

Additional file 1

Supplementary methods, tables, and figures

Multi-Day Actigraphy-Derived Active Time Is Inversely Associated with Problematic Internet Use Severity in Children and Adolescents: A Cross-Sectional Analysis of the Healthy Brain Network

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Table S1 Sensitivity analyses for the association between wearable-derived active time above ENMO 0.05 and problematic internet use outcomes.

Analysis	Outcome	N	Events	Adjusted β or OR	95% CI	P value
Primary complete-case analysis	Moderate/severe PIU	763	99	0.69	0.50 to 0.94	P = 0.018
Primary complete-case analysis	PCIAT total score	763		-3.16	-4.73 to -1.60	P < 0.001
Strict QC: ≥ 96 valid wear hours and ≥ 7 recorded days	Moderate/severe PIU	730	94	0.68	0.48 to 0.95	P = 0.024
Strict QC: ≥ 96 valid wear hours and ≥ 7 recorded days	PCIAT total score	730		-2.97	-4.62 to -1.32	P < 0.001
Wear ratio ≥ 0.70	Moderate/severe PIU	561	64	0.56	0.36 to 0.88	P = 0.012
Wear ratio ≥ 0.70	PCIAT total score	561		-4.44	-6.29 to -2.59	P < 0.001
Additional adjustment for fitness and body composition	Moderate/severe PIU	440	49	0.69	0.43 to 1.11	P = 0.130
Additional adjustment for fitness and body composition	PCIAT total score	440		-3.26	-5.29 to -1.23	P = 0.002
Internet use coded categorically	Moderate/severe PIU	763	99	0.69	0.50 to 0.94	P = 0.019
Internet use coded categorically	PCIAT total score	763		-3.18	-4.74 to -1.62	P < 0.001
Multiple imputation	Moderate/severe PIU	857	117	0.67	0.51 to 0.90	P = 0.007
Multiple imputation	PCIAT total score	857		-3.56	-5.00 to -2.13	P < 0.001
Exclude exposure below 1st or above 99th percentile	Moderate/severe PIU	747	98	0.69	0.50 to 0.95	P = 0.024
Exclude exposure below 1st or above 99th percentile	PCIAT total score	747		-2.88	-4.54 to -1.23	P < 0.001

Note. Exposure standardization was recalculated within each sensitivity sample unless the primary complete-case exposure scale was explicitly retained.

Table S2 Characteristics of participants included in and excluded from the main complete-case analysis.

Age, years	10.00 (2.95)	11.61 (5.76)
Female, n (%)	266 (34.9)	37 (39.4)
Body mass index, kg/m ²	18.94 (4.80)	20.94 (5.89)
Sleep disturbance T score	57.51 (13.14)	58.67 (15.16)
Daily computer/internet use: More than 3 h/day, n (%)	71 (9.3)	14 (14.9)
PCIAT total score	27.07 (19.56)	27.65 (21.89)
Moderate/severe PIU, n (%)	99 (13.0)	18 (19.1)
Active minutes/day, ENMO > 0.05	283.33 [204.36, 382.67]	270.00 [194.20, 353.64]
Active minutes/day, ENMO > 0.10	145.49 [99.15, 202.19]	134.87 [77.02, 189.00]
Mean ENMO	0.04 [0.03, 0.06]	0.04 [0.02, 0.05]
ENMO 75th percentile	0.04 [0.03, 0.05]	0.04 [0.03, 0.05]
Day–night ENMO ratio	11.42 [6.74, 19.34]	9.71 [4.80, 16.92]
Valid wear hours	400.60 [223.05, 496.35]	360.21 [169.25, 493.14]
Recorded days	24.00 [23.00, 29.00]	25.00 [23.00, 31.50]
Wear ratio	0.94 [0.66, 1.00]	0.96 [0.57, 1.00]

Table S3 Sequentially adjusted associations of wearable-derived active time with problematic internet use outcomes in the fixed complete-case sample.

Outcome	Model	N	Events	Effect	95% CI	P value
PCIAT total score	Model 0	763		−5.26	−6.61 to −3.90	P < 0.001
PCIAT total score	Model 1	763		−3.87	−5.54 to −2.20	P < 0.001
PCIAT total score	Model 2	763		−3.58	−5.24 to −1.93	P < 0.001
PCIAT total score	Model 3-current	763		−3.16	−4.73 to −1.60	P < 0.001
PCIAT total score	Model 3-categorical	763		−3.18	−4.74 to −1.62	P < 0.001
Moderate/severe PIU	Model 0	763	99	0.54	0.42 to 0.69	P < 0.001
Moderate/severe PIU	Model 1	763	99	0.64	0.46 to 0.87	P = 0.005
Moderate/severe PIU	Model 2	763	99	0.66	0.48 to 0.90	P = 0.008
Moderate/severe PIU	Model 3-current	763	99	0.69	0.50 to 0.94	P = 0.018
Moderate/severe PIU	Model 3-categorical	763	99	0.69	0.50 to 0.94	P = 0.019

Note. Model 0 was unadjusted. Model 1 added age, sex, BMI, valid wear hours, and recorded days. Model 2 additionally added sleep disturbance T score. Model 3-current additionally added the original internet-use coding. Model 3-categorical is a parallel sensitivity specification with internet use as a categorical factor using <1 h/day as the reference.

Table S4 Exploratory secondary wearable-derived activity associations with Benjamini-Hochberg false-discovery-rate correction.

Exposure	Outcome	N	Events	β or OR	95% CI	Raw P value	FDR q value
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Active time above ENMO 0.10, min/day	PCIAT total score	763		-2.84	-4.36 to -1.31	P < 0.001	0.001
Active time above ENMO 0.10, min/day	Moderate/severe PIU	763	99	0.73	0.54 to 1.00	P = 0.051	0.061
ENMO 75th percentile	PCIAT total score	763		-2.94	-4.48 to -1.40	P < 0.001	0.001
ENMO 75th percentile	Moderate/severe PIU	763	99	0.70	0.50 to 0.98	P = 0.040	0.061
Mean ENMO	PCIAT total score	763		-2.81	-4.45 to -1.17	P < 0.001	0.002
Mean ENMO	Moderate/severe PIU	763	99	0.72	0.51 to 1.01	P = 0.061	0.061
Day-night ENMO ratio	PCIAT total score	749		-1.18	-2.34 to -0.02	P = 0.046	0.061
Day-night ENMO ratio	Moderate/severe PIU	749	97	0.80	0.64 to 1.00	P = 0.054	0.061

Table S5 Targeted influence analyses for the primary logistic regression model.

Analysis	Removed	N	Events	OR	95% CI	P value
Primary model	0	763	99	0.69	0.50 to 0.94	P = 0.018
Exclude observations with exposure-specific $ DFBETA > 2/\sqrt{N}$	42	721	64	0.66	0.50 to 0.86	P = 0.002
Exclude the observation with the largest absolute exposure-specific DFBETA	1	762	98	0.65	0.48 to 0.88	P = 0.005
Exclude the top 3 absolute exposure-specific DFBETA observations	3	760	96	0.65	0.48 to 0.87	P = 0.004
Exclude the top 5 absolute exposure-specific DFBETA observations	5	758	94	0.64	0.47 to 0.87	P = 0.004
Exclude the top 10 absolute exposure-specific DFBETA observations	10	753	90	0.61	0.45 to 0.84	P = 0.002

Note. One-at-a-time deletion among the ten observations with the largest absolute exposure-specific DFBETA values produced ORs ranging from

0.65 to 0.71.

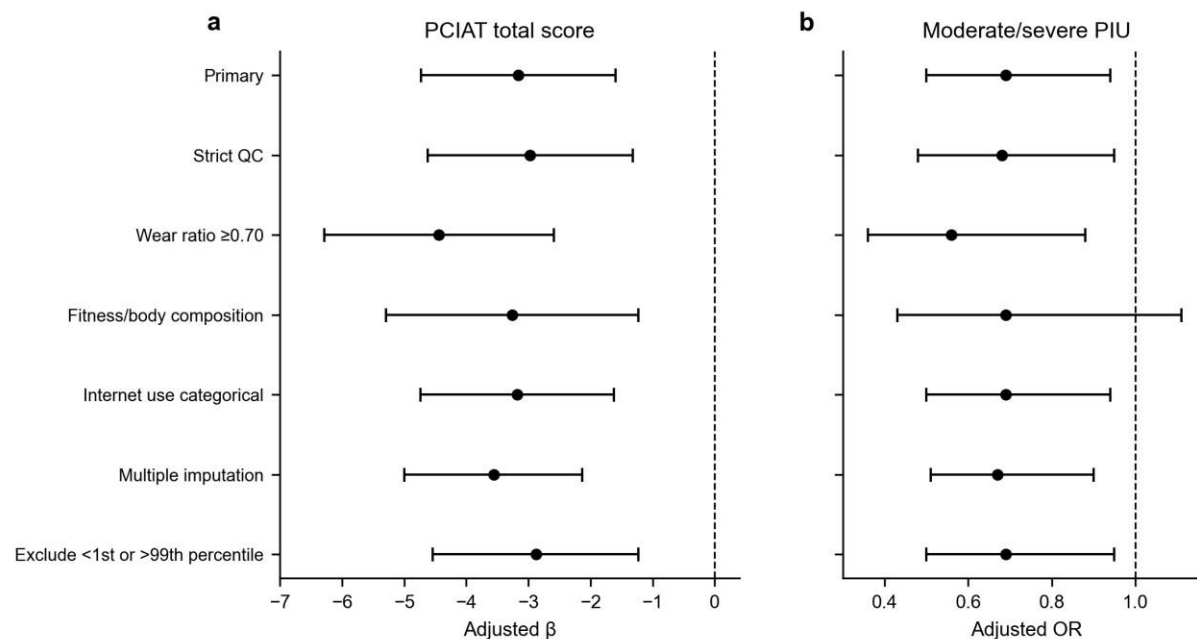


Fig. S1 Sensitivity analyses for the association between active time above ENMO 0.05 and problematic internet use outcomes. Panel a shows adjusted β coefficients for PCIAT total score; panel b shows adjusted ORs for moderate/severe PIU. Horizontal bars indicate 95% confidence intervals.

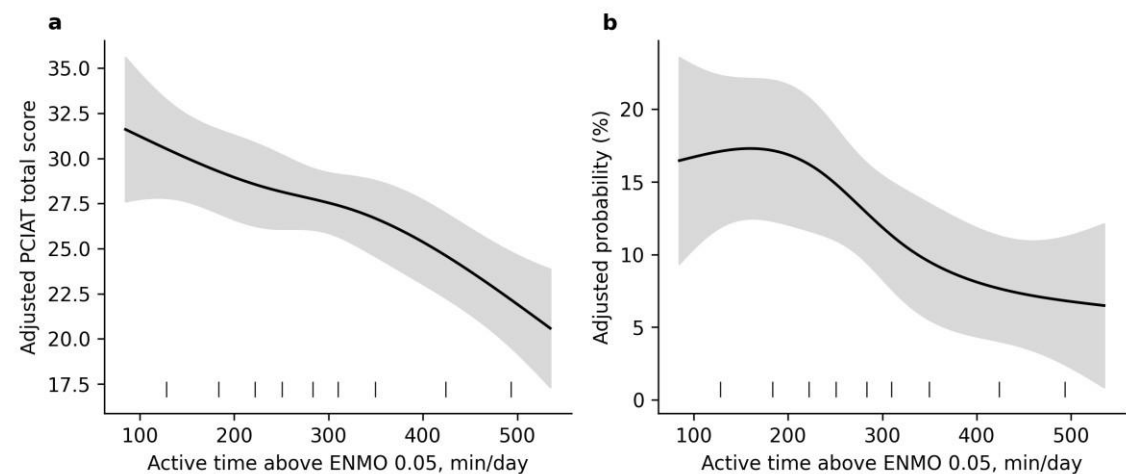


Fig. S2 Restricted cubic spline sensitivity analysis for active time above ENMO 0.05 and problematic internet use outcomes. Panel a shows marginally standardized adjusted PCIAT total score; panel b shows marginally standardized adjusted probability of moderate/severe PIU. Models used the fixed primary complete-case sample (N = 763; 99 events for the binary outcome), adjusted for age, sex, BMI, sleep disturbance T score, daily computer/internet use entered as an ordinal covariate, valid wear hours, and recorded days. Knots were placed at the 5th, 35th, 65th, and 95th percentiles: 84.87, 236.61, 324.01, and 534.93 min/day. The formal nonlinearity test was not significant for PCIAT total score (P = 0.562) or moderate/severe PIU (P = 0.454).

Table S6 Ordinal SII secondary models.

Exposure	N	Ordinal SII OR (95% CI)	P value
Active time above ENMO 0.05, min/day	763	0.67 (0.55, 0.81)	P < 0.001

Active time above ENMO 0.10, min/day	763	0.69 (0.57, 0.84)	P < 0.001
ENMO 75th percentile	763	0.69 (0.57, 0.84)	P < 0.001
Mean ENMO	763	0.67 (0.55, 0.82)	P < 0.001
Day–night ENMO ratio	749	0.85 (0.72, 1.00)	P = 0.053

Note. Ordered-logistic models used the same adjusted specification as the primary analysis. Estimates are odds ratios per 1-SD higher exposure.

Table S7 Raw-actigraphy feature extraction and validation.

Raw feature	Existing summary	N	r	Mean diff.	Median abs. diff.	Raw missing	Existing missing
Mean ENMO	Existing mean ENMO	996	1	0	0	0	0
ENMO 75th percentile	Existing ENMO 75th percentile	996	1	0	0	0	0
Active minutes >0.05 ENMO	Existing active minutes >0.05 ENMO	996	1	−1.8287e-13	0	0	0
Active minutes >0.05 ENMO per valid day	Existing active minutes >0.05 ENMO	996	1	−8.48696e-15	0	0	0
Morning ENMO (06:00-12:00)	Existing morning ENMO	993	1	0	0	3	3
Afternoon ENMO (12:00-18:00)	Existing afternoon ENMO	996	1	0	0	0	0
Evening ENMO (18:00-24:00)	Existing evening ENMO	996	1	0	0	0	0
Night ENMO (00:00-06:00)	Existing night ENMO	958	1	0	0	38	38

Note. Epoch-level features were derived from the source accelerometer files using the supplied non-wear indicators. Derived features were compared with corresponding source summary measures where available.

Table S8 Exploratory raw-actigraphy feature-family summary.

Feature family	Outcome	Features tested	FDR-significant count	Best feature	Best P	Best FDR q	Best estimate
Fragmentation/bout structure	Moderate/severe PIU	6	0	Fragmentation index	0.023	0.141	1.271
Fragmentation/bout structure	PCIAT total	6	4	Inactive bout count/day	P < 0.001	P < 0.001	−4.312
Fragmentation/bout structure	Ordinal SII	6	4	Median active-bout duration	P < 0.001	0.003	0.723
Low-movement/rest proxy	Moderate/severe PIU	4	0	Low-movement minutes overnight	0.214	0.527	1.306
Low-movement/rest proxy	PCIAT total	4	0	Low-movement minutes overnight	0.105	0.380	1.822
Low-movement/rest proxy	Ordinal SII	4	0	Low-movement minutes overnight	0.363	0.976	1.143

Timing	Moderate/severe PIU	6	0	Morning ENMO	0.046	0.157	0.732
Timing	PCIAT total	6	3	Afternoon ENMO	0.002	0.011	-2.428
Timing	Ordinal SII	6	3	Afternoon ENMO	P < 0.001	0.002	0.706
Day-to-day variability	Moderate/severe PIU	6	0	Daily active time mean	0.042	0.240	0.647
Day-to-day variability	PCIAT total	7	2	Daily active time mean	P < 0.001	P < 0.001	-4.137
Day-to-day variability	Ordinal SII	6	3	Daily active time mean	P < 0.001	P < 0.001	0.604
Activity volume	Moderate/severe PIU	10	0	Active time per valid day	0.018	0.101	0.687
Feature family	Outcome	Features tested	FDR-significant count	Best feature	Best P	Best FDR q	Best estimate
Activity volume	PCIAT total	10	9	Active time per valid day	P < 0.001	P < 0.001	-3.165
Activity volume	Ordinal SII	10	9	Active time per valid day	P < 0.001	P < 0.001	0.669
Weekday/weekend pattern	Moderate/severe PIU	5	0	Weekend active time mean	0.029	0.111	0.637
Weekday/weekend pattern	PCIAT total	5	4	Weekend active time mean	P < 0.001	P < 0.001	-3.744
Weekday/weekend pattern	Ordinal SII	5	4	ENMO weekday mean	P < 0.001	P < 0.001	0.686

Note. Feature-family summaries were exploratory and intended to characterize complementary movement patterns.

Table S9 Incremental information and discrimination diagnostics.

Panel A. Incremental-information diagnostics.

Model	N	Events	Adjusted R ²	Change in adjusted R ²	Apparent AUC	CV AUC	CV PR-AUC	CV Brier
M2 covariates + sleep/internet	763	99	0.245	0.000	0.782	0.764	0.322	0.102
M3 + active time	763	99	0.260	0.015	0.795	0.774	0.320	0.102
M4 + prespecified raw features	749	97	0.249	0.004	0.791	0.746	0.290	0.105

Panel B. Cross-validated discrimination diagnostics.

Model	N	Events	CV AUC	CV PR-AUC	CV Brier	Calibration intercept	Calibration slope
Base covariates	763	99	0.764	0.322	0.102	-0.148	0.906
Base + active time	763	99	0.774	0.320	0.102	-0.172	0.888
Base + selected wearable features	749	97	0.761	0.324	0.103	-0.301	0.819

Note. These diagnostics were included as supplementary model-comparison measures and were not used as the primary inferential outcomes.

Table S10 Additional covariate-domain robustness.

Model	Variant	N	Events	P value	Feature coefficient
Active time	Winsor 1st-99th	763	99	P < 0.001	Active time: -3.16
Active time	No winsorization	763	99	P < 0.001	Active time: -3.25
Active time	Wear ratio ≥ 0.70	561	64	P < 0.001	Active time: -4.44
Active time	Exclude extreme PCIAT 1st-99th	755	91	P < 0.001	Active time: -3.06
Active time	Add CGAS	728	94	P < 0.001	Active time: -3.26
Active time	Add PAQ	539	89	P < 0.001	Active time: -3.58
Active time	Add FitnessGram	522	61	P = 0.004	Active time: -2.8
Active time	Add BIA/body composition	551	70	P < 0.001	Active time: -3.93

Note. This table summarizes additional covariate-domain robustness analyses for the primary actigraphy-derived active-time exposure. Estimates were not used to redefine the primary analysis.