5-2020

Screen usage relates to neuroanatomy underlying reward processing.

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Screen Usage Relates to Neuroanatomy Underlying Reward Processing

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Submitted in partial fulfillment of the requirements for Graduation *summa cum laude*
and
for Graduation with Honors from the Department of Psychological and Brain Sciences
and the Department of Anatomical Sciences and Neurobiology

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May, 2020

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Abstract

Today's world is inundated with technology and our use of screens. It is possible that screen usage might affect the structural development of brain systems underlying motivation, reward, and addiction. Two hundred and thirty-two 10-year-old individuals' structural MRI and behavioral data from a publicly accessible database were analyzed to find relations between the cortical and subcortical regions of the reward circuits of the brain and the usage of social media, texting, television, YouTube and other video applications, video games, and video chat applications. Both cortical and subcortical results yielded significant relationships with variables of screen time usage. Most significantly, subcortical brain regions known to be involved in the reward system were structurally affected by duration of screen usage. These results implicate brain changes beyond the explicit structural changes in response to the ubiquitous use of screens within our society and warrant the further study of how this affects our reward system and attention.

Lay Summary

Today's world is inundated with technology and our use of screens. It is possible that screen usage might affect the development of the brain. Specifically, screen usage (*i.e.*, social media and cellular phones) may become addictive, like substances of abuse (*e.g.*, alcohol and cigarettes). The current study examined brain regions related to addiction and the usage of social media, texting, television, YouTube and other video applications, video games, and video chat applications. Results showed that brain regions known to be involved in addiction were structurally affected by duration of screen usage. These results implicate brain changes in

response to the ubiquitous use of screens within our society and warrant the further study of how this affects our behavior.

Introduction

Today's world is inundated with technology and our use of screens. It is possible that screen usage might affect the structural development of brain systems underlying motivation, reward and addiction. Addiction to various substances of abuse hijack dopaminergic brain regions, however it is relatively unknown whether other classes of stimuli result in the same process. Therefore, the current study investigated screen usage in connection to regions of the brain related to reward, dopamine, addiction, and general cognitive function.

One of the brain's primary reward pathways is the dopaminergic mesolimbic pathway which begins at the ventral tegmental area (VTA) of the midbrain and connects to the nucleus accumbens in the ventral striatum. The nucleus accumbens is a key subcortical region for processing reward and aversion. The VTA also innervates the amygdala and the ventral pallidum. The amygdala is known for its role in this reward system as well as its role in emotion. The amygdala also innervates the nucleus accumbens, but through glutamatergic neurons. The nucleus accumbens inhibits the ventral pallidum via GABAergic signaling. The ventral pallidum is part of the globus pallidus which is involved both in reward processing and motoric regulation. Another important reward pathway, the mesocortical pathway connects the VTA with the prefrontal cortex. The prefrontal cortex is known for its role in planning, decision making, and reward. These pathways are well understood to be important to the brain's natural processing of reward.

The mesolimbic and mesocortical pathways are effectively "hijacked" by various substances of abuse (Levy, 2017). Additionally, various addiction prone behaviors such as gambling have been linked to changes in the mesolimbic pathway. Gambling addicts with more severe gambling addictions have higher mesolimbic dopamine release in the ventral striatum, causing over-sensitization of the reward circuitry, compared with gambling addicts with a lower severity gambling addiction (Jousta et al., 2012). Furthermore, gambling addiction is associated with decreased activation of the mesolimbic pathway, especially the ventral striatum, (Reuter et al., 2005), likely due to dopamine over-sensitization.

It is possible that screen usage may interact with the mesolimbic and mesocortical pathways in ways similar to those of substances of abuse and addictive behaviors. While little research has been done in regard to this hypothesis, preliminary implications reveal that Social networking site (SNS) addiction relates to cortical and subcortical gray matter volume in more mature adolescents. Specifically, gray matter volume of the amygdala correlates negatively, while the volume of the anterior cingulate and midcingulate cortex correlates positively with SNS addiction. Interestingly, current studies do not suggest that the morphometry of the nucleus accumbens (the main input of dopamine to subcortical regions) correlates with SNS addiction in any significant way (He, Turel, & Bechara, 2017). Other forms of screen usage (*e.g.*, texting, voice chat) are not as well researched in regard to the mesolimbic and mesocortical pathways.

Based on established literature, we hypothesize that increased screen usage will correlate with changes in the morphometry (the volume, area, and cortical thickness) of neuroanatomy involved in the dopaminergic reward pathways: amygdala, nucleus accumbens, and prefrontal cortex. To address this hypothesis, the current study used behavioral and MRI data to assess the cortical and subcortical morphometric features of the brain and determined which screen variables affect cortical and subcortical morphometry. If such relationships are found, it would suggest that over-usage of screen-based media may hijack these reward pathways in a manner similar to addictive behaviors and substances of abuse.

Methods

Data were obtained from the Adolescent Brain Cognitive Development sample (ABCD). This study is a longitudinal long-term study integrating functional and structural brain imaging with behavioral genetic, and other health assessments. The study is being accomplished by the ABCD Consortium which has sites nation-wide (Adolescent, n.d.).

Sample

The study used a total of 232 ten-year-old adolescents' high-resolution structural/anatomical scans. Participants were excluded if data were unavailable for the behavioral variables of interest. Initially in the exploratory phase of the study, many other variables were also considered beyond those relating to screen usage.

Initially, 232 – ten y.o. individuals were used in cortical and subcortical analyses of grey matter and its relationship to behavioral variables. During quality check 31 individuals were removed for incomplete segmentation/parcellation of subcortical structures, yielding a final N of 232 (cortical) and 201 (subcortical) ten y.o. individuals. Additionally, outliers were removed for each variable producing results. These outliers were analyzed via visual inspection, and those that were 2 standard deviations away from the mean were removed in accordance with extreme value analysis based on Z-scores.

Behavioral Measures (Obtained from ABCD)

Self-reported number of hours of usage on weekend (wknd) and weekdays(wkdy): 1) social media (SM), 2) texting and messaging apps (TXT), 3) TV and movies (TV), 4) video chat (VC), 5) YouTube and similar applications (YT), and 6) video games (VG) were obtained.

Anatomical/Structural Scans (Obtained from ABCD)

High-resolution, T1-weighted anatomical scans were acquired using a Siemens 3-Tesla MRI (Magnetic Resonance Imaging) scanner.

Cortical Morphometry Analysis

Cortical reconstruction and volumetric segmentation was performed with the FreeSurfer image analysis suite, which is documented and freely available for download online (http://surfer.nmr.mgh.harvard. edu/). The technical details of these procedures are described in prior publications (Dale et al., 1999). Briefly, this processing includes motion correction and averaging (Reuter et al., 2010) of volumetric T1weighted images, removal of non-brain tissue using a hybrid watershed/surface deformation procedure (Ségonne et al., 2004), automated Talairach transformation, intensity normalization (Sled et al., 1998), tessellation of the grey matter white matter boundary, automated topology correction (Fischl et al., 2001; Segonne et al., 2007), and surface deformation following intensity gradients to optimally place the grey/white and grey/cerebrospinal fluid borders at the location where the greatest shift in intensity defines the transition to the other tissue class (Dale et al., 1999; Dale and Sereno, 1993; Fischl and Dale, 2000). Once the cortical models were completed, a number of deformable procedures were carried out for further data processing and analysis including surface inflation (Fischl et al., 1999a, 1999b), registration to a spherical atlas which utilized individual cortical folding patterns to match cortical geometry across subjects (Fischletal.,1999a, 1999b), parcellation of the cerebral cortex into units based on gyral and sulcal structure (Desikan et al., 2006; Fischl et al., 2004), and creation of a variety of surface-based data including maps of cortical volume, surface area (SA), thickness, curvature, sulcal depth, and local gyrification index. The resulting probability maps were input into a general linear model (GLM) evaluating correlations between all vertices and behavioral scores of weekday and weekend SM, TXT, TV, YT, VC, and VG.

Vertex-wise/cluster forming threshold was set at $p < 0.005$ level. To correct for multiple comparisons, a cluster-wise Monte Carlo permutation simulation was run in order to get a measure of the distribution of the maximum cluster size under the null hypothesis. Clusters that had a corrected p-value ≤ 0.05 were considered significant. Negative log(p) values are displayed in scale bars and graphs (Fig. 1,2,3) .

Subcortical Analysis

Anatomical imaging data were segmented into subc This software was the only program for cortical analysis that ortical regions, using FMRIB (Functional Magnetic Resonance Imaging of the Brain) Software Library's FMRIB Integrated Registration and Segmentation Tool which is a model-based segmentation tool that allows for parcellation of several subcortical brain structures from high resolution T1-weighted images of the brain. Importantly, this tool enables an unbiased approach to segmentation of the regions, which are hard to manually trace due to their small structure size. This software was the only cortical analysis program available that can also run regression analysis.

Automated segmentation of 14 subcortical structures (bilateral: Accumbens, Amygdala, Caudate, Hippocampus, Putamen, Pallidum, and Thalamus) was performed using FIRST (FSL v5.0.8) which uses a Bayesian probabilistic approach. The shape and appearance models in FIRST are constructed from a library of manually segmented images. The manually generated labels are parameterized as surface meshes and then modeled as a point distribution. Using the learned models, FIRST searches through shape deformations that are linear combinations of the modes of variation to find the most probable shape instance given the observed intensities from the input image. Using T1 images, the segmentation was performed with two-stage affine transformation to standard space of MNI 152 at 1-mm resolution (Morey et al., 2009; Woolrich et al., 2009). The first stage utilized a standard 12 degrees of freedom registration to the template and the second stage applied 12 degrees of freedom registration using an MNI152 subcortical mask to exclude voxels outside the subcortical regions. Default settings for boundary correction and number of modes (iterations) were used, which are tuned to be optimal for each structure. All segmentations were then visually inspected by two independent viewers to ensure satisfactory segmentation of all structures of interest. Volume regressions were then performed to investigate differences in total volume of a structure with weekday and weekend SM, TXT, VC, TV, YT, and VG usage.

Results

Cortical Morphometry Results

In analyzing the relation between cortical morphometry and screen usage, results indicated a significant positive relation between increased weekday VG usage and right hemisphere lateral occipital cortex (LOC) volume ($p = .0032$) and surface area ($p = .0004$) (See Fig. 1).

A significant negative correlation was found between increased weekend VG usage and left hemisphere inferior parietal lobule volume ($p = .0005$) and surface area ($p = .004$) (See Fig. 2). Beyond the visual system, increased weekend VG usage also related negatively to left hemisphere superior temporal gyrus cortical thickness ($p = .0001$), left hemisphere pars opercularis cortical thickness ($p = .004$), right hemisphere postcentral gyrus cortical thickness ($p = .0001$), and right hemisphere transverse temporal gyrus cortical thickness ($p = .003$).

Increased weekend SM usage related negatively to left hemisphere inferior parietal lobule area ($p = .0001$) and positively to superior frontal gyrus volume ($p = .004$ (See Fig. 3).

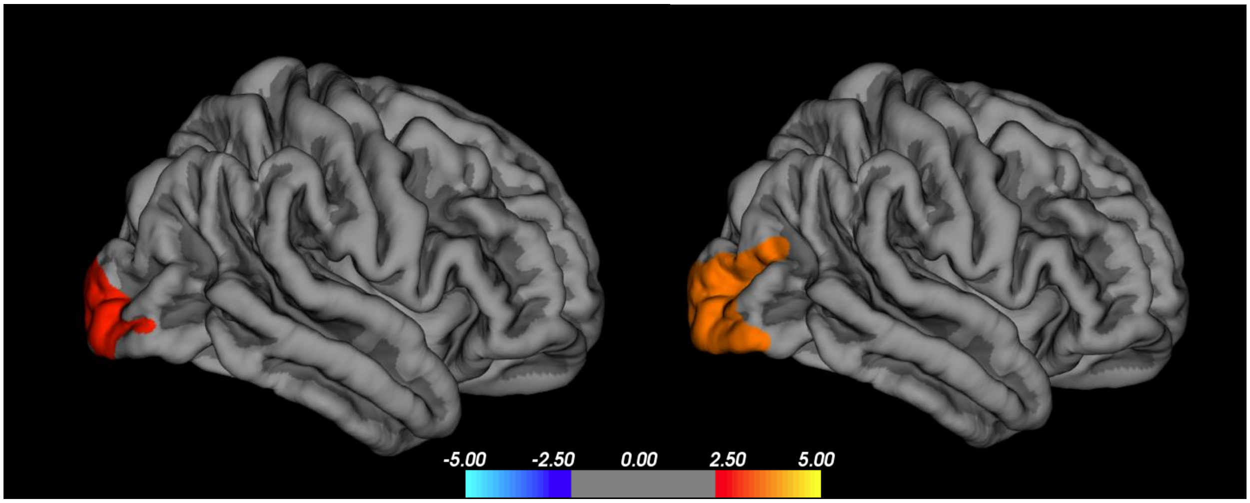

Figure 3 Increased weekday videogame usage correlated positively with volume (left) and area (right) of the lateral occipital cortex (LOC).

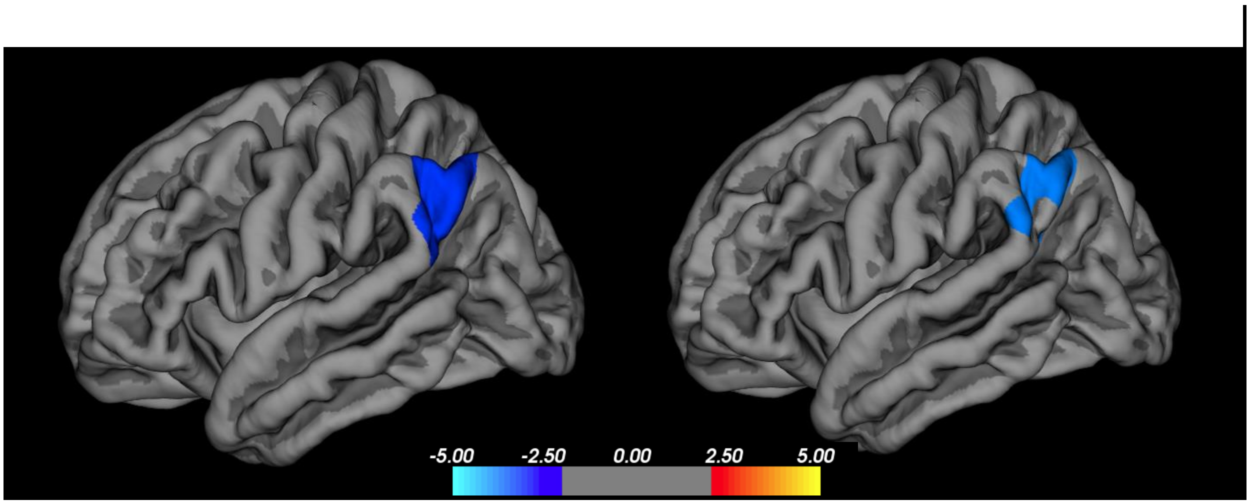

Figure 2 Increased weekend videogame usage correlated negatively with area (left) and volume (right) of the inferior parietal lobule.

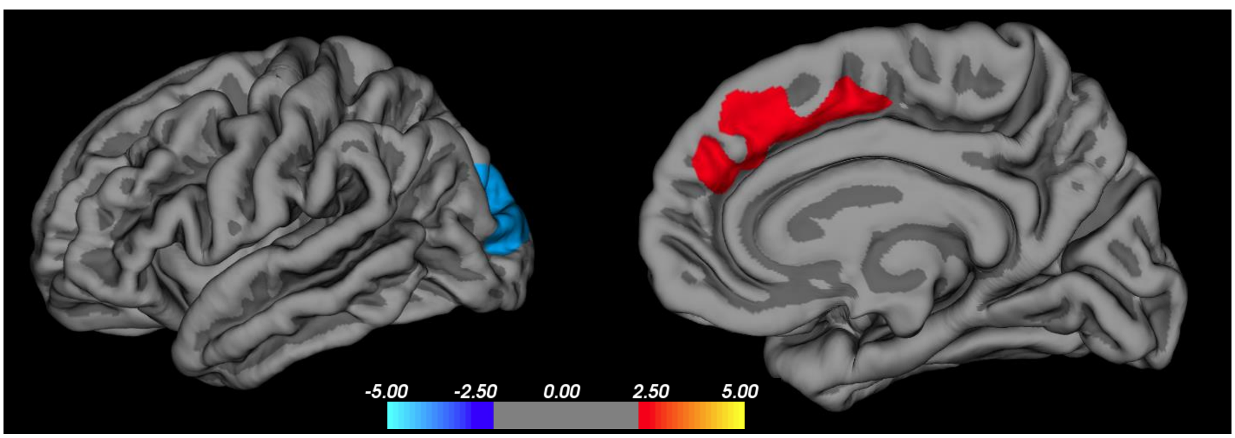

Figure 1 *Increased weekend* social media usage correlated negatively with area of the inferior parietal lobule (left) and positively with volume of the superior frontal gyrus (right).

Subcortical Volumetric Results

Increased volume of the left nucleus accumbens related negatively to weekend SM and weekend TXT usage but related positively to weekday VG and weekday YT usage (wknd_SM: R^2=.0246, p=.029; wknd_TXT: R^2=.0350, p= .009; wkdy_VG: R^2=.0231, p=.032; wkdy_YT: R^2=.0216, p=.037).

Increased volume of the right nucleus accumbens related positively to both weekend and increased weekday VG usage (wkdy_VG: R^2=.0441, p=.003; wknd_VG: R^2=.0256, p=.023).

Increased volume of the left globus pallidus related positively to weekday VG usage (wkdy_VG: R^2=.0201, p=.044). Increased volume of the right globus pallidus related positively to both weekday and weekend VG usage (wkdy_VG: R^2=.0562, p=.001; wknd_VG: R^2=.0320, p=.011)

Increased volume of the left amygdala related positively to both weekday VG and weekday YT usage (wkdy_VG: R^2=.0324, p=.010; wkdy_YT: R^2=.0339, p=.009) (See Fig. 4).

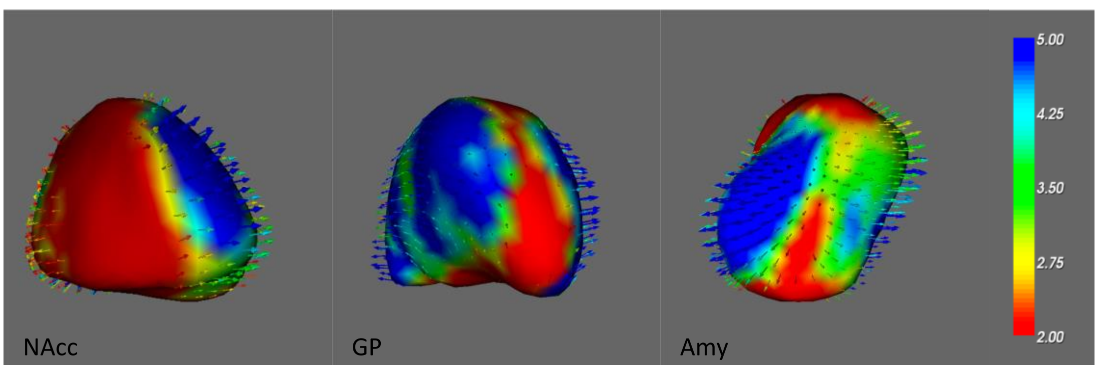

Figure 4 Example of changes to subcortical morphometry of the nucleus accumbens (NAcc), the globus pallidus (GP), and the amygdala (Amy).

Volumetric Analysis				
Measure	Structure	R	R^2	P
wknd_SM	L_NAcc	-0.143	.0245	.029
wknd_TXT	L_NAcc	-0.187	.0350	.009
wkdy_VG	L_NAcc	.152	.0231	.032
Wkdy_YT	L_NAcc	.147	.0216	.037
wkdy_VG	R_Nacc	.210	.0441	.003
wknd_VG	R_NAcc	.160	.0256	.023
wkdy_VG	L_GP	.142	.0201	.044
wkdy_VG	R_GP	.237	.0562	.001
wknd_VG	R_GP	.179	.0320	.011
wkdy_VG	L_Amy	.180	.0324	.010
wkdy_YT	L_Amy	.184	.0339	.009

Table 2. Results of subcortical volumetric analyses. Behavioral variables represented include weekday (wkdy) and weekend (wknd) social media (SM), text message (TXT), video game (VG), and YouTube and video app (YT) usage. Structural variables include left (L) and right (R) nucleus accumbens (NAcc), globus pallidus (GP, and amygdala (Amy) volume.

Discussion

Both cortical and subcortical analyses yielded significant morphometric relationships with screen usage measures. Cortically, the finding that increased lateral occipital cortex (LOC) morphometry relates positively to increased videogame usage may be due to video games inherent visual nature. The LOC is known to be heavily involved in visual experience. In a 2014 study, increased lifetime videogame usage was found to relate positively with increased volume of a region between occipital cortex and inferior parietal lobe in the left hemisphere (Kühn & Gallinat, 2014).

Interestingly, while increased LOC morphometry related positively to videogame usage, increased inferior parietal lobule morphometry related negatively to increased videogame usage.

The inferior parietal lobule is known to function in attention to vison. Video games are very visual in nature and at times require the ability to switch the player's visual attention frequently. Why one area morphometry relates positively to increased videogame usage and the other relates negatively to increased videogame usage is unknown as is the significance of such a difference and is a primary example to warrant more research.

Increased social media usage related negatively to increased inferior parietal lobule morphometry and positively to increased superior frontal gyrus morphometry. The inferior parietal lobule is involved in the frontoparietal attentional network. The superior frontal gyrus is important to movement and movement control. Speculatively, the change to the frontoparietal attentional network may be due to the multitasking nature of how many use social media. The change in the superior frontal gyrus may relate to decreased over all movement while using social media or increased movement in the digits when scrolling.

Subcortically, the findings in the differences in nucleus accumbens volume relating to increased videogame, video app, and social media usage may be evidence that screen usage is affecting the reward pathways of the brain. The nucleus accumbens is a key part of the mesolimbic reward pathway. Interestingly, with increased social media usage, a decrease in volume was seen, while with increased video app and videogame usage, an increase was seen. At this time, the significance of this finding is unknown.

The positive relation between increased videogame usage and increased globus pallidus volume may be due to the ventral regions of the globus pallidus. The ventral pallidum is an important part of the reward circuitry and receives inhibitory GABAnergic input from the nucleus accumbens. Additionally, the relation may be due to the globus pallidus's function in voluntary movement and the at-times quick and precise digit and hand movement required in playing video games.

The positive relation between videogame and video app usage and increased amygdala volume, may also be indicative of screen usage affecting the reward pathway, although it could also be tied to the evocation of other emotions by the media, such as fear by a scary video or game. In the reward circuit, the amygdala is innervated by dopaminergic neurons from the VTA and innervates the nucleus accumbens with glutamate.

In future studies, it may be useful to replicate this study with other populations such as the 9-year-old ABCD sample. Additionally, as the current sample ages they will be imaged and surveyed again by the ABCD study allowing for a longitudinal analysis of the relation between screen usage and the morphometry of the reward pathway. Additionally, by controlling for further variables beyond ICV, such as variables relating to executive function, health, and other sources of addiction, would protect against other confounding factors.

Acknowledgements

Without the data from the ABCD study, this current study could not have been made. I would like to thank my mentor Dr. Brendan Depue for his guidance in writing my thesis. I would also like to thank Kamryn Mattingly who acted as my student mentor and taught me much in how to use the various programs and software libraries and in running proper analyses. Finally, I would like to thank the rest of the members of the NILCAMP lab for always taking time to assist when I would have any questions or issues.

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