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Excess social media use in normal populations is associated with amygdala-striatal but not with prefrontal morphology

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ABSTRACT

This study aims to investigate the gray matter volume (GMV) of key neural systems possibly associated with Excess Social Media Use (ESMU) in the general user population. It employs a sex-balanced case (relatively high ESMU scores) - control (relatively low ESMU scores) design with 50 random university students who have reported varying levels of ESMU. The case and control groups included 25 subjects each. Brain volumes were calculated with Voxel-Based Morphometry techniques applied to structural MRI scans. Results based on voxel-wise and region-of-interest (ROI) analyses showed that the case group had reduced GMV in the bilateral amygdala and right ventral striatum. The GMV of the bilateral amygdala and right ventral striatum negatively correlated with ESMU scores in the voxel-wise analysis. No differences or correlations in relation to prefrontal regions were observed. Using the ROI analysis, the bilateral amygdala volumes correlated with ESMU scores, and insufficient evidence regarding the ventral striatum and ESMU was obtained. It is concluded that excess social media use in the general population is associated in part with GMV reduction in the bilateral amygdala, and possibly the striatum, but not in volumetric differences in prefrontal regions.

1. Introduction

Excess Social Media Use (ESMU) is a behavioral pattern on the spectrum of repeated compulsive online behaviors that can produce addiction-like symptoms, including salience, withdrawal, mood modification, relapse, conflict, and tolerance (Turel, 2015; Turel and Serenko, 2012). While there are no established clinical classification criteria for ESMU, and the appropriate terminology (e.g., addiction, disorder, problematic use, excess use) is not yet determined (Lortie and Guitton, 2013), studies show that most users present some degree of excess use and about 4.5% may be classified as at-risk for addiction (Bányai et al., 2017). Because ESMU can adversely impact large cross-sections of social media users (De Cock et al., 2014; Karaiskos et al., 2010; Kuss et al., 2013), through for instance diminished academic performance (Turel and Qahri-Saremi, 2016), wellbeing (Bright et al., 2015), and sleep (Turel et al., 2016), it is important to study its neural bases. Moreover, since ESMU does not involve neurotoxicity and begins at an early age (as opposed to, for instance, gambling), understanding its neural basis can provide a psycho-behavioral account of addiction, without confounding the finding with chemical effects.

To this end, we turn to the dual system theory (Bechara, 2005), according to which excess behaviors stem from an imbalance between hyperactivity of the reward system (mesolimbic dopamine amygdala-striatal) and hypo-activity of the inhibition system which includes prefrontal regions such as the orbitofrontal cortex (OFC), ventromedial prefrontal cortex (vmPFC), dorsolateral prefrontal cortex (dlPFC) and the Anterior Cingulate Cortex (ACC) (Brand et al., 2014). Using this theory we hypothesize regarding the GMV differences in these regions that may be associated with ESMU in a typical cross-section of social media users (i.e., people who present some degrees of ESMU).

First, the amygdala is important for excess behavior formation and maintenance because it governs learning (linking cues to emotive outcomes) and dopamine release in response to anticipated and received rewards (Bechara et al., 1999). Structural abnormalities in it (typically reduced GMV), are associated with excess behaviors, including substance use (Barros-Loscertales et al., 2011; Makris et al., 2008) and using Facebook (He et al., 2017). This reduced GMV can presumably reflect both hypo-activity in the reward anticipation stage, which promotes reward seeking, and hyper-activity in the reward outcome processing stage, that reflects fast and efficient reward production (Luijten

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et al., 2017). GMV reduction in this system may take place even at low levels of ESMU because the mesolimbic-dopamine system is highly morphologically flexible (Kanai and Rees, 2011). As such, assuming similarities between excess behaviors and ESMU, we hypothesize that **(H1)** the volumes of the bilateral amygdale will be reduced in high (top 50%) vs. low (bottom 50%) ESMU cases in a typical cross-section of users.

Second, the ventral striatum (Nucleus Accumbens, NAcc) is also important in reward processing (Cardinal et al., 2001); it is a central reward hub that has been shown to be involved in many excess behaviors (Gilman et al., 2014). Its activity has been shown to be associated with social media phenomena such as likes (Sherman et al., 2016) and reputation gains (Meshi et al., 2013). It has also been shown to be associated with social media addiction levels (Turel et al., 2014). From a structural standpoint, findings are less consistent. Some studies show that high frequency of checking Facebook on a smartphone is associated with reduced NAcc volumes (Montag et al., 2017) and others find no structural changes in NAcc associated with social media addiction (He et al., 2017). Given the theoretical role of NAcc in excess behaviors, the presumed morphological flexibility of this region (Kanai and Rees, 2011), and the notion that excess behaviors are often associated with reduced NAcc volumes (Seifert et al., 2015), we venture to hypothesize that **(H2)** the volumes of the bilateral NAcc will be reduced in high (top 50%) vs. low (bottom 50%) ESMU cases.

Third, excess Internet behaviors can also be associated with impairment of executive control abilities (Dong et al., 2011a, 2011b). The reason is that when prefrontal inhibition systems are weak, they cannot respond to and override impulsions mediated via the reward system. At low-medium levels of excess behavior, there are mixed findings. Some studies of relatively normal users showed that prefrontal systems are not impaired (Turel et al., 2014), and others showed volume reduction in regions such as the OFC in women (Altbäcker et al., 2016) and in right frontal pole in men (Kuhn and Gallinat, 2015), as a function of excess behavior. At higher levels of excess use (clinical cases of Internet addiction), reduced GMV in the OFC and dlPFC has been observed (Yuan et al., 2013, 2011). The reasons for such inconsistencies may be that prefrontal regions are much less morphologically flexible compared to mesolimbic-dopamine systems (Kanai and Rees, 2011) and that the subject of use in most prior studies (i.e., the Internet) includes many applications with varying use phenomenology (e.g., the use of videogames on the Internet is phenomenologically different from the use of social media). Moreover, many prefrontal functionalities can remain intact among Internet addicts (Nie et al., 2016) and even improve in response to hyper-activity in the amygdala-striatal system (He et al., 2017). Hence, we consider the possibility that especially at low-medium levels of ESMU there will be no observable prefrontal structural changes. We therefore cautiously hypothesize that **(H3)** the volumes of prefrontal regions will not significantly differ between high (top 50%) vs. low (bottom 50%) ESMU cases, in a typical cross-section of social media users.

Together, these hypotheses provide another look at past findings regarding GMV of key regions of the dual system that governs behavior and decision making, and their associations with a specific instance of the family of excess Internet use behaviors (He et al., 2017; Kuhn et al., 2011; Yuan et al., 2013, 2011; Zhou et al., 2011). They specifically replicate and extend such findings to the case a typical cross-section of SNS users (as opposed to comparing those who meet or do not meet criteria for addiction classification). Understanding the underlying brain differences associated with ESMU in typical users can help dealing with the aversive effects of excess use, even on those who do not meet addiction criteria.

2. Methods

Fifty participants who reported using Facebook were recruited for this study using a university bulletin board. ESMU was captured with the 14-item Facebook-specific adaptation of the Compulsive Internet Use instrument, measured on a 1–5 Likert scale ($\alpha_{All} = 0.93$, $\alpha_{Low\ ESMU} = 0.90$, $\alpha_{High\ ESMU} = 0.87$) (Meerkerk et al., 2009; Turel et al., 2014) and median-split was employed for assigning people to the low- vs. high-ESMU groups. The study followed a sex-balanced case (relatively high ESMU, n = 25, 8 female, $M_{age} = 24.12$ [18–44], $SD_{Age} = 6.15$, $M_{ESMU} = 2.49$ [1.86–3.64], $SD_{ESMU} = 0.46$) - control (relatively low ESMU, n = 25, 8 female, $M_{age} = 29.80$ [19–55], $SD_{Age} = 10.90$, $M_{ESMU} = 1.34$ [1.00–1.78], $SD_{ESMU} = 0.26$) design. We were unable to assign people to addicted vs. non-addicted groups, given that such cutoffs are not formally defined. Nevertheless, based on prior research in the video-gaming domain (van Rooij et al., 2011), it was reasonable to assume that both groups largely do not meet addiction criteria, and hence represent normal users with respective low and high excess social media use (Low-ESMU range is aligned mostly with the low-use and no-addiction clusters in the abovementioned study, and High-ESMU here is mostly aligned with the high-use and no-addiction clusters in the abovementioned study). Participants were carefully screened for key neurological and psychiatric disorders using the Structured Clinical Interview for DSM-IV (SCID). They consented to patriciate in the study that was approved by the Institutional Review Boards of two research universities. No exclusions were made.

Brain GMV was calculated using Voxel-Based Morphometry techniques with high-resolution structural MRI scans performed in a 3T Siemens MAGNETOM Tim/Trio scanner at the Dana and David Dornsife Cognitive Neuroscience Imaging Center at the University of Southern California. The T1-weighted 3D-Magnetization Prepared Rapid Gradient Echo (MPRAGE) sequence was used to cover the whole brain [TR /TE = 2530/3.39 ms, flip angel = 7°, matrix = 256 × 256, 128 sagittal slices, 1.33 mm thickness]. The image quality was visually inspected for any distortion and noise before further analysis. The brain was extracted using BET, and then segmented into gray matter, white matter and CSF. The resulting gray-matter partial volume images were then aligned to the gray-matter template in the MNI152 standard space using the affine registration tool FLIRT, followed by nonlinear registration using FNIRT, which used a b-spline representation of the registration warp field. The spatially normalized images were then averaged to create a study-specific template, to which the native gray matter images were registered again using both linear and nonlinear algorithms as described above. The registered partial volume images were then modulated by dividing them with the Jacobian of the warp field to correct for local expansion or contraction. The modulated segmented images that represent the GMV, were then smoothed with an isotropic Gaussian kernel with a 3 mm standard deviation. The resulting images were re-sampled into 2 mm × 2 mm × 2 mm isotropic voxels (8 mm^3). Voxel-wise general linear models were used for statistical inference. To increase robustness, both GMV differences between high and low ESMU participants as well as correlation between ESMU and GMV were analyzed using FSL-VBM toolbox. In both analyses we used age and sex as covariates (note that while sex composition was identical across groups, we used sex to account for possible variation within-groups). We corrected for multiple comparisons in the voxel-wise analysis. First, for the voxel-wise analysis, GMV was compared between the two groups. The null distribution at each voxel was constructed using 10,000 random permutations of the data. Threshold-free cluster enhancement (TFCE) with $p < 0.05$ was employed for correcting for multiple comparisons. This methods can have improved sensitivity and provide richer and more interpretable output compared to cluster-based thresholding methods (Smith and Nichols, 2009). It has been consequently widely used in VBM-based studies. To increase robustness, significant regions from the voxel-wise GMV group difference analysis were extracted for correlation analysis between GMV and ESMU. Second, the Regions of Interest (ROIs) as defined by the Harvard-Oxford cortical probability atlas (25 thresholds, 2 mm resolution) were extracted for correlation analysis between GMV and ESMU. We also compared the GMVs between groups. For all correlational analyses,