOrG	0.13187	0.08743	-0.04022	0.30761	1.508	39	*	166
PoG	-0.0871	0.06135	-0.20941	0.03174	-1.42	42	*	149
IFG	-0.0389	0.0319	-0.10292	0.02229	-1.219	43	*	136
GenderM:SOG	0.10175	0.0869	-0.07282	0.27354	1.171	43	*	97
MPoG	-0.0912	0.06228	-0.21248	0.0316	-1.464	45	*	153
GenderM:ITG	-0.1073	0.10054	-0.30292	0.08973	-1.067	45		126
GenderM:IFG	0.04514	0.04573	-0.04163	0.13971	0.987	45		118
GenderM:MFC	0.11051	0.09312	-0.07185	0.29488	1.187	48	*	109
Pallidum	-0.0735	0.06828	-0.20149	0.05819	-1.076	49		137
FO	0.0845	0.07962	-0.06574	0.23823	1.061	49		115
GenderM:Amyg	0.07444	0.08618	-0.10181	0.24073	0.864	49		116
GenderM:FRP	-0.07646	0.07824	-0.22139	0.08079	-0.977	49		129

NAc	-0.06905	0.07479	-0.21506	0.0821	-0.923	53	115
TTG	-0.07111	0.06382	-0.20137	0.05778	-1.114	54	161
GenderM:LiG	0.09507	0.10239	-0.11493	0.29612	0.929	54	123
AOrG	0.07058	0.06275	-0.05154	0.1925	1.125	56	138
GenderM:MPrG	0.08677	0.08373	-0.08377	0.24846	1.036	57	149
FuG	-0.05552	0.07944	-0.20643	0.09938	-0.699	58	113
GenderM:LORG	0.08812	0.08741	-0.07881	0.27334	1.008	58	120
GenderM:MSFG	-0.02429	0.09835	-0.20053	0.17438	-0.247	60	86
GenderM:PrG	0.07417	0.08947	-0.09942	0.24949	0.829	60	157
Hippocampus	0.03976	0.06844	-0.09228	0.1779	0.581	62	139
OCP	-0.05431	0.05647	-0.16383	0.05676	-0.962	62	173
PCgG	0.03872	0.07815	-0.1061	0.19948	0.495	62	93
GenderM:Hippocampus	-0.05326	0.08324	-0.2194	0.10486	-0.64	62	111
GenderM:ACgG	-0.03352	0.10372	-0.23967	0.16418	-0.323	62	132
GenderM:PCgG	-0.02865	0.10088	-0.2293	0.1583	-0.284	62	83
GenderM: `Hi&CollateralSulcus`	-0.01285	0.1061	-0.22333	0.18816	-0.121	62	129
GenderM:TMP	0.07327	0.07947	-0.08302	0.22898	0.922	62	149
Amyg	0.02326	0.07656	-0.11938	0.17793	0.304	70	135
ACgG	-0.04018	0.0706	-0.17553	0.09513	-0.569	70	58
Ins	-0.00165	0.04214	-0.07301	0.08909	-0.039	70	90
GRe	0.04119	0.06881	-0.09698	0.1731	0.599	70	61
MFC	-0.02277	0.07316	-0.16475	0.11756	-0.311	70	99
SFG	0.01634	0.07412	-0.1268	0.16155	0.22	70	152
SMC	-0.02994	0.06903	-0.16205	0.10126	-0.434	70	141
SPL	0.04731	0.06844	-0.08598	0.18453	0.691	70	119
Age	-0.0001	0.0001	-0.00028	0.00009	-1.028	70	125
GenderM:Putamen	0.04054	0.08906	-0.12721	0.21779	0.455	70	120
Thalamus	0.0383	0.06077	-0.08064	0.15408	0.63	80	152
AnG	0.03677	0.06684	-0.09579	0.16593	0.55	80	115
MFG	0.0164	0.07028	-0.12069	0.15193	0.233	80	146
GenderM:SFG	-0.00387	0.08023	-0.17415	0.15095	-0.048	80	154
GenderM:SMC	0.02524	0.09244	-0.15552	0.20031	0.273	80	122
GenderM:STG	-0.02581	0.085	-0.18713	0.14258	-0.304	80	154

GenderM:TTG	-0.06652	0.08112	-0.22672	0.09109	-0.82	80	165
MOrG	0.00372	0.07352	-0.13282	0.15275	0.051	87	118
SOG	-0.02788	0.06769	-0.16184	0.11139	-0.412	87	129
STG	0.02253	0.06721	-0.11202	0.1532	0.335	87	167
GenderM:FO	-0.02305	0.09564	-0.2165	0.16556	-0.241	87	127
GenderM:POrG	0.03546	0.09153	-0.15062	0.20991	0.387	87	120
ThirdFourthFifthVentricles	-0.02874	0.04856	-0.12633	0.06173	-0.592	92	191
Caudate	-0.00859	0.06599	-0.13942	0.12067	-0.13	92	103
MCgG	-0.01552	0.07282	-0.16653	0.12426	-0.213	92	104
OFuG	-0.0099	0.0664	-0.13429	0.12467	-0.149	92	170
TMP	-0.01292	0.06914	-0.14853	0.12729	-0.187	92	128
GenderM:MCgG	0.03545	0.09043	-0.14658	0.21145	0.392	92	103
LateralVentricles	-0.01007	0.03643	-0.07881	0.06709	-0.276	98	126
GenderM:MPoG	-0.01439	0.08619	-0.18483	0.15883	-0.167	98	157
cons	2.19773	0.36136	1.48615	2.90957	.	.	.

Table depicts mean posterior estimate, standard deviation (SD), 95% credible interval, with asterisk demonstrating if the credible interval of the posterior estimate did not cross zero and hence was significant. Significant negative posterior estimates relate to decreasing volumetry related to that given interaction, in accordance with increasing episodes of concussion. For example, row one depicts an interaction between males and decreased volume to the superior parietal lobule, for an increase in the number of episodes of concussion. Factors are ranked by their predictive fidelity. Amyg., amygdala; ACgG, anterior cingulate gyrus; AOrG, anterior orbital gyrus; AnG, angular gyrus; Calc, calcarine cortex; FO, frontal operculum; FRP, frontal pole; FuG, occipital fusiform gyrus; GRe, gyrus rectus; Hi, hippocampal [sulcus]; Ins, insula; IFG, inferior frontal gyrus; IOG, inferior occipital gyrus; ITG, inferior temporal gyrus; LiG, lingual gyrus; LOrg, lateral orbital gyrus; MCgG, middle cingulate gyrus; MFC, medial frontal cortex; MFG, middle frontal gyrus; MOG, middle occipital gyrus; MOrG, medial orbital gyrus; MPoG, postcentral gyrus medial segment; MPrG, precentral gyrus medial segment; MSFG, superior frontal gyrus medial segment; MTG, middle temporal gyrus; NAc, nucleus accumbens; OCP, occipital pole; OFuG, occipital fusiform gyrus; PCgG, posterior cingulate gyrus; PCu, precuneus; PoG, postcentral gyrus; POrG, posterior orbital gyrus; PrG, precentral gyrus; SFG, superior frontal gyrus; SMC, supplementary motor cortex; SMG, supramarginal gyrus; SOG, superior occipital gyrus; SPL, superior parietal lobule; STG, superior temporal gyrus; TMP, temporal pole; TTG, transverse temporal gyrus.