Towards a Better Understanding of the Neurobiological Basis of Problematic Social Media Use in Young Adults

By

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Abstract

Problematic social media use is a maladaptive and detrimental pattern of addictive behaviours towards social media including tolerance, withdrawal, and loss of control. Although problematic social media use has been based upon framework characterizing a behavioural addiction, it is currently not part of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5). Both substance-related and non-substance related addictive disorders have been associated with functional and structural reward system deficits, including the striatum. Morphological abnormalities to the putamen and pallidum regions of the striatum have been found in behavioural addictions such as gambling disorder, suggesting these regions may be implicated in addictive behaviours. The neurobiological basis of problematic social media use has yet to be investigated. Therefore, the present study aimed to investigate volumetric and shape differences in the striatum in association with both problematic social media use and frequency of social media use. Increased problematic social media use was positively associated with higher frequency of social media use, but not with the number of years using social media. Higher levels of problematic social media use and increased frequency of social media use were not significantly related to the volume of the striatum. However, when examining the shape of the striatum, surface area deformations of the left and right putamen and pallidum regions of the striatum were significantly associated with higher problematic social media use scores. Frequency of social media use was not associated with any morphological alterations to the striatum. Considering the reward system alterations in the current study, problematic social media use may represent an adverse pattern of use distinct from frequency of social media use. We call for continued research to further validate problematic social media use as a behavioural addiction.
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I would like to dedicate this thesis to my parents. I would not be where I am today without their unconditional love, endless encouragement in following my dreams, and of course the daily dad jokes to brighten my day.
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Towards a Better Understanding of the Neurobiological Basis of Problematic Social Media Use in Young Adults

Social media platforms exist with the primary function of content sharing, where users can create profiles, share information publicly, view content and interact with other users (Wadsley et al., 2021). The development of social media platforms has advanced communication, allowing for rapid and accessible connectivity among individuals across the globe (Andreassen et al., 2017). However, negative mental health effects have been identified among individuals who use social media at higher frequencies such as depressive symptoms, anxiety, low self-esteem, loneliness, psychological distress, and overall lower well-being (Barry et al., 2017; Nishida et al., 2019; Primack et al., 2017; Sampasa-Kaneyinga & Lewis, 2015; Twenge & Campbell, 2019; Vannucci et al., 2017; Woods & Scott, 2016). In addition to higher frequencies, different patterns of social media use can also contribute to the extent to which negative mental health outcomes occur, such as passively browsing or scrolling through social media sites (Aalbers et al., 2019; Thorisdottir et al., 2019), engaging with a higher number of social media platforms (Barry et al., 2017; Primack et al., 2017), motivations related to social status (i.e. seeking social gratification) (Sun & Zhang, 2021) and using social media as an avoidance coping strategy (Blachnio et al., 2017; Marino et al., 2018). Despite the evidence of adverse mental health being associated with higher frequencies of social media use or intensity of use, the relationship between problematic patterns of social media use and negative mental health outcomes appear stronger (Cunningham et al., 2021; Shannon et al., 2022).
Problematic Social Media Use

Both excessive engagement and adverse patterns of social media use can contribute to maladaptive behaviours characterizing problematic social media use (Griffiths et al., 2014; Sun & Zhang, 2021). Problematic social media use is defined not only by frequency of use, but by measuring symptoms related to addictive disorders (Banyai et al., 2017). The fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (5th ed.; DSM-5; American Psychiatric Association, 2013) includes two subdivisions to the category of Substance-Related and Addictive Disorders, consisting of substance-related and non-substance-related disorders. Since non-substance-related disorders do not involve consumption of a psychoactive substance, these disorders are commonly referred to as behavioural addictions (Kardefelt-Winther et al., 2017). Currently, in terms of behavioural addictions, gambling disorder is the only diagnosable disorder in the DSM-5. As part of its appendix, the DSM-5 includes internet gaming disorder as a potential disorder for future consideration and requesting further research (5th ed.; DSM-5; American Psychiatric Association, 2013). Although increasing evidence suggests substantial overlap between behavioural addictions and substance use disorders, pathological gambling remains to be the most extensively researched behavioural addiction, leaving insufficient data for the classification for other behavioural addictions such as problematic social media use (Grant et al., 2010); (Henzel et al., 2021). Since problematic social media use does not represent a diagnostic term (yet), a combination of diagnostic criteria within the behavioural addiction framework has been adopted to identify behaviours that might be characterizing problematic social media use (Cheng et al., 2021); (Griffiths, 2005). These criteria are 1) using in order to reduce negative feelings, 2) experiencing tolerance (needing to be on social media for longer periods of time), 3) functional impairment, 4) loss of control, 5) withdrawal
symptoms, and 6) salience (Griffiths, 2005). Those criteria are integrated into and measured by the Bergen Facebook Addiction Scale (Andreassen et al., 2012) and by an adapted version of this scale that has been validated to measure social media sites in general (Andreassen et al., 2017). Typically problematic social media users tend to exhibit attributes of behavioural addiction, along with devoting more time to being online and having stronger motivations for logging on to social networking sites compared to non-problematic social media users (Hussain & Griffiths, 2018). There is considerable variation in the predicted prevalence of problematic social media use depending on geographical location, however it is estimated to range between 1% and 34% of the population (Henzel et al., 2021).

Social Media Use in Young Populations

The prevalence of problematic social media use is more common in younger populations, as they are now among the first generations to grow up in a society that is highly saturated with technology (Andreassen et al., 2017). From 2014 to 2016, social media use increased from 89.42% to 97.5% in young adults residing in the US (Villanti et al., 2017). A recent study found individuals between the ages of 16-34 had the highest levels of problematic social media use (Henzel et al., 2021). In addition to being more prominent in adolescence and young adults, increased problematic social media use is more likely among those who identify as female (Ryan et al., 2014; Banyai et al., 2017), single individuals (Kuss et al., 2014), individuals scoring highly on narcissism, and in those with low self-esteem (Andreassen et al., 2017). Therefore, wide variations in the prevalence rates of problematic use are presumably due to sample differences such as age and social behaviours based on cultural values in different geographical locations (Banyai et al., 2017; Cheng et al., 2021).
The Reward System

A rich body of research demonstrates that substance use disorders are associated with brain changes in key circuits implicated with reward, such as alterations to the mesolimbic and mesocortical dopamine systems (Wise, 2009). Behavioural addictive disorders such as gambling disorders, show similar reward deficits and inhibitory control impairments in the brain (Koob & Volkow, 2016). Some scholars suggest social media use may target these same circuits (Meshi et al., 2013; Turel et al., 2014; Sherman et al., 2016). Striatal connections with the amygdala underlie cue-behaviour-reward associations, driving impulsivity, motivation, and strengthening of reward value (Cardinal et al., 2002). Furthermore, increased striatal activity is positively associated with levels of problematic Facebook use (Turel et al., 2014), and is observed in both substance use and other behavioural addictions (Fareri & Delgado, 2014). Social media provides social reward to users based off of numerous motives (e.g. need for approval, acceptance, maintaining connections, etc.) that elicit comparable activity in the brain to substance-based rewards (Davey et al., 2010; Fareri & Delgado, 2014; Wadsley et al., 2021). Thus, it is possible that increased social media use may drive striatal changes; however, to date, this has not been explored.

Functional Connectivity of the Reward System and Social Media Use

Evidence from functional imaging data suggests behaviours associated with social media use target the reward circuits. One group investigated the neural correlates of the social media experience by developing an fMRI paradigm that mimics Instagram in the scanner (Sherman et al 2016). Participants would view photos and decide to either like the photo or skip to the next photo (Sherman et al 2016). Greater activation in striatal
subregions, such as the nucleus accumbens, caudate, putamen, and in the ventral tegmental area, occurred when participants viewed both their own photos and photos of others’ with more “likes” compared to their own photos and photos of others with fewer “likes”. As this study consisted of high school aged participants, Sherman et al., (2017), aimed to replicate these findings in a college-aged sample. In both high school and college-aged participants, significant increased activation of the left and right nucleus accumbens was observed when viewing photos that received more “likes”. When comparing high school and college-aged participants the extent to which the nucleus accumbens was activated when viewing these photos did not significantly differ between the groups. (Sherman et al., 2017). Although this functional imaging data suggests Instagram behaviours associated with social media use target the reward circuits, more research is still needed on problematic social media use.

Volumetric Alterations of the Striatum and Social Media Use

Volumetric reductions to subcortical structures (i.e. the striatum) have been reported cross-sectionally in individuals with substance use disorders and behavioural addictions, such as gambling disorder, versus those without a disorder (Rahman et al., 2014; Yip et al., 2018). The striatum is composed of subregions (see Figure 1) that have been identified to have particular functions in reward processing (Fareri & Delgado, 2014). The dorsal striatum (i.e. caudate nucleus and putamen) have been associated with cognitive and motor features of reward, whereas the ventral striatum (i.e. nucleus accumbens, ventral caudate, and ventral putamen) has been associated with reward seeking and outcome (Fareri & Delgado, 2014).

Even though social media behaviours have been associated with reward system dysfunction, there are very few and inconsistent findings on the impact of social media use
on the structural morphology of the reward system (He et al., 2017; Turel et al., 2014). Two studies have reported volume reductions of the striatum to be linked with higher frequency of social media use and excessive use (He et al., 2017; Montag et al., 2017). When examining compulsive Facebook use in 62 participants from the general population, a reduction in gray matter volume of the ventral striatum was found among individuals who had high levels of compulsive Facebook use versus individuals who had low-medium levels of compulsive use (He et al., 2017). Similarly, in a student population consisting of 50 participants, a reduction in the volume of the nucleus accumbens was associated with higher daily frequencies of checking Facebook and the duration of time actually spent on Facebook (Montag et al., 2017). Structural abnormalities could underlie the maladaptive reward processing as a result of the reinforcement social media provides, and therefore perpetuate problematic use behaviours (Montag et al., 2017). Volumetric changes to the striatum remain to be investigated in problematic social media use.

Figure 1. Subregions of the striatum.

Shape Alterations of the Striatum and Social Media Use

Structural neuroimaging studies have identified volume reductions of the striatum in regards to social media use, however shape differences have not previously been explored.
in association with social media use (Montag et al., 2018). Examining shape differences provides a more sensitive morphological measure by capturing dimensional variation in a structure, rather than standard volumetric analysis (Copersino et al., 2019). For instance, a previous study in patients with a substance use disorder found significant striatal shape differences when performing shape analysis compared to healthy controls that volumetric analysis did not capture (Garza-Villarreal et al., 2017). In this case shape analysis was able to pinpoint a specific region of the striatum, where a significant difference was found in the ventral striatum of cocaine users, while volume analysis remained non-significant. Interestingly, striatal morphology can differ based on the type of drug(s) consumed, the number of substances being used, and the length of exposure (Copersino et al., 2019). Both lateral and medial shape differences have been found with cocaine exposure (Wheeler et al., 2013), whereas shape differences associated with tobacco cigarette craving were specific to the dorsal striatum (Janes et al., 2015). When examining behavioural addictions, shape abnormalities were found in the bilateral pallidum and left putaman in individuals with a gambling disorder compared to individuals without a gambling disorder (Grant et al., 2019). Since problematic social media use shares similar reward deficit features with substance-related and non-substance-related disorders, levels of problematic social media use could be associated with similar volumetric and shape differences of the striatum.

The Reward System and Problematic Social Media in Young Adults

Emergence into adulthood is an important time where individuals typically experience increased autonomy and less parental monitoring (Stockdale & Coyne, 2020). Chronic patterns of use that lead to substance use disorders often begin to occur in young adulthood (Johnston et al., 2015). High exposure to social media has the potential to
influence brain plasticity, rendering young adults vulnerable to developing problematic social media use (Cataldo et al., 2020; Stockdale & Coyne, 2020). Young adults commonly display limited prefrontal control in addition to elevated striatal activity, resulting in an increased sensitivity to reward (Lorenz et al., 2014). Vulnerability specifically to social reward has been demonstrated in this population and reflected in different social media activities, including frequency of Facebook use and viewing images with a high number of likes (Meshi et al., 2013; Crone and Konikn, 2018; Sherman et al., 2018). With increased ventral striatal hyperactivity in young populations, using social media at younger ages could increase risk for the development of problematic social media use (Lorenz et al., 2014). Therefore, it is imperative to investigate if structural changes occur within the striatum in young adults that experience problematic social media use.

Previous research has only examined the volume of the striatum in association with frequency of social media use and in Facebook use. Since the reward system seems to be implicated in behavioural addictions, examining the volume of the striatum in problematic social media use could confirm if structural alterations are seen similarly in problematic social media use. Furthermore, to our knowledge the shape of the striatum has not been previously investigated in the context of problematic social media use.

**Study Aims and Hypotheses**

The general objective of this thesis is to explore whether morphological changes in the striatum are associated with problematic social media use compared to frequency of social media use. More specifically, this thesis will explore two research aims: 1) determine whether higher frequencies of use and higher levels of problematic social media use among
young adults are associated with lower volume of the striatum; 2) examine whether the shape of the striatum, as measured by surface area, is associated with greater frequencies of use and/or problematic social media use.

Based on previous research of the reward system in substance-related and non-substance-related disorders, it is hypothesized that a reduction in volume of the striatum will be associated with greater problematic social media use and higher frequencies of social media use. We also hypothesize that surface area deformation of the striatum will occur with greater problematic social media use and higher frequencies of social media use, particularly in regions previously associated with non-substance related addictive behaviour, such as the pallidum and left putaman.

Methods

Participants

The study recruited 24 youth aged 15-25 from the Ottawa area via flyers and social media advertisements. Participants were excluded if they had: (1) a diagnosis of a mental health disorder; (2) a significant neurological or medical disorder that may produce cognitive impairment; (3) current epilepsy or a previous history of seizures; (4) a previous head injury with continuing symptoms; (5) a history of problematic substance use or dependance in the last 6 months or previous treatment for drug or alcohol use; (6) MRI contraindications. However, based on these criteria none of the participants were excluded from participation or analysis.
**Procedure**

Participants came into the laboratory at the Royal’s Institute of Mental Health Research on the day of their study visit. A detailed description of the study, roles and responsibilities were explained to the participants. Written informed consent was obtained (REB#2019033, CUREB-B #116463). Participants completed the Bergen Social Media Addiction Scale, followed by an magnetic resonance imaging scan at the Royal’s Brain Imaging Centre. As the current study is part of a larger study, participants completed additional questionnaires over a period of two study visits and received monetary compensation at the end of their second visit.

**Social Media Measure**

The Bergen Social Media Addiction Scale (Andreassen et al., 2012) is an 18-item scale which reflects elements of addiction. Individuals score themselves on each item on a 5 point Likert scale, ranging from ‘Very often’ to ‘Very Rarely’. There are 3 items addressing each of the 6 core elements of addiction previously outlined by Griffiths (2005). The BSMAS evaluates negative life situations reported by participants attributed to social media use. It has been validated in multiple versions including; Thai (Phanasathit et al., 2015), Greek (Dadiotis et al., 2021), Persian (Lin et al., 2017), Italian (Monacis et al., 2017), Portuguese (Pontes et al., 2016), Chinese (Leung et al., 2020) and Romanian (Stanculescu, 2022). Previously a cut-off score of 19 was recommended to determine problematic use based on the 6-item BSMAS scale (Banyai et al., 2017), however more recently scholars have suggested a total score of 24 should be considered the gold standard on the 6-item BSMAS (Luo et al., 2021). In the current study, we also assessed which social media platforms were
used by our participants with an additional question. This modified scale was used to assess problematic social media use among participants (see Appendix B).

Participants were asked two additional questions about their social media use. First, how many years they have used social media for. Secondly, on average how much time per day they have spent on social media in the past week.

**Neuroimaging**

A 3T Siemens Biograph mMR PET-MR scanner was used at the Royal’s Institute of Mental Health Research to obtain structural magnetic resonance imaging data. The MRI scan consisted of a high-resolution 3D MPRAGE sagittal sequence to obtain the T1-weighted images for structural analysis. Images were acquired using the following parameters (TR=2.5s, slices = 192, matrix = 256 x 256, voxel size = 1.0 mm x 1.0mm x 1.0mm). Preprocessing of T1-weighted images was done using the minc bpipe library (https://github.com/CobraLab/minc-bpipe-library). Quality control for motion artifacts was performed on all scans by visual inspection. Motion artifacts were graded on a scale (1 = no motion, 2 = small to moderate motion, 3 = severe motion). Total intracranial volume was estimated using Freesurfer 7.1.1 to control for variability among participants.

The striatum was segmented automatically from the pre-processed T1-weighted images using the Multiple Automatically Generated Templated (MAGeT) Brain segmentation algorithm (Chakravarty et al., 2013). This method of segmentation provides more reliable results than manual segmentation by utilizing a template library of a subset of unlabeled participants (Treadway et al., 2015). Previously, a three-dimensional reconstruction of the striatum was developed using histological data that warped to an MRI template (Holmes et
al., 1998); (Chakravarty et al., 2006). A subsample of 10 participants were used from the cohort being studied as templates to which striatal volume of all other subjects will be segmented. Advanced Normalization Tools (ANTS) match each atlas to the templates to generate surface-based models to estimate surface deformation of each subject by using linear and non-linear transformation estimates (Avants et al., 2008). To ensure homology a Voronoi diagram was then used to redefine surface vertices (Lyttelton et al., 2009). Surface area was then represented as a sum for each polygon on the surface of the striatum. MAGeT segmentations for each participant were graded for quality by visual inspection. Striatal segmentation quality was also graded on a 3 point scale (1 = label accurately covers the striatum in all slices, 2 = small over or under segmentation errors in a few slices, 3 = severe over or under segmentation errors in all slices). All scans were graded as a 1 or 2, therefore no participants were excluded based on severe segmentation errors.

**Statistical analyses**

All behavioural data was stored on REDCap and exported to R (version 3.6.1), to perform analyses. First, descriptive statistics on participant demographics and social media platforms were run in R. Pearson correlations were used to examine the relationship between frequency of social media use and BSMAS score, and between years using social media and BSMAS scores.

Imaging data analysis of the striatum was performed using R for volumetric analysis and using the SurfStat toolbox (https://www.math.mcgill.ca/keith/surfstat/) in Matlab (version R2021b) for shape analysis. First we used a general linear model to investigate volumetric analysis of the striatum. Total striatum volume was inputted in the model as the dependent variable and BSMAS as the independent variable, with age, sex, ethnicity,
intracranial volume, and handedness of participants entered as covariates. To analyze frequency of social media use, these same linear models were used, however frequency of social media use was inputted in the model as the independent variable.

To investigate shape differences, a general linear model was used with surface area as a dependent variable and BSMAS scores as the independent variable. False discovery rate (FDR) corrections (with $p < .05$ corrected) were applied across all vertices of the striatum (6178 vertices on the left and 6450 vertices on the right) to correct for Type 1 error. Again, age, sex, ethnicity, intracranial volume, and handedness of participants were entered as covariates in the model. Similarly, to analyze shape difference with frequency of social media use, frequency of use was inputted in the model as the independent variable with the same covariate.

Bilateral striatal volume changes across the lifespan, therefore age was included as a covariate to account for natural fluctuations in striatal volume with age (Tullo et al., 2019). In terms of sex differences, males tend to exhibit larger striatal volume than females (Duerden et al., 2020). In addition, a recent study found volume and surface area of subcortical brain regions and cortical thickness differ between sexes (Forde et al., 2020). Ethnicity was also included as a covariate seeing that neural activity in brain regions associated with social behaviour has previously been found to differ between ethnic groups, and therefore may influence volume and shape of the striatum (Mathur et al., 2012). Total intracranial volume (i.e. volume of the total brain within the skull) was used as a covariate to account for variations in striatal volume as a result of differences in head size between participants (Whitwell et al., 2001). Finally, handedness was included as a covariate as neuroimaging evidence suggests functional and structural asymmetries in the brain can vary depending upon right or left hand dominance (Panta et al., 2021).
Results

Participant Characteristics

The current study included 24 participants ranging from 18-25 years of age, with a mean age of 22.21 years (SD = 1.96). Over half of the participant reported their biological sex as female (n = 16). Participant ethnicity was self-reported as 75.0% Caucasian, 12.5% Asian, 8.3% Black, and 4.2% Indigenous. Of the participants, 62.5% had partially completed a college diploma or university degree, 25.0% had completed an undergraduate degree or college diploma, and 12.5% had completed a graduate or professional degree.

Social Media Characteristics

Total scores on the BSMAS ranged from 20 to 61, with a mean score of 43.21 (SD = 12.29). Based on the original cut-off score suggested by Banyai et al., (2017), 7 participants are considered to have problematic social media use in our sample. When asking participants to select which social media platforms they use, the most commonly used social media site was Instagram, with 23 out of 24 participants reporting they used the platform (see Table 1). Levels of problematic social media use did not significantly differ between social media platforms used (p = 0.99) (See Figure 2).

The number of years participants have used social media ranged from 2 years to 14 years, with a mean of 10.76 years (SD = 1.34). Frequency of social media use ranged from 45 minutes a day to 6.5 hours a day, with a mean of 3.8 hours per day (SD = 2.12). Bergen Social Media Addiction scores were not significantly correlated with the number of years using social media (r = 0.06, p = 0.81), however they were significantly positively correlated with frequency of social media use (r = 0.53, p = 0.01).
Table 1. Number of participants reporting usage of each social media platform.

<table>
<thead>
<tr>
<th>Social Media Platform</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instagram</td>
<td>23</td>
</tr>
<tr>
<td>Facebook</td>
<td>19</td>
</tr>
<tr>
<td>Snapchat</td>
<td>19</td>
</tr>
<tr>
<td>TikTok</td>
<td>11</td>
</tr>
<tr>
<td>Twitter</td>
<td>6</td>
</tr>
<tr>
<td>Reddit</td>
<td>4</td>
</tr>
<tr>
<td>VSCO</td>
<td>2</td>
</tr>
<tr>
<td>LinkedIn</td>
<td>1</td>
</tr>
<tr>
<td>Tumblr</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 2. Mean BSMAS scores for each of the top 5 social media platforms.

Volume Analysis of the Striatum

We did not observe significantly lower volume of the left striatum ($t_{(14)} = -1.416, p = 0.179$) (see Figure 3) or right striatum ($t_{(14)} = -1.013, p = 0.328$) (see Figure 4) to be associated with greater problematic social media use, as measured by the BSMAS. No other factors
were significant in the regression, except for age ($t_{(14)} = 3.558, p < 0.003$) on the left striatum, and ($t_{(14)} = 3.213, p < 0.006$) on the right striatum.

**Figure 3.** Association between the total volume of the left striatum and Bergen Social Media Addiction scores.

**Figure 4.** Association between total volume of the right striatum and Bergen Social Media Addiction scores.
Frequency of social media use was not significantly associated with left ($t_{(14)} = -1.303$, $p = 0.214$) (see Figure 5) or right ($t_{(14)} = -1.456$, $p = 0.168$) (see Figure 6) total striatum volume.

Figure 7. Association between the total volume of the left striatum and frequency of social media use.

Figure 8. Association between total volume of the right striatum and frequency of social media use.
Shape Analysis of the Striatum

A significant association was found between both left striatal surface area and right striatal surface area with the Bergen Social Media Addiction scores (see Figure 7).

Figure 7. Significant t-statistics (p<0.05) for surface area deformations in the left and right striatum based on BSMAS scores. Areas in gray were not significant.
On the left striatum, 5 clusters and 9 peaks were significant, mostly seen on the putamen (see supplementary Table 1 in Appendix A). On the right striatum, 6 clusters and 8 peaks were significant, similarly seen on the putamen (see supplementary Table 2 in Appendix A). Clusters are groups of multiple voxels that have a uniform p-value, whereas peaks represent a single significant voxel with a distinct p-value. The largest effect size was observed on the left putamen (see Figure 8) at peak (MNI coordinates: $x = 28.4185, y = 13.7217, z = 2.1618$), with a t-value of 6.506 ($p = 0.002$). This association was similar in men and women (see supplementary Figure 1 in Appendix A). There were no significant associations between left or right striatal surface area and frequency of social media use.

![Figure 8](image.png)

**Figure 8.** Example of the direction of the association between BSMAS scores and surface area on the left putamen, at MNI coordinates $x = -28.4185, y = 13.7217, z = 2.1618$. The t-value of this peak is 6.506 ($p = 0.002$).

### Discussion

#### Summary of Findings

The present study aimed to investigate volumetric and shape differences in the striatum in association with both frequency of and problematic social media use. There
were no significant reductions in volume of the left or right striatum with higher levels of problematic social media use or frequency of use. However, when examining the shape of the striatum, smaller surface area of the left and right putamen and pallidum regions of the striatum were significantly associated with higher problematic social media use scores, but did not relate to frequency of social media use. These results add to the literature on social media use by providing neuroimaging evidence that striatal deformations in the reward system are associated with problematic social media use, but not frequency of social media use. The neurobiological alterations in the dopaminergic mesolimbic pathways observed with problematic social media use share similarities across substance-related and non-substance-related addictive disorders (Grant at al., 2010; Koob & Volkow, 2016; Meshi et al., 2013; Turel et al., 2014).

Although problematic social media use has been based upon framework characterizing a behavioural addiction, there is still a lack of a diagnostic term identified by the Diagnostic and Statistical Manual of Mental Disorders (DSM-5). In the current study, higher frequencies of social media use were positively associated with increased problematic social media use. The incentive-sensitization theory of addiction puts forward the notion that hypersensitization of the reward system can occur with repeated exposure to pleasurable stimuli (Seo & Ray, 2019; Sun & Zhang, 2021). While it is possible that higher frequencies of social media use play a role in the development of problematic social media use as a result of increased exposure to rewarding stimuli. Frequency of use was not associated with any morphological alterations to the reward system. This finding suggests problematic use is a unique pattern of maladaptive use that is distinct from how often an individual is using social media platforms.
Lower volume of the nucleus accumbens has been associated with higher frequency of Facebook checking and duration of time spent on Facebook (Montag et al., 2017). This study did have a larger sample size (N = 62) than the current study, therefore it is possible frequency of social media use has more mild effects on the striatum that may be significant with a larger sample size. Since the nucleus accumbens is associated with impulsivity, Montag et al., (2017) suggested checking Facebook more often could be a result of higher impulsivity. Frequency of social media use could indirectly indicate traits such as higher impulsivity, that may lead to the development of problematic use. Problematic social media use may have a larger effect on striatal deformities, and could be a more meaningful behavioural pattern to study.

Previous neuroimaging evidence has established that striatal activity is influenced by predictors of reward (Knutson et al., 2001; Rademacher et al., 2010), the magnitude of a reward (Abler et al., 2009; Yacubian et al., 2007), and behavioural outcomes associated with reward attainment (Cromwell & Schultz, 2003). The striatal shape deformations associated with greater problematic social media use in the current study provides evidence of similarities between problematic social media use and other substance-related and non-substance related disorders. The shape deformations that were associated with greater problematic use were specifically significant in the putamen and pallidum regions of the striatum. Morphological alterations to the putamen and pallidum have been previously found in young adults aged 18-29 with a gambling disorder compared to healthy controls (Grant et al., 2019).
Striatal Alterations and Social Media Use

Potential Role of the Putamen

Our data shows the greatest surface area deformations in the putamen region of the striatum in association with greater problematic social media use. The putamen is responsible for habit learning, with dysfunction being previously linked to substance use disorders (Sjoerds et al., 2013; Tricomi et al., 2009). Activation of the putamen has been associated with reward prediction (O’Doherty et al., 2003) and outcome (Breiter et al., 2001), with higher activation observed once a reward has been attained (Haber & Knutson et al., 2009). Structural alterations to the putamen have been found with the use of various substances that provide reward such as nicotine (Janes et al., 2015), stimulants (Mackey et al., 2014), and cocaine (Jacobsen et al., 2011). In nicotine-dependent individuals, morphological analysis of the striatum revealed a significant association between the shape of the putamen and caudate with cue-induced craving, but not subjective craving on its own (Janes et al., 2015).

Habitual repetitive behaviour of checking social media without a specific purpose encourages compulsive use, as many social media platforms are designed to show an endless supply of content, facilitating prolonged use (Montag et al., 2019; Noe et al., 2019). Passing the time by using social media as an escape mechanism has previously been shown to predict problematic use (Brailovskaia et al., 2020; Gao et al., 2019). Since the putamen is involved in stimulus driven habit formation, the shape deformations seen in the putamen in association with problematic social media use could be a result of social reward attainment and craving from continued habitual social media use (Ersche et al., 2021).
Potential Role of the Pallidum

Surface area deformations were also present in the pallidum region of the striatum in association with greater problematic social media use. The pallidum has been linked to hedonic aspects of reward, specifically drug seeking behaviour and reinstatement of drug seeking behaviours (Berridge & Robinson, 2016; Pecina et al., 2006; Smith & Berridge, 2007). The pallidum has become a target for treatment to regulate relapse for substance use disorders including cocaine, heroin, and alcohol (Kupchik et al., 2021). On the other hand, shape abnormalities of the pallidum have been associated with higher impulsivity scores in individuals with gambling disorders (Grant et al., 2019). We suggest the deformations present in the pallidum are a result of the interplay between impulsivity and reward seeking in problematic social media use. However, further investigation should be done to explore the role of the pallidum in problematic social media use.

Social Media Use and the Developing Brain

Young adults are in a developmental period rendering them vulnerable to social reward (Caraldo et al., 2020). With high levels of social media use among young adults, the rewards that social media provides remain to be evaluated in the context of a behavioural addiction. The reward system can become sensitized to repetitive rewarding behaviours, contributing to continuous craving for reward (Robinson & Berridge, 2001). Factors such as spending more time on social media in conjunction with impulsive tendencies and craving for social gratification could put young adults at risk for developing problematic social media use. In our study, almost 30% of participants qualify for problematic use based on the original cut-off score suggested by Banyai et al., (2017).
As a result of their developmental period, there is reduced connectivity between cognitive control and subcortical structures involved in reward processing in young populations (Marciano et al., 2021). Previous evidence did not find a difference between problematic social media use between younger adolescents and young adults, however psychopathological risk for the development of problematic use did differ between ages (Cerniglia et al., 2019). In our study, problematic social media use scores did not differ based on age within our sample of young adults. Age was a significant factor in the association between volume of the left and right striatum and problematic social media use, however this is likely due to the natural changes in striatal volume with age (Tullo et al., 2019).

**Strengths**

This thesis revealed a lack of literature examining the neurobiological basis of problematic social media use. Frequency of checking and compulsive Facebook use have previously been associated with volume of the ventral striatum, however presently there is no neuroimaging evidence to confirm the role of the reward system in problematic social media use. The current study is the first to investigate volume and shape deformations of the striatum in association with levels of problematic social media use. Utilizing shape analysis of the striatum is a more sensitive measure, and can detect morphological changes (Copersino et al., 2019). With shape analysis, we were able to identify structural deformations to the putamen and pallidum with higher problematic social media use scores. These regions of the striatum are key in patterns of addictive behaviour that relate to problematic social media use. In addition, providing such novel neurobiological evidence of alterations to the morphology of the striatum with greater levels of problematic social media use, confirms the role of the reward system. The striatum morphology put forth by
this study is in line with reward deficit features in behavioural addictions, such as gambling disorder (Grant et al., 2019). While more investigations are needed, our findings provide some support for the addition of problematic social media use to the DSM-5 as a non-substance-related disorder (i.e. behavioural addiction).

Limitations

A small sample size is a limitation for the current study, as a result of the COVID-19 pandemic. While 24 participants were included, it would be beneficial to have a larger sample size to confirm if volumetric reductions to the striatum could become significant with stronger statistical power. The neurobiological results of the current study are heterogeneous, therefore it is possible that they may become insignificant with a larger sample size. Since problematic social media use is still not an official diagnosis, scholars question whether it should be considered a behavioural addiction or if activities such as social media use are being over pathologized (Griffiths, 2012; Billieux et al., 2015). Therefore, future research in addition to a larger sample in the current study is important in accurately defining and classifying problematic social media use. Secondly, the data is cross-sectional and therefore we cannot imply causality in the relationship between problematic social media use and morphological deformations to the striatum. It is unknown if alterations to the reward system may predispose individuals to developing problematic social media use, or if problematic social media use behaviours cause changes to the reward system over time. Similarly, this bi-directional effect is also unclear in substance use disorders (Kim-Spoon et al., 2022). Neurodevelopmental abnormalities could act as risk factors predisposing individuals to substance use disorders, or longer and greater quantities of substance use could result in abnormalities to the reward system (Kim-Spoon et al.,
Finally, it is unknown how long individuals have been using social media in a way that is considered problematic. It is unclear how long problematic social media use might need to occur in order to see morphological alterations to the striatum. While an individual may score high on the Bergen Social Media Addiction Scale, we cannot infer how long they have used social media in a problematic way when determining its direct effect on striatal morphology.

**Future Directions**

Although the current study adds to the neuroimaging evidence of the implication of the reward system in problematic social media use, there is still much to be determined about this relationship. Longitudinal studies could aid in understanding the directionality of the relationship between problematic use and alterations to the reward system. Albeit reward system dysfunction is present in problematic social media use, factors that may lead to vulnerability in developing problematic use remain unclear. Personal traits such as impulsivity (Barber et al., 2021; File et al., 2022) and narcissism (Casale & Banshee, 2020) have been associated with problematic social media use. There is also a strong relationship between traumatic experiences and substance use, which has yet to be examined in problematic social media use (Simmons & Suarez, 2016).

Motivations underlying the drive for social reward such as self-expression, social comparison, fear of missing out, etc. may facilitate social media use (Wadsley et al., 2021). Self-expression by disclosing information on social media platforms can be rewarding in itself for some, however this can be especially detrimental if users rely on publicly expressing certain aspects that they perceive to be more desirable to others in order to gain affirmation via “likes” (Tamir & Mitchell, 2012; Toma & Hancock, 2013). Along with self-
expression on social media profiles comes social comparison. Although negative self-comparisons on social media can contribute to negative mental health, upward social comparisons can act in an opposite way by boosting self-esteem and driving users to compulsively seek higher social status (Nesi & Prinstein, 2015; Vogel et al., 2014).

Likewise, fear of missing out can occur when viewing social media content from other users. Although fear of missing out often creates feelings of anxiety and exclusions, it can intensify social media use by causing individuals to compulsively check social media in order to stay informed or maintain social connections (Przybylski et al., 2013). Associations between fear of missing out and problematic social media use are especially evident in adolescents and young adults (Blackwell et al., 2017; Oberst et al., 2017; Sheldon et al., 2021).

Incentives such as these can vary depending on the individual; however, the extent to which these motives drive an individual is important in understanding the impact on the reward system in the development of problematic social media use. Considering behavioural addictions do not involve consuming a substance, various factors of incentives and personal traits have been proposed to play a role in eliciting the reward response in the development and maintenance of problematic social media use (Wadsley et al., 2021).

Conclusions

The current study is the first to investigate striatum morphology in terms of both volumetric and shape analysis in association to problematic social media use. Significant surface area deformations were found in the striatum, mainly in the putamen and pallidum, in association with higher problematic social media. No morphological alterations of the striatum were present, in terms of volume or shape, in association with frequency of social
media use. These results confirm that reward system deficits are present with increased problematic use of social media. Analogous to substance use disorders and behavioural addictions such as gambling disorder, problematic social media use brings about a multitude of detrimental effects in terms of decreased mental health, poor sleep quality and impaired social relationships (Sun & Zhang, 2021; Wong et al., 2020). Considering the emerging negative effects and neurobiological results of the current study, continued research is necessary to further validate problematic social media use as a behavioural addiction.
Appendix A

Supplementary Figure 1. Association between BSMAS scores and surface area on the left putamen in females and males, at MNI coordinates $x = -28.4185$, $y = 13.7217$, $z = 2.1618$. 
### Supplementary Table 1. Peaks and clusters on the left striatum that are significant in association with BSMAS scores.

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### Supplementary Table 2. Peaks and clusters on the right striatum that are significant in association with BSMAS scores.

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Appendix B

The Bergen Facebook Addiction Scale (modified by replacing “Facebook” with Social Media)

How often in the past year have you:

1. Spent a lot of time thinking about social media or planned use of social media?
2. Thought about how you could free more time to spend on social media?
3. Thought a lot about what has happened on social media recently?
4. Spent more time on social media than initially intended?
5. Felt an urge to use social media more and more?
6. Felt that you had to use social media more and more in order to get the same pleasure from it?
7. Used social media in order to forget about personal problems?
8. Used social media to reduce feelings of guilt, anxiety, helplessness, and depression?
9. Used social media in order to reduce restlessness?
10. Experienced that others have told you to reduce your use of social media but not listened to them?
11. Tried to cut down on the use of social media without success?
12. Decided to use social media less frequently, but not managed to do so?
13. Become restless or troubled if you have been prohibited from using social media?
14. Become irritable if you have been prohibited from using social media?
15. Felt bad if you, for different reasons, could not log on to social media for some time?
16. Used social media so much that it has had a negative impact on your job/studies?
17. Given less priority to hobbies, leisure activities, and exercise because of social media?
18. Ignored your partner, family members, or friends because of social media?

All items are scored on the following scale: 1: Very rarely, 2: Rarely, 3: Sometimes, 4: Often, 5: Very often.

Adding:

19. What type of social media do you use?
   a. Facebook
   b. Instagram
   c. Snapchat
   d. Twitter
   e. VSCO
   f. TikTok
   g. Other (specify): ___________________

References


Kong and Taiwan among three internet-related addiction scales: Bergen Social Media Addiction Scale (BSMAS), Smartphone Application-Based Addiction Scale (SABAS), and Internet Gaming Disorder Scale-Short Form (IGDS-SF9) (Study Part A). *Addictive behaviors, 101*, 105969. https://doi.org/10.1016/j.addbeh.2019.04.027


