
Supplementary Materials for

**Physical-Digital and Social-Nonsocial Extracurricular Engagement: Differential Effects on
Brain Development and Psychological Outcomes in Children**

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Supplementary Methods 1. Measurement Resources and Preprocessing Details for Weekly Activity Engagement

Digital activities

Detailed item information and response scales for the six screen time activities measured in the ABCD Youth Screen Time Survey are provided in Table S1. Participants' engagement with each type of digital activity (screen media activity) was assessed through separate inquiries regarding weekday and weekend use:

For instance, for the activity type "watching TV shows or movies," participants were asked:

- "On a typical weekday, how many hours do you spend watching TV shows or movies?"
- "On a typical weekend day, how many hours do you spend watching TV shows or movies?"

Participants reported their engagement using seven options: none, less than 30 minutes, 30 minutes, 1 hour, 2 hours, 3 hours, and 4 or more hours¹. We converted these categorical responses to numerical values (0, 0.25, 0.5, 1, 2, 3, and 4 respectively) for standardized analysis. Overall weekly engagement for each digital activity was calculated as: (weekday engagement hours $\times$ 5) + (weekend engagement hours $\times$ 2)².

Physical activities

Children's engagement in physical activities was assessed using caregiver-reported information from the Sports and Activities Involvement Questionnaire (SAI-Q). The SAI-Q, adapted from the Vermont Health and Behavioral Questionnaire (VHBQ) and the Dutch Health Behavioral Questionnaire (DHBQ), evaluates participation in various activities over the lifetime and during the past year. Caregivers were asked to provide details about their child's most active period of participation in each activity, including: (1) the number of minutes per session (*tspent*), (2) the number of days per week (*perwk*), and (3) the number of months per year (*nmonth*)³. For example, children's engagement in a specific activity type was recorded through caregiver-reported responses to the following questions:

- **Minutes per session (*tspent*):** "About how many minutes per session?"
 - Responses were coded as: 0 (none), 1 (<30 minutes), 2 (30 minutes), 3 (45 minutes), 4 (60 minutes/1 hour), 5 (90 minutes/1.5 hours), 6 (120 minutes/2 hours), 7 (150 minutes/2.5 hours), 8 (180 minutes/3 hours), 9 (>3 hours), and 999 (Don't know).
- **Days per week (*perwk*):** "About how many days per week?"
 - Responses were coded as: 0 (none); 1–7 = exact number of days; 8 = once every 2 weeks; 9 = one day every month; 10 = less than one day per month; and 999 = Don't know.
- **Months per year (*nmonth*):** "About how many months per year did your child participate?"
 - Responses were recorded across 13 categories: months 1–12 and 999 (Don't know).

After excluding participants with responses coded as 999, we recoded the responses for *tspent* and *perwk* to ensure that higher values represented greater engagement duration, as follows:

- ***Tspent*:** Session durations were coded in hours, 0 = 0 hours, <0.5 = 0.25 hours, 0.5 = 0.5 hours, 0.75 = 0.75 hours, 1 = 1 hour, 1.5 = 1.5 hours, 2 = 2 hours, 2.5 = 2.5 hours, 3 = 3 hours, and >3 = 3.5 hours.
- ***Perwk*:** Responses were mapped to weekly engagement values: 0–7 days were retained as exact counts, "once every two weeks" was recoded as 0.5 days/week, "one day every month" as 0.23 days/week, and "less than one day per month" as 0.033 days/week.

The average weekly engagement hours for a specific activity were calculated using the recoded responses with the formula: (*tspent* $\times$ *perwk* $\times$ *nmonth*) / (12 $\times$ 60)⁴.

Supplementary Methods 2. Description of Outcomes Measures

Mental Health Outcomes

We analyzed behavioral outcomes using the Child Behavior Checklist (CBCL), which comprises three primary domains: internalizing problems, externalizing problems, and problem behaviors. Each domain contains symptom-specific scales. The severity of behavioral problems was indicated by higher scores, with values exceeding 60 considered clinically significant for potential disorders. The following CBCL metrics were incorporated in our analysis:

- Internalizing Problems:
 - Anxious/Depressed
 - Withdrawn/Depressed
 - Somatic Complaints
 - Internalizing Problems Total
- Externalizing Problems:
 - Rule-Breaking Behavior
 - Aggressive Behavior
 - Externalizing Problems Total
- Problem behaviors:
 - Social Problems
 - Thought Problems
 - Attention Problems
- Mental Health Total Problems

Psychiatric Diagnoses Assessment

To evaluate the relationship between activity engagement and psychiatric diagnoses, we preprocessed Wave 1 (baseline) records from the ABCD Parent Diagnostic Interview for DSM-5 Full, producing two primary outputs: (1) the Symptoms/Comments Report, which details individual symptom endorsements, and (2) the Diagnosis Report, which categorizes current and past diagnoses using ICD-10 codes⁵. Initially, 145 diagnostic items were retained, from which 112 clinically meaningful items were selected based on predefined exclusion criteria. These items were further categorized into 17 diagnostic groups following the KSADS-COMP modular taxonomy⁶. For statistical analyses, we focused on mental health-relevant diagnostic groups, as defined by the Hierarchical Taxonomy of Psychopathology (HiTOP) framework⁷. After applying this classification, 15 diagnostic groups and their corresponding diagnostic items (106 items) were retained for analysis, with items of extremely low prevalence (≤ 1 case in the total sample) excluded. A complete workflow diagram is available in Fig. S2, and detailed variable information is provided in Table S2.

Imaging Acquisition and Preprocessing

Neuroimaging data in the ABCD study were acquired using harmonized protocols across sites with 3T MRI scanners (Siemens, Phillips, or General Electric) equipped with 32-channel head coils. All participants underwent T1-weighted structural imaging at 1-mm isotropic resolution. The ABCD Data Analysis and Informatics Core's preprocessing pipeline included gradient nonlinearity correction for T1/T2-weighted images, T2 to T1 image registration using mutual information, B1-bias field correction for signal inhomogeneity, and spatial normalization to a standardized template (for preprocessing details, see Hagler et al⁸). FreeSurfer v5.3 was then employed for cortical surface reconstruction and subcortical segmentation to generate morphometric measures. In the current study, we focused on analyzing regional gray matter volumes across 68 cortical regions as defined by the Desikan-Killiany atlas⁹.

Supplementary Methods 3. Neurosynth Decoding

To elucidate the functional significance of brain volumetric patterns associated with different extracurricular activity engagement profiles, we conducted meta-analytic decoding using Neurosynth (<https://github.com/neurosynth/neurosynth>), which aggregates over 15,000 fMRI studies. This platform facilitates cognitive interpretation of brain activity patterns by establishing probabilistic relationships between reported neural activation coordinates and psychological constructs through automated text-mining of neuroimaging literature. The inference framework enables systematic mapping between spatial activation patterns and their associated cognitive states or functions based on the statistical co-occurrence of brain regions and psychological terms across the literature. We focused on 42 terms across three primary functional domains: Mental and Physical Health (N=18; such as depression, anxiety, psychosis, sleep, and pain), Attention and Executive Function (N=9; such as maintenance, focus, and attention), and Social Cognition and Communication (N=15; such as face recognition, facial expression, empathy, communication, social interaction, and social cognitive). Decoding was performed by correlating brain volumetric t-maps derived from each extracurricular engagements pattern with the 42 term-specific meta-analytic maps, following procedures in the Neurosynth repository (<https://github.com/neurosynth/neurosynth>)¹⁰.

Supplementary Results 1. Neurosynth Functional Annotations for Category-Specific Volume Alteration Patterns

Neurosynth term correlation analyses revealed systematic associations between activity-specific gray matter volume and brain regions supporting mental health, executive function, and social cognitive processes (Table S9). The strongest associations were observed in mental health-related terms, where physical social and digital non-social activities showed differential associations with pain ($r = -0.186$ and $r = 0.229$, respectively), stress ($r = -0.132$ and $r = 0.157$, respectively), and anxiety ($r = -0.109$ and $r = 0.143$, respectively). Other mental health indicators, including depression, psychosis, and addiction, showed associations of smaller magnitude ($|r| < 0.10$) across all activity categories. In the domain of attention and executive function, attention-related processes showed notable associations with both physical social ($r = 0.109$) and digital non-social ($r = -0.140$) activities, while executive components including maintenance ($r = 0.071$) and updating ($r = 0.061$) demonstrated specific associations with physical social activities. Analysis of social cognitive processes revealed activity-specific patterns, with face recognition showing differential associations with physical activities (social: $r = 0.102$; non-social: $r = -0.119$), and mentalizing processes demonstrating associations with both physical social ($r = 0.085$) and digital social ($r = -0.104$) activities. Higher-order social cognitive processes, including judgment and inference, showed consistent associations across physical activities ($|r|$ range, 0.051-0.098), while digital activities demonstrated relatively modest associations ($|r| < 0.05$) in these domains. Collectively, these findings suggest that different activity categories may influence child development through activity-specific modulation of gray matter volume in brain regions supporting key developmental functions.

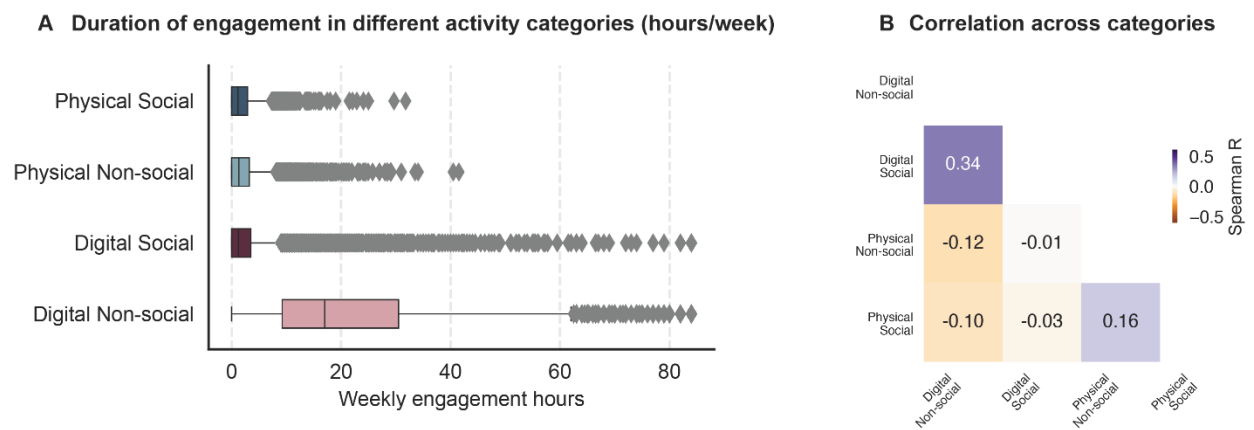
Supplementary Results 2. Sensitivity Analysis of Development Outcome Patterns Across Activity Categories

To mitigate potential bias from the left-skewed distribution of weekly participation hours, we implemented a sensitivity analysis focusing on participants with non-zero engagement (>0 hours/week) across activity categories. Among participants with non-zero engagement, digital non-social activities showed the highest median weekly participation (median [IQR], 17.0 [9.2-30.5] hours; n=8,198), followed by digital social activities (median [IQR], 3.5 [1.8-6.0] hours; n=4,649). Physical activities showed comparable patterns, with non-social (median [IQR], 2.2 [1.0-4.0] hours; n=6,071) and social activities (median [IQR], 2.0 [1.0-3.5] hours; n=6,041). Critically, our sensitivity analysis corroborated the primary findings, with consistent mental health (Fig. S4, Table S5) and neuroanatomical associations (Fig. S5), thereby substantiating the robustness of our original observations.

Supplementary References

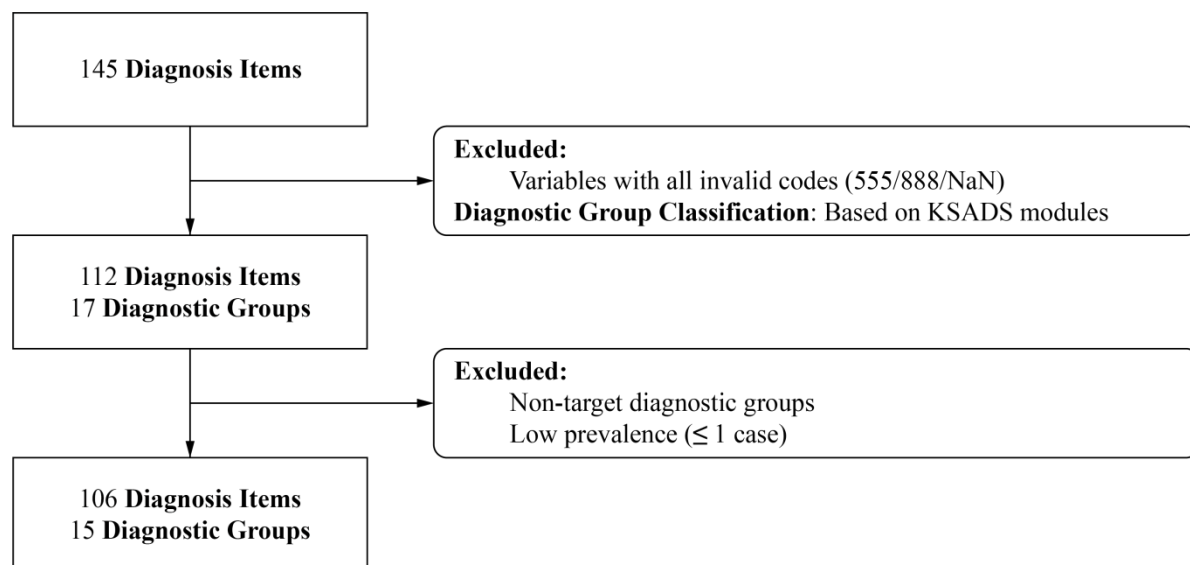
- 1 Bagot, K. S. *et al.* Youth screen use in the ABCD study. *Dev. Cogn. Neurosci.* **57**, 101150 (2022).
- 2 Nagata, J. M. *et al.* Association of Physical Activity and Screen Time With Body Mass Index Among US Adolescents. *JAMA Netw. Open* **6**, e2255466 (2023).
- 3 Huppertz, C. *et al.* Individual Differences in Exercise Behavior: Stability and Change in Genetic and Environmental Determinants From Age 7 to 18. *Behav. Genet.* **46**, 665-679 (2016).
- 4 Ku, B. S. *et al.* Associations Between Genetic Risk, Physical Activities, and Distressing Psychotic-like Experiences. *Schizophr. Bull.* (2024).
- 5 Townsend, L. *et al.* Development of Three Web-Based Computerized Versions of the Kiddie Schedule for Affective Disorders and Schizophrenia Child Psychiatric Diagnostic Interview: Preliminary Validity Data. *Journal of the American Academy of Child & Adolescent Psychiatry* **59**, 309-325 (2020).
- 6 Barch, D. M. *et al.* Demographic and mental health assessments in the adolescent brain and cognitive development study: Updates and age-related trajectories. *Dev. Cogn. Neurosci.* **52**, 101031 (2021).
- 7 Cicero, D. C. *et al.* State of the Science: The Hierarchical Taxonomy of Psychopathology (HiTOP). *Behavior. Therapy* **55**, 1114-1129 (2024).
- 8 Hagler, D. J., Jr. *et al.* Image processing and analysis methods for the Adolescent Brain Cognitive Development Study. *Neuroimage* **202**, 116091 (2019).
- 9 Desikan, R. S. *et al.* An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest. *Neuroimage* **31**, 968-980 (2006).
- 10 Yarkoni, T., Poldrack, R. A., Nichols, T. E., Van Essen, D. C. & Wager, T. D. Large-scale automated synthesis of human functional neuroimaging data. *Nat. Methods* **8**, 665-670 (2011).

Supplementary Figure 1. Data Distribution and Correlations of Four Activity Categories at Wave1



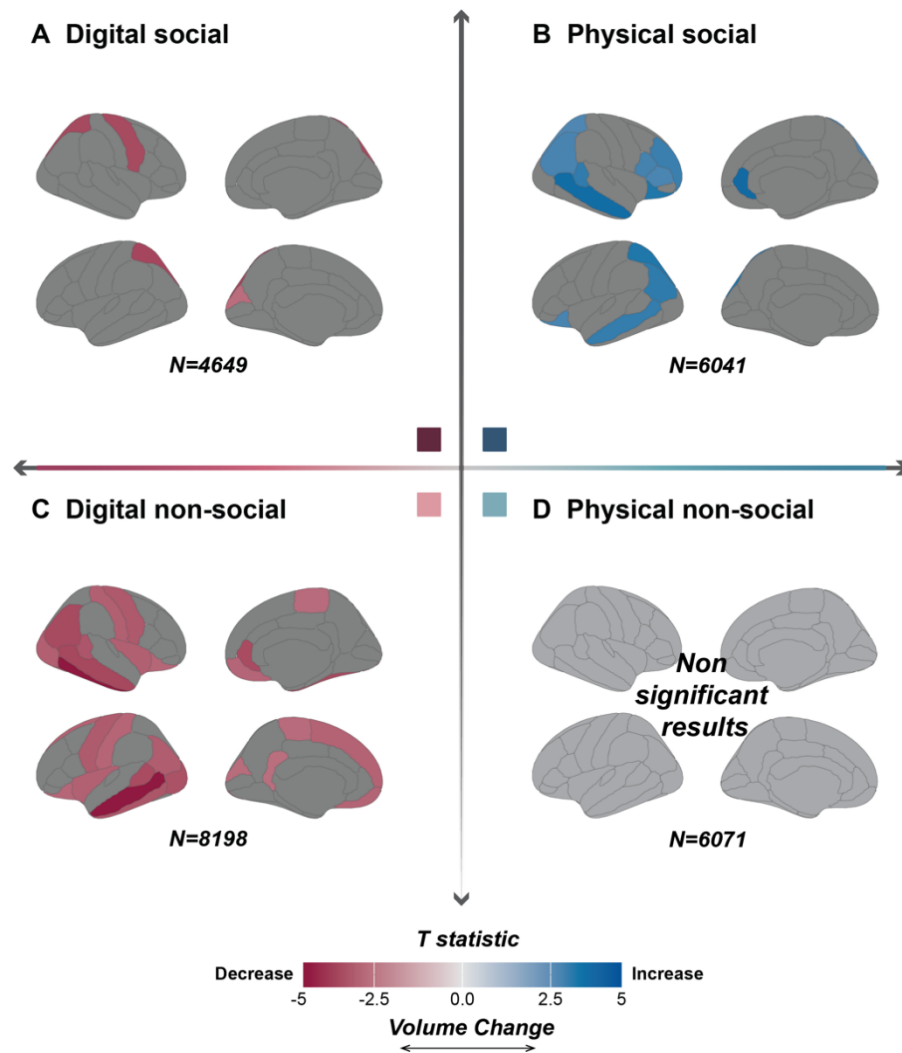
Note: (A) Each box displays the first quartile, median and third quartile of engagement duration within specific categories. The whiskers represent the non-outlier endpoints of the distribution, and the crosses denote outliers. (B) The heatmap shows Spearman correlation coefficients across four categories.

Supplementary Figure 2. Diagnostic Variable Selection and Grouping Workflow



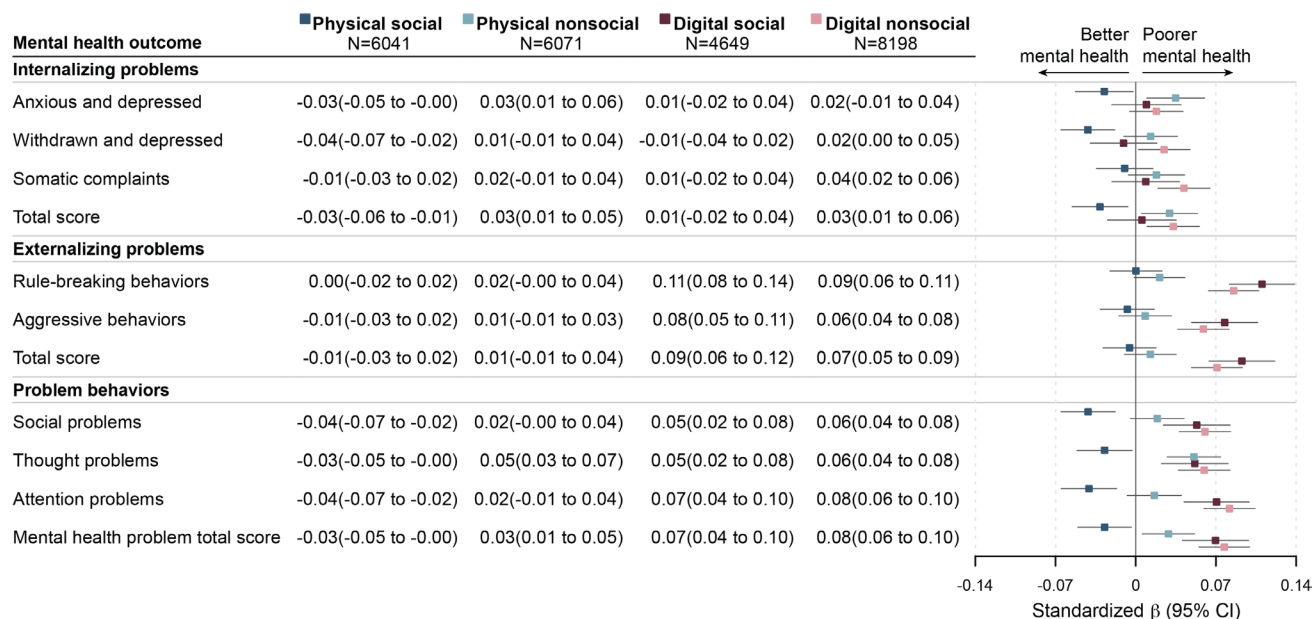
Note: The flowchart shows the inclusion of diagnostic items and groups.

Supplementary Figure 3. Significant Associations Between Regional Gray Matter Volume and Weekly Activity Engagement Across Categories (FDR-Corrected $P < 0.05$)



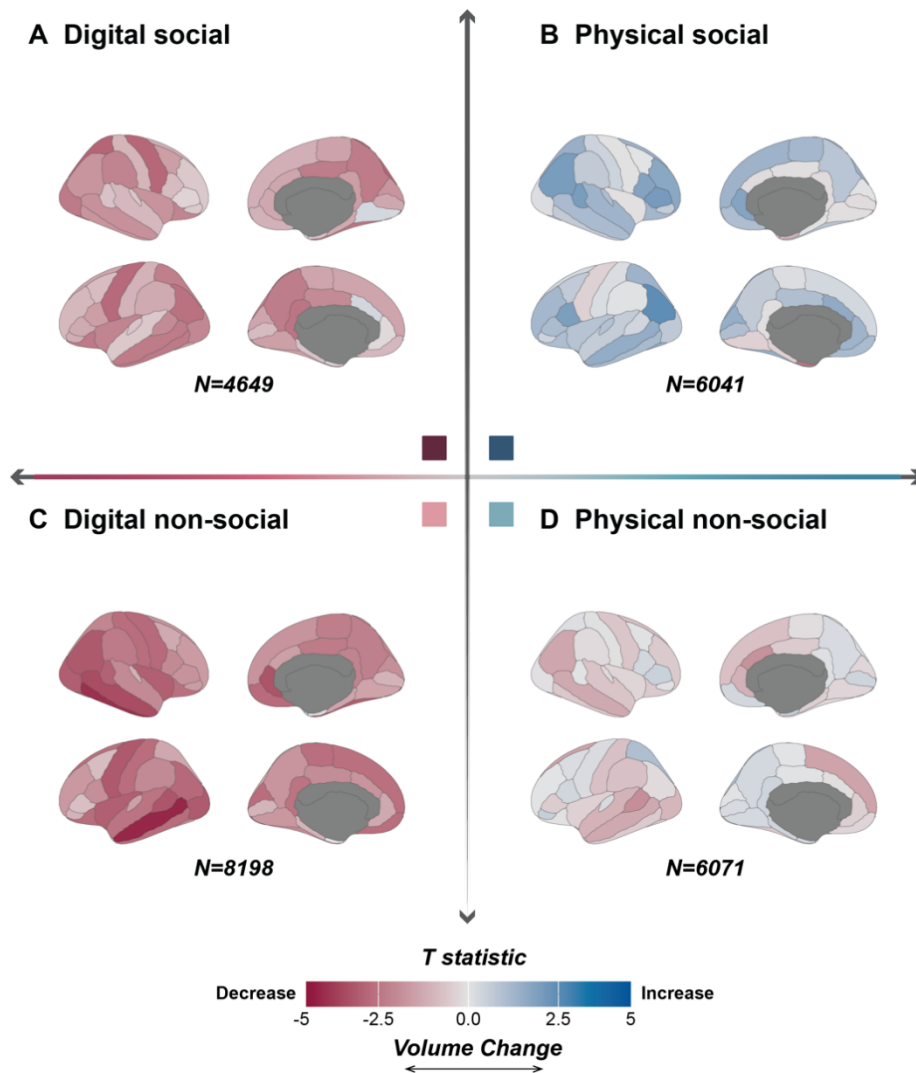
Note: T-maps for regions with significant associations between gray matter volume and weekly activity engagement: (A) digital social, (B) physical social, (C) digital non-social, and (D) physical non-social. Corresponding estimate effects, t -values, and p -values are provided in Table S8.

Supplementary Figure 4. Forest Plot showing Associations Between the Weekly Engagement Duration (>0 hour/week) Across Activity Categories and Mental Health Outcomes (Sensitivity Analysis)



Note: β (95% CI) and P values were estimated using linear mixed-effects regression analyses, based on data from subgroup samples with weekly engagement duration (>0 hours/week) and their CBCL symptom measures. The modeling details and covariate adjustments were consistent with those described in the main analysis. Sample sizes for each association are specified in the text annotations. P values are provided in Table S5.

Supplementary Figure 5. Neuroanatomical Outcomes Across Activity Engagement (>0 hour/week) Categories (Sensitivity Analysis)



Note: T-maps for associations between gray matter volume and weekly activity engagement based on data from subgroup samples with weekly engagement duration (>0 hours/week): (A) digital social, (B) physical social, (C) digital non-social, and (D) physical non-social. The modeling details and covariate adjustments were consistent with those described in the main analysis. Sample sizes for each association are specified in the text annotations.

Supplementary Table 1. List of Investigated Activities Across Four Categories

Activity categories	Activity types	Data elements
Physical Social (11)	Baseball, Softball	sai_ss_base
	Basketball	sai_ss_basket
	Field Hockey	sai_ss_fhock
	Ice Hockey	sai_ss_ihock
	Lacrosse	sai_ss_lax
	Rugby	sai_ss_rugby
	Soccer	sai_ss_soc
	Swimming, Water Polo	sai_ss_wpolo
	Volleyball	sai_ss_vball
	Drama, Theater, Acting, Film	sai_ss_drama
	Competitive Games like Chess, Cards, or Darts	sai_ss_chess
Physical Non-social (17)	Ballet, Dance	sai_ss_dance
	Climbing	sai_ss_climb
	Gymnastics	sai_ss_gym
	Ice or Inline Skating	sai_ss_iskate
	Martial Arts	sai_ss_m_arts
	Skateboarding	sai_ss_skate
	Skiing, Snowboarding	sai_ss_sboard
	Surfing	sai_ss_surf
	Horseback Riding, Polo	sai_ss_polo
	Tennis	sai_ss_tennis
	Track, Running, Cross-country	sai_ss_run
	Wrestling, Mixed Martial Arts	sai_ss_mma
	Yoga, Tai Chi	sai_ss_yoga
	Musical Instrument	sai_ss_music
	Drawing, Painting, Graphic Art, Photography, Pottery, Sculpting	sai_ss_art
	Crafts like Knitting, Building Model Cars or Airplanes	sai_ss_crafts
	Hobbies like collecting stamps or coins	sai_ss_collect
Digital Social (3)	Text on a cell phone, tablet, or computer (weekday/weekend)	screen4_wkdy_y, screen10_wknd_y
	Visit social networking sites(weekday/weekend)	screen5_wkdy_y, screen11_wknd_y
	Video chat(weekday/weekend)	screen_wkdy_y, screen12_wknd_y
Digital Non-social (3)	Watch TV shows or movies(weekday/weekend)	screen1_wkdy_y, screen7_wknd_y
	Watch videos(weekday/weekend)	screen2_wkdy_y, screen8_wknd_y
	Play video games on a computer, console, phone or other device(weekday/weekend)	screen3_wkdy_y, screen9_wknd_y

Note: The data element names represent original variable names from two ABCD questionnaires. **Physical activities:** ABCD Parent Sports and Activities Involvement Questionnaire (SAIQ), detailed at https://nda.nih.gov/data-structure/abcd_spacss01 (baseline); https://nda.nih.gov/data-structure/abcd_lsssa01 (follow-up). **Digital activities:** ABCD Youth Screen Time Survey (STQ), detailed at https://nda.nih.gov/data-structure/abcd_stq01 (baseline and follow-up). Weekly engagement hours were calculated using parent-reported (*tspent*), (*perwk*), and (*nmonth*) from SAIQ for physical activities and combined weekday and weekend data from STQ for digital activities. For detailed method, see Supplementary Methods 1.

Supplementary Table 2. List of Investigated diagnostic items and groups

Supplementary Table 2 is provided in a separate Excel file (Sheet 1) due to length exceeding one page.

Description: Comprehensive list of investigated psychiatric diagnostic items and clinical subgroups, derived from the ABCD Parent Diagnostic Interview for DSM-5 Full (KSAD). Data element names correspond to original variable labels in the KSAD-5 instrument (NDA Structure: https://nda.nih.gov/data-structure/abcd_ksad01, baseline version). Full methodological details are provided in Supplementary Methods 2.

Supplementary Table 3. Description of Study Sites

Site ID	No. (%)	Site ID	No. (%)
site01	241(2.93%)	site12	385(4.68%)
site02	438(5.32%)	site13	488(5.93%)
site03	432(5.25%)	site14	464(5.64%)
site04	491(5.97%)	site15	258(3.13%)
site05	244(2.96%)	site16	810(9.84%)
site06	438(5.32%)	site17	404(4.91%)
site07	224(2.72%)	site18	275(3.34%)
site08	239(2.9%)	site19	371(4.51%)
site09	291(3.54%)	site20	523(6.35%)
site10	454(5.52%)	site21	422(5.13%)
site11	316(3.84%)	site22	22(0.27%)

Note: More information about Study Sites is available at the following link: <https://abcdstudy.org/study-sites/>.

Supplementary Table 4. *P* Values and FDR-Corrected *P* Values of Associations Between Weekly Engagement Duration Across Activity Categories and Mental Health Outcomes

Activity Type/Mental Health	Physical social		Physical non-social		Digital social		Digital non-social	
	<i>P</i> value	Corrected <i>P</i> value	<i>P</i> value	Corrected <i>P</i> value	<i>P</i> value	Corrected <i>P</i> value	<i>P</i> value	Corrected <i>P</i> value
Internalizing problems								
Anxious and depressed	0.004	0.009	<0.001	<0.001	0.932	0.932	0.253	0.300
Withdrawn and depressed	<0.001	<0.001	0.363	0.409	0.002	0.006	0.182	0.229
Somatic complaints	0.282	0.327	0.009	0.018	0.152	0.196	<0.001	0.001
Total score	0.001	0.002	0.001	0.002	0.634	0.648	0.021	0.036
Externalizing problems								
Rule-breaking behaviors	0.123	0.169	0.383	0.421	<0.001	<0.001	<0.001	<0.001
Aggressive behaviors	0.074	0.109	0.474	0.496	0.013	0.023	<0.001	<0.001
Total score	0.069	0.105	0.417	0.447	<0.001	0.001	<0.001	<0.001
Problem behaviors								
Social problems	<0.001	<0.001	0.059	0.093	0.022	0.038	<0.001	<0.001
Thought problems	0.005	0.011	<0.001	<0.001	0.129	0.172	<0.001	<0.001
Attention problems	<0.001	<0.001	0.230	0.281	0.112	0.159	<0.001	<0.001
Mental health problem total score	<0.001	0.002	0.004	0.009	0.030	0.049	<0.001	<0.001

Note: Results with $P < 0.05$ are highlighted in **bold**.

Supplementary Table 5. *P* Values and FDR-Corrected *P* Values of Associations Between the Weekly Engagement Duration Across Activity Categories (>0 Hours/Week) and Mental Health Outcomes (Sensitivity Analysis)

Activity Type/Mental Health	Physical social		Physical non-social		Digital social		Digital non-social	
	<i>P</i> value	Corrected <i>P</i> value	<i>P</i> value	Corrected <i>P</i> value	<i>P</i> value	Corrected <i>P</i> value	<i>P</i> value	Corrected <i>P</i> value
Internalizing problems								
Anxious and depressed	0.034	0.053	0.007	0.015	0.547	0.601	0.130	0.185
Withdrawn and depressed	<0.001	0.001	0.277	0.349	0.475	0.560	0.031	0.050
Somatic complaints	0.446	0.545	0.149	0.205	0.562	0.603	<0.001	<0.001
Total score	0.012	0.025	0.018	0.033	0.724	0.741	0.005	0.011
Externalizing problems								
Rule-breaking behaviors	0.987	0.987	0.065	0.099	<0.001	<0.001	<0.001	<0.001
Aggressive behaviors	0.545	0.601	0.484	0.560	<0.001	<0.001	<0.001	<0.001
Total score	0.652	0.683	0.270	0.349	<0.001	<0.001	<0.001	<0.001
Problem behaviors								
Social problems	<0.001	0.001	0.117	0.172	<0.001	0.001	<0.001	<0.001
Thought problems	0.028	0.047	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
Attention problems	<0.001	0.002	0.182	0.242	<0.001	<0.001	<0.001	<0.001
Mental health problem total score	0.023	0.041	0.015	0.029	<0.001	<0.001	<0.001	<0.001

Note: Results with $P < 0.05$ are highlighted in **bold**.

Supplementary Table 6. T-Test Results for Weekly Engagement in Activity Categories Across Psychiatric Groups and Control Groups

Supplementary Table 6 is provided in a separate Excel file (Sheet 2) due to length exceeding one page.

Description: Independent-samples t-tests results comparing weekly engagement in activity categories between psychiatric groups and control groups, with significant differences highlighted across behavioral domains (FDR-corrected $P < .05$).

Supplementary Table 7. T-Test Results for Weekly Engagement in Activity Categories Across Psychiatric Items and Control Groups

Supplementary Table 7 is provided in a separate Excel file (Sheet 3) due to length exceeding one page.

Description: Independent-samples t-tests results comparing weekly engagement in activity categories between psychiatric items and control groups, with significant differences highlighted across behavioral domains (FDR-corrected $P < .05$).

Supplementary Table 8. Effects from Brain Regions with Significant Gray Matter Volume Associations Across Activity Categories

Gray matter volume associations	Estimate (CI 95%)	T value	P value	FDR P value
Physical social				
right rostral anterior cingulate	0.0423 (0.0198, 0.0647)	3.69	< 0.001	0.014
right middle temporal	0.0380 (0.0171, 0.0589)	3.57	< 0.001	0.014
left superior parietal	0.0357 (0.0140, 0.0573)	3.22	0.001	0.021
right lateral orbitofrontal	0.0344 (0.0134, 0.0554)	3.21	0.001	0.021
left inferior parietal	0.0349 (0.0126, 0.0572)	3.06	0.002	0.028
right bankssts	0.0343 (0.0123, 0.0564)	3.05	0.002	0.028
left middle temporal	0.0327 (0.0115, 0.0539)	3.02	0.003	0.028
right rostral middle frontal	0.0320 (0.0108, 0.0531)	2.96	0.003	0.030
right pars opercularis	0.0326 (0.0103, 0.0549)	2.87	0.004	0.034
left lateral orbitofrontal	0.0307 (0.0094, 0.0521)	2.82	0.005	0.036
right inferior parietal	0.0305 (0.0093, 0.0517)	2.82	0.005	0.036
right pars triangularis	0.0317 (0.0093, 0.0540)	2.78	0.005	0.039
right superior parietal	0.0297 (0.0082, 0.0512)	2.70	0.007	0.043
Digital social				
left superior parietal	-0.0381 (-0.0592, -0.0170)	-3.55	< 0.001	0.014
right superior parietal	-0.0371 (-0.0580, -0.0162)	-3.48	0.001	0.014
right precentral	-0.0362 (-0.0568, -0.0155)	-3.43	0.001	0.014
left cuneus	-0.0297 (-0.0511, -0.0083)	-2.72	0.007	0.043
Digital non-social				
right inferior temporal	-0.0477 (-0.0689, -0.0266)	-4.43	< 0.001	0.001
left middle temporal	-0.0483 (-0.0697, -0.0268)	-4.41	< 0.001	0.001
right middle temporal	-0.0379 (-0.0591, -0.0168)	-3.52	< 0.001	0.014
right inferior parietal	-0.0378 (-0.0593, -0.0163)	-3.44	0.001	0.014
right fusiform	-0.0370 (-0.0581, -0.0159)	-3.44	0.001	0.014
left bankssts	-0.0396 (-0.0623, -0.0169)	-3.42	0.001	0.014
right rostral anterior cingulate	-0.0396 (-0.0624, -0.0169)	-3.42	0.001	0.014
left lateral occipital	-0.0355 (-0.0565, -0.0144)	-3.31	0.001	0.020
right bankssts	-0.0368 (-0.0592, -0.0145)	-3.23	0.001	0.021
left inferior temporal	-0.0353 (-0.0568, -0.0138)	-3.21	0.001	0.021
right precentral	-0.0346 (-0.0561, -0.0131)	-3.15	0.002	0.025
left precentral	-0.0340 (-0.0554, -0.0126)	-3.12	0.002	0.026
left inferior parietal	-0.0353 (-0.0579, -0.0127)	-3.06	0.002	0.028
right lateral occipital	-0.0319 (-0.0526, -0.0113)	-3.03	0.002	0.028
right postcentral	-0.0341 (-0.0562, -0.0120)	-3.02	0.003	0.028
right insula	-0.0323 (-0.0533, -0.0112)	-3.01	0.003	0.028
left insula	-0.0326 (-0.0541, -0.0112)	-2.98	0.003	0.029
left superior frontal	-0.0324 (-0.0539, -0.0109)	-2.95	0.003	0.030
left medial orbitofrontal	-0.0307 (-0.0515, -0.0100)	-2.91	0.004	0.033
left postcentral	-0.0321 (-0.0539, -0.0103)	-2.89	0.004	0.034
right medial orbitofrontal	-0.0321 (-0.0540, -0.0102)	-2.88	0.004	0.034
left lateral orbitofrontal	-0.0314 (-0.0531, -0.0098)	-2.85	0.004	0.035
right lateral orbitofrontal	-0.0309 (-0.0522, -0.0096)	-2.84	0.005	0.035
right paracentral	-0.0317 (-0.0542, -0.0091)	-2.75	0.006	0.042
left paracentral	-0.0313 (-0.0537, -0.0089)	-2.74	0.006	0.042
left cuneus	-0.0310 (-0.0534, -0.0087)	-2.72	0.006	0.043
left isthmus cingulate	-0.0296 (-0.0512, -0.0079)	-2.68	0.007	0.046

Supplementary Table 9. Correlations Between Activity Duration-Related Gray Matter Volume T-Maps and Neurosynth Terms

	Physical social	Physical non-social	Digital social	Digital non-social
Mental & Physical Health				
depression	-0.060	0.000	0.024	0.089
anxiety	-0.109	-0.060	0.082	0.143
psychosis	-0.004	-0.005	0.002	0.046
addiction	-0.080	-0.037	0.000	0.099
hyperactivity	-0.030	-0.008	0.027	0.074
impulsivity	0.001	-0.014	-0.001	0.028
fear	-0.098	-0.065	0.102	0.112
stress	-0.132	-0.014	0.034	0.157
distress	0.011	-0.007	-0.022	-0.007
mood	-0.023	-0.031	0.029	0.035
emotion	-0.056	-0.001	-0.005	0.113
valence	-0.039	0.000	-0.013	0.081
risk	-0.076	-0.029	0.029	0.120
trauma	-0.036	-0.013	0.021	0.061
pain	-0.186	-0.067	0.093	0.229
sleep	-0.111	-0.060	0.062	0.109
arousal	-0.053	-0.004	0.017	0.118
disability	0.011	0.003	-0.012	-0.036
Attention & Executive Function				
inhibition	0.009	0.006	-0.028	0.057
updating	0.061	-0.027	0.025	-0.053
maintenance	0.071	-0.022	-0.068	-0.062
detection	0.006	0.028	0.052	-0.071
monitoring	0.020	0.002	-0.090	0.032
focus	-0.012	0.007	-0.037	0.003
attention	0.109	0.033	0.017	-0.140
perception	0.020	-0.015	0.041	-0.103
Social Cognition & Communication				
face recognition	0.102	-0.119	0.012	-0.160
facial expression	-0.021	0.001	0.044	-0.017
mentalizing	0.085	0.069	-0.104	-0.081
empathy	-0.044	0.079	-0.053	0.067
communication	-0.001	0.050	-0.041	-0.007
interaction	0.027	-0.014	-0.036	0.004
discrimination	0.013	-0.029	0.033	-0.082
competition	0.028	-0.011	-0.013	-0.045
inference	0.051	0.092	-0.067	-0.013
judgment	0.076	0.098	-0.088	-0.090
intention	0.079	0.058	-0.043	-0.084
belief	0.003	0.046	-0.064	-0.018
interpersonal	0.003	0.054	-0.033	0.016
social interaction	0.016	0.012	-0.039	-0.014
social cognitive	0.042	0.050	-0.077	-0.071

Supplementary Table 10. Standardized Path Coefficients from CLPM Analysis Between Activity Engagement and Mental Health Outcomes

Supplementary Table 10 is provided in a separate Excel file (Sheet 4) due to length exceeding one page.

Description: Standardized path coefficients from cross-lagged panel model (CLPM) analyses testing bidirectional temporal associations between activity engagement and mental health outcomes.

Supplementary Table 11. *P* values and FDR-corrected *P* values from CLPM Analysis Between Activity Engagement and Mental Health Outcomes

Supplementary Table 11 is provided in a separate Excel file (Sheet 5) due to length exceeding one page.

Description: Raw and false discovery rate (FDR)-adjusted p-values from cross-lagged panel model (CLPM) analyses testing bidirectional associations between activity engagement and mental health outcomes, highlighting significant temporal associations after multiple comparisons adjustment (FDR-corrected $P < .05$).

Supplementary Table 12. Standardized Estimate effects and *P* values in Mediation Analysis

Independent / dependent variables	Total effect		Direct effect		Indirect effect		% Mediated
	Estimate (95% CI)	<i>P</i> value	Estimate (95% CI)	<i>P</i> value	Estimate (95% CI)	<i>P</i> value	Percentage
Physical social							
Withdrawn and depressed	-0.077 (-0.102, -0.053)	<0.001	-0.077 (-0.101, -0.052)	<0.001	-0.001 (-0.002, 0.001)	0.300	1.0%
Social problems	-0.056 (-0.081, -0.031)	<0.001	-0.054 (-0.079, -0.029)	<0.001	-0.002 (-0.004, -0.000)	0.004	3.8%
Digital social							
Rule-breaking behaviors	0.075 (0.045, 0.105)	<0.001	0.072 (0.042, 0.102)	<0.001	0.003 (0.001, 0.005)	<0.001	3.7%
Digital non-social							
Rule-breaking behaviors	0.084 (0.058, 0.110)	<0.001	0.080 (0.055, 0.106)	<0.001	0.004 (0.002, 0.006)	<0.001	4.7%
Social problems	0.050 (0.023, 0.078)	<0.001	0.048 (0.020, 0.076)	0.002	0.003 (0.000, 0.005)	0.006	5.0%
Thought problems	0.064 (0.037, 0.090)	<0.001	0.063 (0.036, 0.090)	<0.001	0.001 (-0.001, 0.002)	0.460	1.0%
Attention problems	0.087 (0.060, 0.115)	<0.001	0.083 (0.056, 0.111)	<0.001	0.004 (0.002, 0.006)	<0.001	4.5%
Mental health problem total score	0.072 (0.045, 0.099)	<0.001	0.069 (0.042, 0.096)	<0.001	0.003 (0.001, 0.005)	<0.001	4.2%

Note: Results with $P < .05$ are highlighted in **bold**.