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Longitudinal multimodal MRI and imaging genetics reveal functional and structural brain plasticity following social media exposure

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Abstract

This study aimed to investigate neuroimaging correlates of social media use and examine whether genetic factors contribute to interindividual variability in these correlates. Seventy-seven participants were enrolled and underwent multimodal MRI, longitudinal assessments, and genotype sampling. Multimodal MRI was used to evaluate cerebral blood flow (CBF), functional connectivity (FC), and white matter integrity. The longitudinal protocol included short-term and long-term social media tasks. APOE and BDNF genotypes were collected and incorporated into linear mixed-effects models. A control group was also included, in which participants read science fiction on their smartphones. Short-term social media use was associated with alterations in CBF and FC, with the magnitude of these changes differing according to participants' habitual levels of social media use. Long-term social media use was associated with reduced white matter integrity, whereas no comparable changes were observed in the science-fiction reading group. In addition, changes in functional network efficiency following short-term social media use were associated with subsequent changes in structural network efficiency observed after long-term use. Furthermore, interindividual variability in CBF and white matter integrity changes was associated with APOE and BDNF genotypes, respectively. Short-term social media use was associated with changes in CBF and FC, whereas long-term use was associated with reduced white matter integrity. Functional changes observed following short-term use were related to structural changes observed after long-term use. Variability in short- and long-term neuroimaging responses associated with social media use was related to genetic background.

Trial registration

This study has been registered in ClinicalTrials.gov (NCT05097807).

1. Introduction

Daily social media use has been associated with alterations in attention, memory performance, and learning-related processes, as well as higher levels of depressive symptoms and paranoid ideation (Baumgartner, van der Schuur, Lemmens, & te Poel; Silk et al., 2014; Storm & Stone, 2015; Ward, 2013). Despite growing interest, direct neurobiological evidence remains limited (Loh & Kanai, 2016; Mills, 2014). A major limitation of previous studies is their reliance on cross-sectional designs, which primarily identify associations and provide limited insight into the temporal dynamics of brain plasticity (Choi et al., 2021; Firth et al., 2019; Lamblin, Murawski, Whittle, & Fornito, 2017; Loh & Kanai, 2016; Moisala et al., 2016; Uncapher et al., 2017; Uncapher & Wagner, 2018).

Longitudinal studies have enhanced our understanding of brain plasticity by revealing functional and structural changes in the brain following behavioral interventions (Farrington, 1991; Kühn, Gleich, Lorenz, Lindenberger, & Gallinat, 2014; Kühn et al., 2019; Takeuchi et al., 2016; West et al., 2018). Similar longitudinal approaches may help characterize neural adaptations associated with social media use. However, prior research has generally examined either short-term functional changes (Moisala et al., 2016) or long-term structural alterations (Achterberg et al., 2022), without integrating both timescales.

Because transient functional adaptations are thought to contribute to subsequent structural remodeling (Boyke, Driemeyer, Gaser, Büchel, & May, 2008; Sagi et al., 2012; Sampaio-Baptista et al., 2014; Wang et al., 2014), combining short-term and long-term assessments within a unified longitudinal framework may offer a more comprehensive view of brain plasticity patterns associated with social media engagement.

Multimodal magnetic resonance imaging (MRI) provides complementary information on brain structure and function. Diffusion tensor imaging (DTI) characterizes white matter microstructure (Perlini, Bellani, & Brambilla, 2012), arterial spin labeling (ASL) quantifies cerebral perfusion (Hernandez-Garcia, Lahiri, & Schollenberger, 2019), and blood oxygen level-dependent (BOLD) imaging assesses functional activity and connectivity (Poldrack, 2012). Together, these modalities enable comprehensive assessment of functional and structural brain changes associated with social media use. However, considerable interindividual variability exists in neural plasticity, highlighting the need for imaging genetics approaches to investigate the biological basis of these differences.

Imaging genetics integrates genetic and neuroimaging data to explore sources of variability in brain plasticity (Jickling et al., 2012; Mufford et al., 2017). The apolipoprotein E (APOE) gene, which supports cerebrovascular integrity and contributes to cerebral blood flow regulation (Hays et al., 2019; Scarmeas, Habeck, Stern, & Anderson, 2003; Tiraboschi et al., 2004; Wierenga et al., 2013; Yip et al., 2005), could be examined for its association with CBF changes following short-term social media exposure. Similarly, the brain-derived neurotrophic factor (BDNF) gene, critical for neuronal development, maintenance, and structural plasticity (Bramham & Messaoudi, 2005; Chao, Rajagopal, & Lee, 2006; Park & Poo, 2013), could be assessed in relation to white matter microstructural changes following prolonged social media use. Together, these analyses provide a framework for linking genetic variation to individual differences in neural responses associated with social media engagement.

In the present study, we combined a longitudinal design, multimodal MRI, and genetic information to investigate: (1) neuroimaging changes associated with short-term social media use; (2) neuroimaging changes associated with long-term social media use; (3) the relationship between short-term functional alterations and long-term structural changes; and (4) the contribution of APOE and BDNF genotypes to interindividual variability in these neuroimaging measures.

2. Methods

2.1 Subject recruitment

Participants were recruited from undergraduate students at our university through online advertisements. The target sample size was determined with reference to previous longitudinal neuroimaging studies investigating behavioral interventions, particularly video game training (Iyadurai et al., 2018; Kühn & Gallinat, 2014; Kühn et al., 2014; Kühn et al., 2019; West et al., 2018), which typically enrolled 48-90 participants. To account for potential exclusions and attrition during longitudinal follow-up, approximately 90 participants were initially targeted for recruitment.

A total of 85 individuals responded to the advertisement and underwent eligibility screening. Participants with obesity (BMI > 30), current smoking, regular alcohol consumption, left-handedness, a history of traumatic brain injury, or a family history of psychiatric disorders were excluded because these factors have been associated with neuroimaging measures (Nutt et al., 2021; Potvin, Tikàsz, Dinh-Williams, Bourque, & Mendrek, 2015; Syan et al., 2021). Following screening, 8 participants were excluded due to obesity, smoking or alcohol use, and left-handedness. The remaining 77 eligible participants were enrolled in the study (**Fig. 1**).

The rationale for participant grouping and the reliability of this recruitment strategy have been described previously (Hu et al., 2022). Briefly, the 35 participants reporting the highest daily social media use were assigned to the heavy social media (HSM) group. The remaining 42 participants were randomly allocated to either the light social media (LSM) group or the science fiction (SF) group, with 21 participants in each group. Participants in the LSM group completed the social media protocol, while those in the SF group engaged in smartphone-based science-fiction reading, serving as an active control condition.

This study was approved by the Institutional Review Board of Tangdu Hospital and conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent prior to enrollment.

2.2 Study design

2.2.1 Social media task

Microblog (Weibo.com) is a widely used social media application in China, has features broadly similar to Twitter or Facebook. To minimize variability introduced by different platforms, browsing Microblog on a smartphone was designated as the social media task. For the short-term task, participants engaged in this activity for two hours in an independent, quiet room, corresponding to the average daily usage of the HSM group. For the long-term task, participants completed the same activity for two hours per day over four consecutive weeks.

2.2.2 Science fiction task

To control for the potential effects of reading on a smartphone independent of social media use, the 21 participants in the SF group served as an active control. They completed short- and long-term reading tasks using a science fiction text (The Three-Body Problem by Ci-Xin Liu) on their smartphones, matching the duration and schedule of the social media tasks.

2.2.3 Overall arrangement

The experiment was designed as follows (**Fig. 1**): (1) all subjects received genotype sampling and multimodal MRI scanning on their first visit; (2) the subjects performed a short-term task; (3) the subjects then received a second multimodal MRI scanning immediately after the short-term task; (4) the

LSM group and SF group performed the long-term task; and (5) on the day after the long-term task, the subjects received another multimodal MRI scanning.

2.3 Demographic information

A total of 175 undergraduate students completed a questionnaire assessing demographic characteristics and smartphone use patterns (**Supplementary Table S1**). Demographic variables included age, sex, height, weight, smoking status, alcohol consumption, color blindness, handedness. Smartphone usage data were obtained from the built-in screen-time monitoring function of participants' smartphones, including average daily time spent on social media, gaming, chatting, video streaming, and other activities during the previous week. To standardize the assessment of social media exposure, usage time was calculated based on the three most popular social media applications in China (Microblog, TikTok, and Kwai).

2.4 Genotype

Genomic DNA was extracted from 3 mL of peripheral whole blood using the Illumina Infinium HTS Assay. APOE (rs7412 and rs429358) and BDNF (rs6265) genotypes were determined for each participant. Among the 77 participants included in the study, 70 underwent genotyping, while seven declined blood sampling. The final genotyped sample consisted of 34 participants in the HSM group, 18 in the LSM group, and 18 in the SF group.

2.5 Imaging data acquisition and analysis

Multimodal neuroimaging data acquisition and analysis were consistent with standard procedures (Esteban et al., 2019; Smith et al., 2006), please see **Supplementary note and Supplementary Fig. S1** for details.

2.5.1 Cerebral perfusion

The CBF images were obtained from the ASL data. Then, it was processed in SPM12 software running on the MATLAB 2014a platform. The preprocessing procedure of CBF images included normalization to the MNI space (resampled to 2×2×2 mm^3), z-score transformation, and smoothness.

2.5.2 White matter integrity

We used the FSL software (https://FSL.FMRIB.ox.ac.UK/FSL/fslwiki) to process DTI data, and the fractional anisotropy (FA) and mean diffusion (MD) maps were derived to reflect the integrity of white matter (WM). The FA and MD maps were then fed into the tract-based spatial statistics (TBSS) pipeline (Smith et al., 2006). In TBSS, FA and MD images of all subjects were nonlinearly registered to the standard template and the standard MNI space (resampled to 2×2×2 mm^3).

2.5.3 Functional and structural network efficiency

BOLD images were processed in SPM12 software, and the procedures included removing the first 10 time points, slice time correction, head motion correction, excluding scans with excessive head motion (translation > 2.0 mm or rotation > 2°), normalization to the MNI space, smoothness, and nuisance signal regression. After that, functional connectivity (FC) matrices were obtained with a 116-region anatomical automatic labeling (AAL-116) atlas. The structural connectivity (SC) matrices were obtained from the DTI data with probabilistic tractography and the AAL-116 atlas by the Diffusion Toolbox in FSL. Two of the most commonly used graph-theory characteristics, namely global efficiency and local efficiency, were calculated from the FC and SC matrices, separately.

2.6 Statistical analysis

2.6.1 Demographic information

Continuous variables were compared using the independent-samples *t*-test or the Mann–Whitney *U* test, as appropriate. Categorical variables were compared using the chi-square test or Fisher's exact test.

2.6.2 Impact of short-term task on CBF

Voxel-wise paired t-tests were performed to assess changes in CBF before and after the short-term task. Multiple comparisons were corrected using the false discovery rate (FDR) method, with statistical significance set at $P < 0.05$.

2.6.3 Impact of short-term task on functional network

Changes in FC following the short-term task were assessed using paired *t*-tests combined with network-based statistics (NBS). Statistical significance was determined using permutation testing (5,000 permutations), with a corrected threshold of $P < 0.05$. For network-level interpretation, brain regions were classified into nine large-scale functional networks according to the atlas proposed by Schaefer et al. (Schaefer et al., 2018) (**Supplementary Fig. S2**).

2.6.4 Impact of long-term task on WM integrity

FA and MD maps were analyzed using the TBSS pipeline (Smith et al., 2006) (see **Supplementary note**). Statistical significance was assessed using permutation testing (5,000 permutations) combined with threshold-free cluster enhancement (TFCE), with $P < 0.05$ considered significant.

2.6.5 Relationship between short-term functional changes and long-term structural changes

The relationship between functional and structural changes was evaluated using two widely adopted graph-theoretical measures: global efficiency and local efficiency. Changes in functional efficiency following the short-term task were correlated with changes in structural efficiency following the long-term task using Spearman's rank correlation coefficient because the data did not satisfy the assumption of normality. Differences between correlation coefficients were further evaluated using Fisher's *Z* test implemented in the Cocor software package (Diedenhofen & Musch, 2015).

2.6.6 Genetic prediction of neuroimaging plasticity

Associations between genetic variation and neuroimaging plasticity were examined using linear mixed-effects models. Post-task mean cortical CBF was modeled as a function of APOE genotype (rs429358 and rs7412), baseline CBF, age, and BMI, with group included as a random effect. Post-task mean FA or MD values were modeled as a function of BDNF genotype (rs6265), baseline FA or MD values, age, and BMI, with group included as a random effect. The models were specified as follows: (1) CBF after task ~ rs429358 + rs7412 + baseline CBF + age + BMI + (1|group); (2) FA (or MD) after task ~ rs6265 + baseline FA (or MD) + age + BMI + (1|group).

3. Results

3.1 Demographic information

The statistics of demographic information, habits of smartphone use, and genotypic information are listed in **Table 1**. demographic characteristics, including age, height, weight, and BMI, did not differ significantly among the HSM, LSM, and SF groups (all $P > 0.05$). The HSM group spent significantly more time on social media (1.96 [1.71–2.20] h) than the LSM (0.40 [0.31–0.50] h) and SF groups (0.35 [0.25–0.46] h, $P < 0.001$), whereas time spent on chatting, gaming, film/TV viewing, and other activities was similar across groups (all $P > 0.05$). Besides, APOE and BDNF genotype distributions did not differ significantly among groups (all $P > 0.05$).

3.2 Short-term reading tasks were associated with CBF redistribution

Following the short-term social media task, participants in the HSM group exhibited widespread CBF changes (**Fig. 2a**), including increased perfusion in the visual cortex, right middle frontal gyrus (MFG), thalamus, and pons, together with decreased CBF in the left frontal lobe, bilateral medial prefrontal cortex (mPFC), bilateral temporal lobes, and right angular gyrus. In the LSM group (**Fig. 2b**), increased CBF was observed in the right MFG, whereas decreased CBF was detected in the bilateral superior temporal gyrus and bilateral mPFC. Following the short-term science-fiction reading task, participants in the SF group (**Fig. 2c**) showed increased CBF in the right MFG and left supramarginal gyrus, accompanied by decreased CBF in the left middle temporal gyrus, left insula, and left superior frontal gyrus. Detailed information on significant clusters, including cluster size, MNI coordinates, and peak t values, is provided in **Supplementary Table S2**. Overall, the HSM group exhibited substantially more extensive CBF redistribution than the LSM and SF groups.

3.3 Short-term social media use was associated with functional network changes

After short-term social media use, a resting-state subnetwork in the HSM group (**Fig. 2d**) showed a significant decrease ($P = 0.024$), primarily between the visual network (VN) and limbic system, as well as between the default mode network (DMN) and cerebellum (**Fig. 2e**). In contrast, a resting-state subnetwork in the LSM group exhibited a widespread increase across nearly the entire brain, except for

the VN (P = 0.028, **Fig. 2d and 2e**). No significant changes in functional networks were observed following science fiction reading.

3.4 Long-term social media use was associated with decreased integrity of WM tracts

Long-term social media use was associated with impaired WM integrity, as evidenced by significantly decreased FA (**Fig. 2f,** P_{peak} = 0.038) and increased MD (**Fig. 2g,** P_{peak} = 0.027). These alterations were primarily observed in the corpus callosum, bilateral corona radiata, bilateral superior longitudinal fasciculus, bilateral posterior thalamic radiation, optic radiation, and sensorimotor cortex. In contrast, no significant changes in either FA (P_{peak} = 0.289) or MD (P_{peak} = 0.365) were detected following the long-term science fiction reading task.

3.5 Functional efficiency changes after the short-term social media use were related to structural efficiency changes after long-term social media use

As shown in **Fig. 3**, changes in functional efficiency following short-term social media use were negatively associated with structural efficiency changes after long-term social media use (global efficiency: Spearman's ρ = -0.230, P = 0.358; local efficiency: Spearman's ρ = -0.517, P = 0.028). In contrast, after science fiction reading, the correlation was positive (global efficiency: Spearman's ρ = 0.565, P = 0.008; local efficiency: Spearman's ρ = 0.359, P = 0.110). Moreover, both correlations in the SF group were significantly stronger than those in the LSM group (global efficiency: P = 0.006; local efficiency: P = 0.003).

3.6 APOE and BDNF predicted the neuroimaging plasticity after tasks

According to **Table 2**, the APOE genotype (rs7412) significantly predicted mean CBF changes following the short-term task (F = 5.017, P = 0.036). After the long-term task, the BDNF genotype (rs6265) significantly predicted mean FA changes (F = 3.987, P = 0.034) and showed a trend toward predicting mean MD changes (F = 3.378, P = 0.053). To further examine the specificity of these associations, we also tested whether APOE genotype predicted FA and MD changes and whether BDNF genotype predicted CBF changes. None of these analyses reached statistical significance (all P > 0.4, **Table 2**), supporting the specificity and robustness of the observed genotype-imaging associations.

4. Discussion

Using a longitudinal multimodal MRI and imaging genetics framework, we found that short-term social media exposure was associated with changes in cerebral blood flow and functional connectivity, whereas long-term exposure was associated with reduced white matter integrity. Moreover, short-term functional changes were related to long-term structural alterations, and individual variability in these neuroimaging responses was partly explained by APOE and BDNF genotypes.

After short-term social media use, heavy social media users exhibited activation in the visual cortex, which may partly explain why individuals using social media before sleep often experience insomnia and increased dreaming (LeBourgeois et al., 2017; Levenson, Shensa, Sidani, Colditz, & Primack, 2016). Consistent with this, Sherman et al. (Sherman, Payton, Hernandez, Greenfield, & Dapretto, 2016) reported visual cortex activation when participants viewed photos with many “likes” on social media. Additionally, the right MFG was activated, overlapping with findings by Moisala et al. (Moisala et al., 2016), who associated this region with media multitasking scores and susceptibility to distraction. Notably, similar MFG changes were also observed in the SF group, suggesting a potential relation to screen-based reading in general. CBF was decreased in the medial prefrontal cortex, temporal pole, and angular gyrus, key nodes of the default mode network (Raichle, 2015) that are typically deactivated during tasks. Moreover, decreased CBF was observed in the dorsolateral prefrontal cortex, a region critical for decision making (Greene, Sommerville, Nystrom, Darley, & Cohen, 2001) and working memory (Barbey, Koenigs, & Grafman, 2013), indicating suppression of these cognitive functions during social media use.

Long-term social media use was associated with impaired WM integrity, consistent with previous findings (He, Turel, & Bechara, 2018; Hutton, Dudley, Horowitz-Kraus, DeWitt, & Holland, 2020). WM organization and myelination are highly sensitive to environmental factors such as music training, reading, and physical activity (Forbes & Gallo, 2017). Specifically, long-term social media exposure led to reduced integrity in the corpus callosum, corona radiata, superior longitudinal fasciculus, posterior thalamic radiation, optic radiation, and sensorimotor cortex. Prior studies have reported deleterious effects of internet addiction on the corpus callosum (Lin et al., 2012), which may further compromise decision-making abilities (Olson et al., 2009). The superior and inferior longitudinal fasciculi connect visual cortices to parietal and frontal regions, supporting social-semantic processing and memory formation. Consequently, deficits in these tracts have been linked to impaired working memory, language deficits, and schizophrenia (Karlsgodt et al., 2008; Romeo et al., 2018).

Genotype has been previously linked to baseline brain MRI signals (Wen, Goyal, Astafiev, Raichle, & Yablonskiy, 2018), fMRI patterns (Zhong et al., 2021), and DTI metrics (Zhao et al., 2021), and has been used to predict disease diagnosis and severity (Stenton, Zou, Cheng, Prokisch, & Fang, 2021; Wiberg et al., 2019). Prior studies utilized genetic information at the single-gene (Hiatt et al., 2019), polygenic (Cao, Zhou, & Cannon, 2021), and genome-wide association study (GWAS) levels (Elliott et al., 2018). To our knowledge, this study is the first to leverage genotypes to predict neuroimaging plasticity in the context of social media use, providing a potential avenue to understand individual differences in susceptibility and to identify those more vulnerable to social media effects.

Several limitations should be noted. First, the 4-week reading task may not have been sufficient to fully capture the neural effects of social media, although prior studies have shown that this duration is adequate for detecting structural brain changes (Wang et al., 2014). Second, our sample size, particularly in the longitudinal component, was relatively small, and future studies should include more participants to improve reliability. Third, due to a highly imbalanced sex ratio, only male subjects were included to

minimize bias. This was a difficult decision, as females typically engage more with social media than males (Spiller, Ackerman, Spiller, & Casavant, 2019).

5. Conclusion

Short-term social media use was associated with changes in CBF and FC, whereas long-term use was associated with reduced white matter integrity. Functional changes observed following short-term use were related to structural changes observed after long-term use. Variability in short- and long-term neuroimaging responses associated with social media use was related to genetic background.

Abbreviations

APOE: apolipoprotein E; ASL: artery spin labeling; BDNF: brain-derived neurotrophic factor; BOLD: blood oxygen level dependent; CBF: cerebral blood flow; DMN default mode network; DTI: diffusion tensor imaging; FA: fractional anisotropy; FC: functional connectivity; HSM: heavy social media user group; LSM: light social media group; MD: mean diffusion; MFG: middle frontal gyrus; mPFC: medial prefrontal cortex; SC: structural network; SF: science fiction group; TBSS: tract-based spatial statistics; T1WI: T1 weighted imaging; WM: white matter; VN: visual network;

Declarations

Acknowledgments

Authors' contribution statements

T.X.Z. and B.H., Conceptualization; T.X.Z., Formal analysis and Visualization; B.H. and Y.L.C., Methodology; B.H., Investigation, Project administration, and Supervision; T.X.Z., Writing – original draft; B.H. and Y.L.C., Writing – review & editing. All authors have read and agreed to the published version of the manuscript.

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Compliance with Ethical Standards

This study was approved by the Institutional Review Board of Tangdu Hospital and conducted in accordance with the Declaration of Helsinki.

Consent to participate

All participants provided written informed consent prior to enrollment.

Consent for publication

Not applicable.

Conflict of Interest

The authors declare that they have no competing interests. All participants provided written informed consent.

Availability of data and material

All data are available on https://www.nitrc.org/projects/socialbrain_22/

Code availability

Not applicable.

References

1. Achterberg, M., Becht, A., van der Cruijsen, R., van de Groep, I. H., Spaans, J. P., Klapwijk, E., & Crone, E. A. (2022). Longitudinal associations between social media use, mental well-being and structural brain development across adolescence. *Dev Cogn Neurosci, 54*, 101088. doi:10.1016/j.dcn.2022.101088
2. Barbey, A. K., Koenigs, M., & Grafman, J. (2013). Dorsolateral prefrontal contributions to human working memory. *Cortex, 49*(5), 1195-1205. doi:10.1016/j.cortex.2012.05.022
3. Baumgartner, S. E., van der Schuur, W. A., Lemmens, J. S., & te Poel, F. The Relationship Between Media Multitasking and Attention Problems in Adolescents: Results of Two Longitudinal Studies. *Human Communication Research*.
4. Boyke, J., Driemeyer, J., Gaser, C., Büchel, C., & May, A. (2008). Training-induced brain structure changes in the elderly. *J Neurosci, 28*(28), 7031-7035. doi:10.1523/jneurosci.0742-08.2008
5. Bramham, C. R., & Messaoudi, E. (2005). BDNF function in adult synaptic plasticity: the synaptic consolidation hypothesis. *Prog Neurobiol, 76*(2), 99-125. doi:10.1016/j.pneurobio.2005.06.003
6. Cao, H., Zhou, H., & Cannon, T. D. (2021). Functional connectome-wide associations of schizophrenia polygenic risk. *Mol Psychiatry, 26*(6), 2553-2561. doi:10.1038/s41380-020-0699-3
7. Chao, M. V., Rajagopal, R., & Lee, F. S. (2006). Neurotrophin signalling in health and disease. *Clin Sci (Lond), 110*(2), 167-173. doi:10.1042/cs20050163
8. Choi, J., Cho, H., Choi, J. S., Choi, I. Y., Chun, J. W., & Kim, D. J. (2021). The neural basis underlying impaired attentional control in problematic smartphone users. *Transl Psychiatry, 11*(1), 129.

doi:10.1038/s41398-021-01246-5

9. Diedenhofen, B., & Musch, J. (2015). cocor: a comprehensive solution for the statistical comparison of correlations. *PLoS One, 10*(3), e0121945. doi:10.1371/journal.pone.0121945
10. Elliott, L. T., Sharp, K., Alfaro-Almagro, F., Shi, S., Miller, K. L., Douaud, G., . . . Smith, S. M. (2018). Genome-wide association studies of brain imaging phenotypes in UK Biobank. *Nature, 562*(7726), 210-216. doi:10.1038/s41586-018-0571-7
11. Esteban, O., Markiewicz, C. J., Blair, R. W., Moodie, C. A., Isik, A. I., Erramuzpe, A., . . . Gorgolewski, K. J. (2019). fMRIPrep: a robust preprocessing pipeline for functional MRI. *Nat Methods, 16*(1), 111-116. doi:10.1038/s41592-018-0235-4
12. Farrington, D. P. (1991). Longitudinal research strategies: advantages, problems, and prospects. *J Am Acad Child Adolesc Psychiatry, 30*(3), 369-374. doi:10.1097/00004583-199105000-00003
13. Firth, J., Torous, J., Stubbs, B., Firth, J. A., Steiner, G. Z., Smith, L., . . . Sarris, J. (2019). The "online brain": how the Internet may be changing our cognition. *World Psychiatry, 18*(2), 119-129. doi:10.1002/wps.20617
14. Forbes, T. A., & Gallo, V. (2017). All Wrapped Up: Environmental Effects on Myelination. *Trends Neurosci, 40*(9), 572-587. doi:10.1016/j.tins.2017.06.009
15. Greene, J. D., Sommerville, R. B., Nystrom, L. E., Darley, J. M., & Cohen, J. D. (2001). An fMRI investigation of emotional engagement in moral judgment. *Science, 293*(5537), 2105-2108. doi:10.1126/science.1062872
16. Hays, C. C., Zlatar, Z. Z., Meloy, M. J., Bondi, M. W., Gilbert, P. E., Liu, T. T., . . . Wierenga, C. E. (2019). APOE modifies the interaction of entorhinal cerebral blood flow and cortical thickness on memory function in cognitively normal older adults. *Neuroimage, 202*, 116162. doi:10.1016/j.neuroimage.2019.116162
17. He, Q., Turel, O., & Bechara, A. (2018). Association of excessive social media use with abnormal white matter integrity of the corpus callosum. *Psychiatry Res Neuroimaging, 278*, 42-47. doi:10.1016/j.pscychresns.2018.06.008
18. Hernandez-Garcia, L., Lahiri, A., & Schollenberger, J. (2019). Recent progress in ASL. *Neuroimage, 187*, 3-16. doi:10.1016/j.neuroimage.2017.12.095
19. Hiatt, S. M., Thompson, M. L., Prokop, J. W., Lawlor, J. M. J., Gray, D. E., Bebin, E. M., . . . Cooper, G. M. (2019). Deleterious Variation in BRSK2 Associates with a Neurodevelopmental Disorder. *Am J Hum Genet, 104*(4), 701-708. doi:10.1016/j.ajhg.2019.02.002
20. Hu, B., Yu, Y., Yan, L. F., Qi, G. Q., Wu, D., Li, Y. T., . . . Wang, W. (2022). Intersubject correlation analysis reveals the plasticity of cerebral functional connectivity in the long-term use of social media. *Hum Brain Mapp, 43*(7), 2262-2275. doi:10.1002/hbm.25786
21. Hutton, J. S., Dudley, J., Horowitz-Kraus, T., DeWitt, T., & Holland, S. K. (2020). Associations Between Screen-Based Media Use and Brain White Matter Integrity in Preschool-Aged Children. *JAMA Pediatr, 174*(1), e193869. doi:10.1001/jamapediatrics.2019.3869

22. Iyadurai, L., Blackwell, S. E., Meiser-Stedman, R., Watson, P. C., Bonsall, M. B., Geddes, J. R., . . . Holmes, E. A. (2018). Preventing intrusive memories after trauma via a brief intervention involving Tetris computer game play in the emergency department: a proof-of-concept randomized controlled trial. *Mol Psychiatry, 23*(3), 674-682. doi:10.1038/mp.2017.23
23. Jickling, G. C., Stamova, B., Ander, B. P., Zhan, X., Liu, D., Sison, S. M., . . . Sharp, F. R. (2012). Prediction of cardioembolic, arterial, and lacunar causes of cryptogenic stroke by gene expression and infarct location. *Stroke, 43*(8), 2036-2041. doi:10.1161/strokeaha.111.648725
24. Karlsgodt, K. H., van Erp, T. G., Poldrack, R. A., Bearden, C. E., Nuechterlein, K. H., & Cannon, T. D. (2008). Diffusion tensor imaging of the superior longitudinal fasciculus and working memory in recent-onset schizophrenia. *Biol Psychiatry, 63*(5), 512-518. doi:10.1016/j.biopsych.2007.06.017
25. Kühn, S., & Gallinat, J. (2014). Amount of lifetime video gaming is positively associated with entorhinal, hippocampal and occipital volume. *Mol Psychiatry, 19*(7), 842-847. doi:10.1038/mp.2013.100
26. Kühn, S., Gleich, T., Lorenz, R. C., Lindenberger, U., & Gallinat, J. (2014). Playing Super Mario induces structural brain plasticity: gray matter changes resulting from training with a commercial video game. *Mol Psychiatry, 19*(2), 265-271. doi:10.1038/mp.2013.120
27. Kühn, S., Kugler, D. T., Schmalen, K., Weichenberger, M., Witt, C., & Gallinat, J. (2019). Does playing violent video games cause aggression? A longitudinal intervention study. *Mol Psychiatry, 24*(8), 1220-1234. doi:10.1038/s41380-018-0031-7
28. Lamblin, M., Murawski, C., Whittle, S., & Fornito, A. (2017). Social connectedness, mental health and the adolescent brain. *Neurosci Biobehav Rev, 80*, 57-68. doi:10.1016/j.neubiorev.2017.05.010
29. LeBourgeois, M. K., Hale, L., Chang, A. M., Akacem, L. D., Montgomery-Downs, H. E., & Buxton, O. M. (2017). Digital Media and Sleep in Childhood and Adolescence. *Pediatrics, 140*(Suppl 2), S92-s96. doi:10.1542/peds.2016-1758J
30. Levenson, J. C., Shensa, A., Sidani, J. E., Colditz, J. B., & Primack, B. A. (2016). The association between social media use and sleep disturbance among young adults. *Prev Med, 85*, 36-41. doi:10.1016/j.ypmed.2016.01.001
31. Lin, F., Zhou, Y., Du, Y., Qin, L., Zhao, Z., Xu, J., & Lei, H. (2012). Abnormal white matter integrity in adolescents with internet addiction disorder: a tract-based spatial statistics study. *PLoS One, 7*(1), e30253. doi:10.1371/journal.pone.0030253
32. Loh, K. K., & Kanai, R. (2016). How Has the Internet Reshaped Human Cognition? *Neuroscientist, 22*(5), 506-520. doi:10.1177/1073858415595005
33. Mills, K. L. (2014). Effects of Internet use on the adolescent brain: despite popular claims, experimental evidence remains scarce. *Trends Cogn Sci, 18*(8), 385-387. doi:10.1016/j.tics.2014.04.011
34. Moisala, M., Salmela, V., Hietajärvi, L., Salo, E., Carlson, S., Salonen, O., . . . Alho, K. (2016). Media multitasking is associated with distractibility and increased prefrontal activity in adolescents and young adults. *Neuroimage, 134*, 113-121. doi:10.1016/j.neuroimage.2016.04.011

35. Mufford, M. S., Stein, D. J., Dalvie, S., Groenewold, N. A., Thompson, P. M., & Jahanshad, N. (2017). Neuroimaging genomics in psychiatry-a translational approach. *Genome Med, 9*(1), 102. doi:10.1186/s13073-017-0496-z

36. Nutt, D., Hayes, A., Fonville, L., Zafar, R., Palmer, E. O. C., Paterson, L., & Lingford-Hughes, A. (2021). Alcohol and the Brain. *Nutrients, 13*(11). doi:10.3390/nu13113938

37. Olson, E. A., Collins, P. F., Hooper, C. J., Muetzel, R., Lim, K. O., & Luciana, M. (2009). White matter integrity predicts delay discounting behavior in 9- to 23-year-olds: a diffusion tensor imaging study. *J Cogn Neurosci, 21*(7), 1406-1421. doi:10.1162/jocn.2009.21107

38. Park, H., & Poo, M. M. (2013). Neurotrophin regulation of neural circuit development and function. *Nat Rev Neurosci, 14*(1), 7-23. doi:10.1038/nrn3379

39. Perlini, C., Bellani, M., & Brambilla, P. (2012). Structural imaging techniques in schizophrenia. *Acta Psychiatr Scand, 126*(4), 235-242. doi:10.1111/j.1600-0447.2012.01868.x

40. Poldrack, R. A. (2012). The future of fMRI in cognitive neuroscience. *Neuroimage, 62*(2), 1216-1220. doi:10.1016/j.neuroimage.2011.08.007

41. Potvin, S., Tikàsz, A., Dinh-Williams, L. L., Bourque, J., & Mendrek, A. (2015). Cigarette Cravings, Impulsivity, and the Brain. *Front Psychiatry, 6*, 125. doi:10.3389/fpsyt.2015.00125

42. Raichle, M. E. (2015). The brain's default mode network. *Annu Rev Neurosci, 38*, 433-447. doi:10.1146/annurev-neuro-071013-014030

43. Romeo, R. R., Segaran, J., Leonard, J. A., Robinson, S. T., West, M. R., Mackey, A. P., . . . Gabrieli, J. D. E. (2018). Language Exposure Relates to Structural Neural Connectivity in Childhood. *J Neurosci, 38*(36), 7870-7877. doi:10.1523/jneurosci.0484-18.2018

44. Sagi, Y., Tavor, I., Hofstetter, S., Tzur-Moryosef, S., Blumenfeld-Katzir, T., & Assaf, Y. (2012). Learning in the fast lane: new insights into neuroplasticity. *Neuron, 73*(6), 1195-1203. doi:10.1016/j.neuron.2012.01.025

45. Sampaio-Baptista, C., Scholz, J., Jenkinson, M., Thomas, A. G., Filippini, N., Smit, G., . . . Johansen-Berg, H. (2014). Gray matter volume is associated with rate of subsequent skill learning after a long term training intervention. *Neuroimage, 96*, 158-166. doi:10.1016/j.neuroimage.2014.03.056

46. Scarmeas, N., Habeck, C. G., Stern, Y., & Anderson, K. E. (2003). APOE genotype and cerebral blood flow in healthy young individuals. *Jama, 290*(12), 1581-1582. doi:10.1001/jama.290.12.1581

47. Schaefer, A., Kong, R., Gordon, E. M., Laumann, T. O., Zuo, X. N., Holmes, A. J., . . . Yeo, B. T. T. (2018). Local-Global Parcellation of the Human Cerebral Cortex from Intrinsic Functional Connectivity MRI. *Cereb Cortex, 28*(9), 3095-3114. doi:10.1093/cercor/bhx179

48. Sherman, L. E., Payton, A. A., Hernandez, L. M., Greenfield, P. M., & Dapretto, M. (2016). The Power of the Like in Adolescence: Effects of Peer Influence on Neural and Behavioral Responses to Social Media. *Psychol Sci, 27*(7), 1027-1035. doi:10.1177/0956797616645673

49. Silk, J. S., Siegle, G. J., Lee, K. H., Nelson, E. E., Stroud, L. R., & Dahl, R. E. (2014). Increased neural response to peer rejection associated with adolescent depression and pubertal development. *Soc Cogn Affect Neurosci, 9*(11), 1798-1807. doi:10.1093/scan/nst175

50. Smith, S. M., Jenkinson, M., Johansen-Berg, H., Rueckert, D., Nichols, T. E., Mackay, C. E., . . . Behrens, T. E. (2006). Tract-based spatial statistics: voxelwise analysis of multi-subject diffusion data. *Neuroimage, 31*(4), 1487-1505. doi:10.1016/j.neuroimage.2006.02.024
51. Spiller, H. A., Ackerman, J. P., Spiller, N. E., & Casavant, M. J. (2019). Sex- and Age-specific Increases in Suicide Attempts by Self-Poisoning in the United States among Youth and Young Adults from 2000 to 2018. *J Pediatr, 210*, 201-208. doi:10.1016/j.jpeds.2019.02.045
52. Stenton, S. L., Zou, Y., Cheng, H., Prokisch, H., & Fang, F. (2021). Pediatric Leigh Syndrome: Neuroimaging Features and Genetic Correlations. *Ann Neurol, 89*(3), 629-631. doi:10.1002/ana.25998
53. Storm, B. C., & Stone, S. M. (2015). Saving-enhanced memory: the benefits of saving on the learning and remembering of new information. *Psychol Sci, 26*(2), 182-188. doi:10.1177/0956797614559285
54. Syan, S. K., McIntyre-Wood, C., Minuzzi, L., Hall, G., McCabe, R. E., & MacKillop, J. (2021). Dysregulated resting state functional connectivity and obesity: A systematic review. *Neurosci Biobehav Rev, 131*, 270-292. doi:10.1016/j.neubiorev.2021.08.019
55. Takeuchi, H., Taki, Y., Hashizume, H., Asano, K., Asano, M., Sassa, Y., . . . Kawashima, R. (2016). Impact of videogame play on the brain's microstructural properties: cross-sectional and longitudinal analyses. *Mol Psychiatry, 21*(12), 1781-1789. doi:10.1038/mp.2015.193
56. Tiraboschi, P., Hansen, L. A., Masliah, E., Alford, M., Thal, L. J., & Corey-Bloom, J. (2004). Impact of APOE genotype on neuropathologic and neurochemical markers of Alzheimer disease. *Neurology, 62*(11), 1977-1983. doi:10.1212/01.wnl.0000128091.92139.0f
57. Uncapher, M. R., Lin, L., Rosen, L. D., Kirkorian, H. L., Baron, N. S., Bailey, K., . . . Wagner, A. D. (2017). Media Multitasking and Cognitive, Psychological, Neural, and Learning Differences. *Pediatrics, 140*(Suppl 2), S62-s66. doi:10.1542/peds.2016-1758D
58. Uncapher, M. R., & Wagner, A. D. (2018). Minds and brains of media multitaskers: Current findings and future directions. *Proc Natl Acad Sci U S A, 115*(40), 9889-9896. doi:10.1073/pnas.1611612115
59. Wang, W., Nakadate, K., Masugi-Tokita, M., Shutoh, F., Aziz, W., Tarusawa, E., . . . Shigemoto, R. (2014). Distinct cerebellar engrams in short-term and long-term motor learning. *Proc Natl Acad Sci U S A, 111*(1), E188-193. doi:10.1073/pnas.1315541111
60. Ward, A. F. (2013). Supernormal: How the Internet Is Changing Our Memories and Our Minds. *Psychological Inquiry, 24*(4), 341-348.
61. Wen, J., Goyal, M. S., Astafiev, S. V., Raichle, M. E., & Yablonskiy, D. A. (2018). Genetically defined cellular correlates of the baseline brain MRI signal. *Proc Natl Acad Sci U S A, 115*(41), E9727-e9736. doi:10.1073/pnas.1808121115
62. West, G. L., Konishi, K., Diarra, M., Benady-Chorney, J., Drisdelle, B. L., Dahmani, L., . . . Bohbot, V. D. (2018). Impact of video games on plasticity of the hippocampus. *Mol Psychiatry, 23*(7), 1566-1574. doi:10.1038/mp.2017.155
63. Wiberg, A., Ng, M., Al Omran, Y., Alfaro-Almagro, F., McCarthy, P., Marchini, J., . . . Furniss, D. (2019). Handedness, language areas and neuropsychiatric diseases: insights from brain imaging and

genetics. *Brain, 142*(10), 2938-2947. doi:10.1093/brain/awz257

64. Wierenga, C. E., Clark, L. R., Dev, S. I., Shin, D. D., Jurick, S. M., Rissman, R. A., . . . Bondi, M. W. (2013). Interaction of age and APOE genotype on cerebral blood flow at rest. *J Alzheimers Dis, 34*(4), 921-935. doi:10.3233/jad-121897
65. Yip, A. G., McKee, A. C., Green, R. C., Wells, J., Young, H., Cupples, L. A., & Farrer, L. A. (2005). APOE, vascular pathology, and the AD brain. *Neurology, 65*(2), 259-265. doi:10.1212/01.wnl.0000168863.49053.4d
66. Zhao, B., Li, T., Yang, Y., Wang, X., Luo, T., Shan, Y., . . . Zhu, H. (2021). Common genetic variation influencing human white matter microstructure. *Science, 372*(6548). doi:10.1126/science.abf3736
67. Zhong, S., Wei, L., Zhao, C., Yang, L., Di, Z., Francks, C., & Gong, G. (2021). Interhemispheric Relationship of Genetic Influence on Human Brain Connectivity. *Cereb Cortex, 31*(1), 77-88. doi:10.1093/cercor/bhaa207

Tables

Table 1. Demographics of subjects in the HMSR, LMSR, and SF groups

	HSM (N = 34)	LSM (N = 20)	SF (N = 21)	*P* value
Age (years)	21.00 [20.73, 21.27]	20.90 [20.43, 21.38]	20.91 [20.52, 21.30]	0.905
Height (cm)	175.15 [173.67, 176.85]	174.51 [171.05, 177.37]	177.41 [174.68, 180.14]	0.171
Weight (kg)	67.25 [64.71, 69.39]	67.75 [63.77, 71.13]	68.93 [64.66, 73.21]	0.679
BMI (kg/m^2)	21.86 [21.23, 22.48]	22.07 [21.31, 22.83]	21.82 [21.02, 22.63]	0.880
Smartphone use habits				
Chatting (h)	1.03 [0.73, 1.33]	0.91 [0.49, 1.32]	1.11 [0.83, 1.40]	0.715
Game (h)	0.59 [0.34, 0.84]	0.60 [0.32, 0.87]	0.69 [0.32, 1.06]	0.869
Film/TV series (h)	0.33 [0.15, 0.52]	0.19 [-0.01, 0.39]	0.35 [0.12, 0.58]	0.519
Social media (h)	1.96 [1.71, 2.20]	0.40 [0.31, 0.50]	0.35 [0.25, 0.46]	<0.001
Other activities (h)	0.44 [0.28, 0.61]	0.39 [0.11, 0.67]	0.81 [0.37, 1.26]	0.092
Genotype				
APOE: rs429358 (TT/TC/CC)	24/10/0	15/2/0	13/5/0	0.278
APOE: rs7412 (CC/CT/TT)	29/5/0	16/1/0	16/2/0	0.407
BDNF: rs6265 (GG/GA/AA)	10/17/7	6/8/3	5/10/3	0.737

The 95% confidence interval (CI) values are given in square brackets.

Table 2. The prediction of plasticity of CBF and white matter integrity

		Age	BMI	Baseline value	APOE		BDNF	Group
					rs7412	rs429358	rs6265	
Mean CBF	*F* value	0.002	2.373	1.885	5.017	0.349	0.762	0.766
	P value	0.967	0.138	0.184	0.036*	0.561	0.478	0.477
Mean FA	*F* value	4.310	0.266	172.427	0.078	0.140	3.987	0.895
	P value	0.050	0.611	1.359×10^{-11}*	0.783	0.712	0.034*	0.355
Mean MD	*F* value	1.171	1.212	496.828	0.002	0.691	3.378	0.057
	P value	0.292	0.283	4.248×10^{-16}*	0.962	0.415	0.053	0.813

A linear mixed-effect model was built, in which the APOE genotype (or BDNF genotype) contained fixed effects independent of behavioral tasks, and the group variable contained random effects specific to behavioral tasks, and CBF value (or FA, MD value) at baseline, age, and BMI were considered as covariates of no interest. Significant predictors were marked with asterisks.

Figures

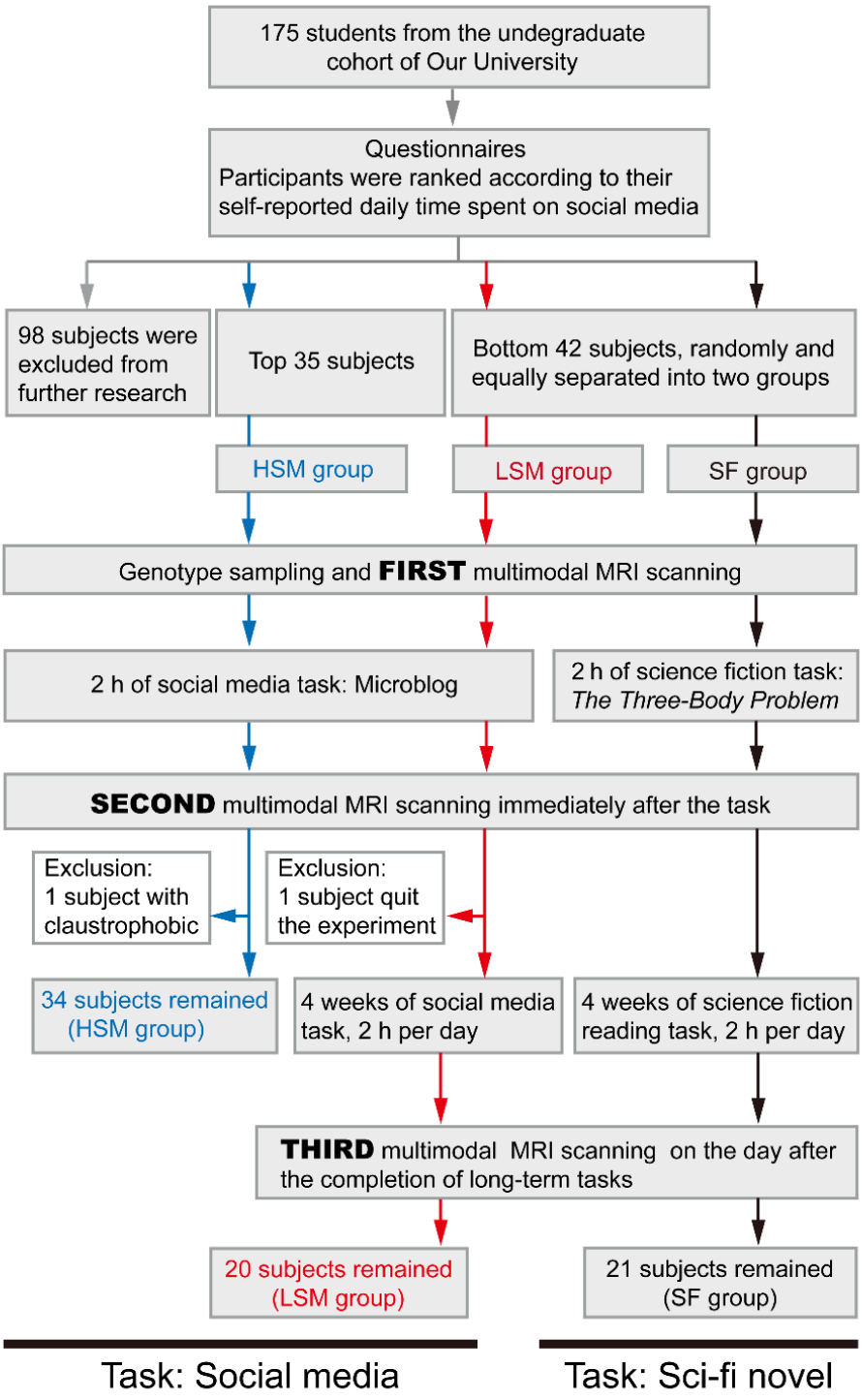


Figure 1

Subject recruitment and experimental design. A total of 175 participants completed the questionnaires. Among them, the 35 participants with the highest daily social media use and the 42 participants with the lowest daily social media use were selected for further study, whereas the remaining 98 participants were excluded. The 35 high-use participants were assigned to the heavy social media (HSM) group. The 42 low-use participants were randomly allocated to either the light social media (LSM) group or the

science fiction (SF) group. Participants in the HSM and LSM groups underwent short-term and long-term social media intervention tasks, together with multimodal MRI scans acquired at baseline and following the short- and long-term interventions. The SF group followed the same experimental protocol as the LSM group, except that both intervention tasks consisted of science fiction reading. HSM, heavy social media; LSM, light social media; SF, science fiction.

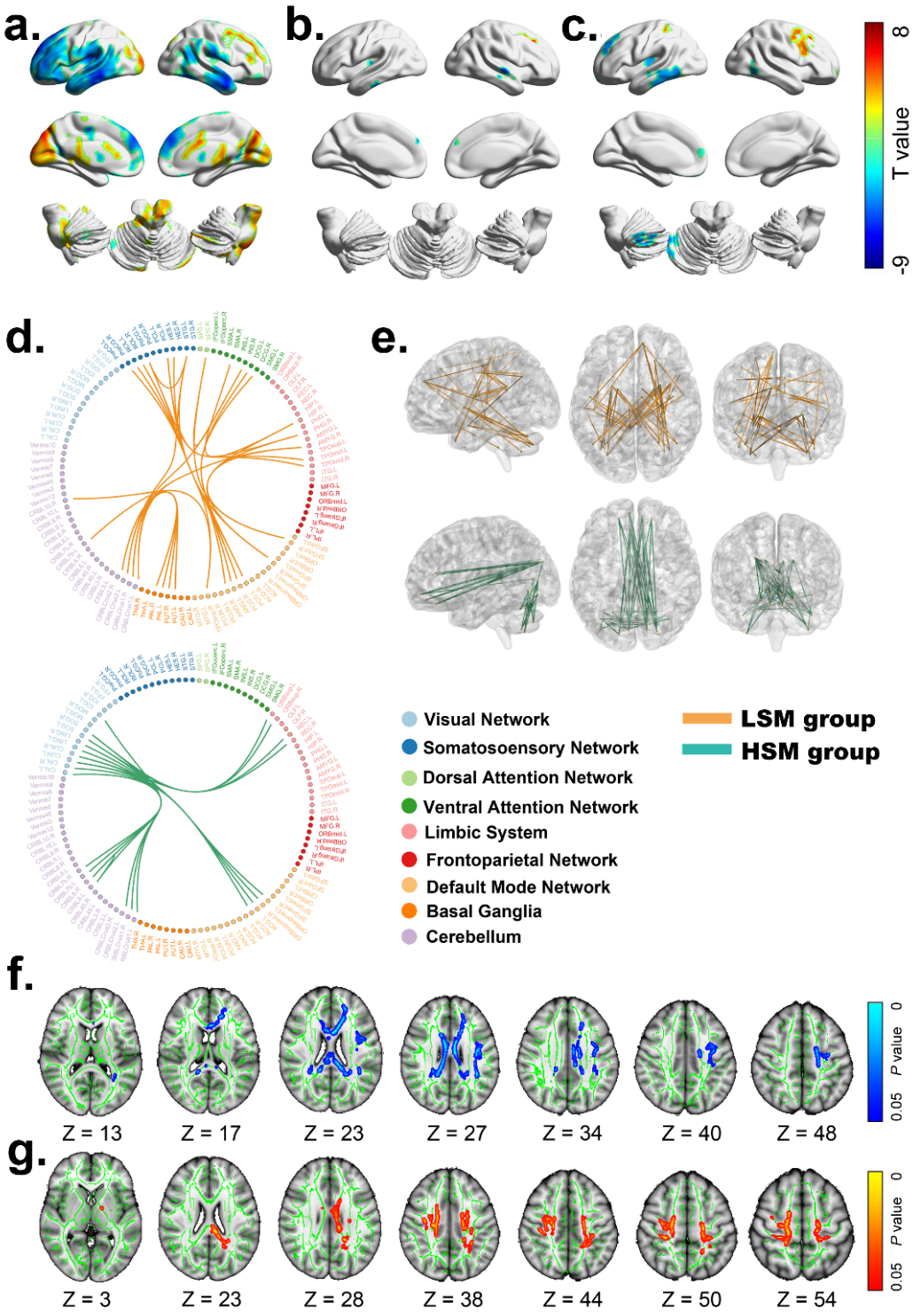


Figure 2

The impact of social media use and science fiction reading on cerebral blood flow (CBF), functional connectivity (FC), and white matter integrity. (a) Effects of short-term social media use in the HSM group. Increased CBF was observed in the visual cortex, right middle frontal gyrus (MFG), and thalamus, whereas decreased CBF was detected in the left frontal lobe, bilateral medial prefrontal cortex (mPFC), bilateral temporal lobes, and right angular gyrus. (b) Effects of short-term social media use in the LSM group. Increased CBF was observed in the right MFG, while decreased CBF was found in the bilateral superior temporal gyrus and bilateral mPFC. (c) Effects of short-term science fiction reading in the SF group. Increased CBF was observed in the right MFG and left supramarginal gyrus, whereas decreased CBF was detected in the left middle temporal gyrus, left insular gyrus, and left superior frontal gyrus. (d) Significantly altered FC patterns following short-term social media use. An increased functional network was identified in the LSM group, whereas a decreased functional network was observed in the HSM group. (e) Brain network-level visualization of the increased and decreased functional connections. (f) Long-term social media use was associated with reduced fractional anisotropy (FA) in the bilateral corpus callosum (CC), superior longitudinal fasciculus (SLF), and sensorimotor regions. (g) Long-term social media use was also associated with increased mean diffusivity (MD) in the bilateral CC, SLF, and sensorimotor regions.

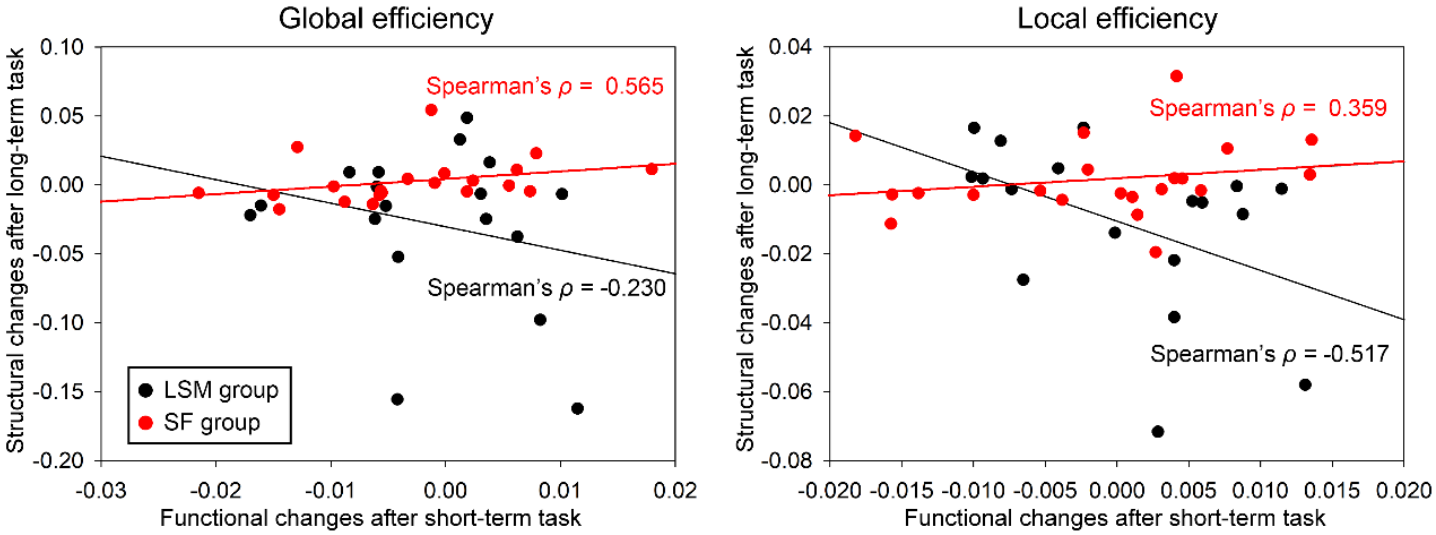


Figure 3

Associations between short-term functional network efficiency changes and long-term structural netowkr efficiency changes following social media use. In the LSM group, changes in functional efficiency were negatively correlated with changes in structural efficiency. In contrast, a positive correlation was observed in the SF group. Moreover, the strength of this relationship was significantly greater in the SF group than in the LSM group.

Supplementary Files

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