Social networking sites use and the morphology of a social-semantic brain network

Ofir Turel, **

- California State University, Fullerton, USA
- Brain and Creativity Institute, Department of Psychology, University of Southern California, USA

*Qinghua He***

- Faculty of Psychology, Southwest University, Beibei, Chongqing, China.
- Brain and Creativity Institute, University of Southern California, USA

Damien Brevers

- Medical Psychology Laboratory, Université Libre de Bruxelles, Belgium
- Brain and Creativity Institute, University of Southern California, USA

Antoine Bechara

- Department of Psychology and Brain and Creativity Institute, University of Southern California, USA

* Corresponding author contact information:

Hedco Neuroscience Building, 3641 Watt Way, HNB-28C, University of Southern California, Los Angeles, CA 90089-1061, USA. Ph: (657) 278-5613
Emails: oturel@fullerton.edu; ot_739@usc.edu

** These authors made an equal contribution to this paper.

Keywords: MRI, voxel-based morphometry, social networking sites, Facebook, social-semantic brain network

Social networking sites use and the morphology of a social-semantic brain network

Abstract:

Social lives have shifted, at least in part, for large portions of the population to social networking sites. How such lifestyle changes may be associated with brain structures is still largely unknown. In this manuscript, we describe two preliminary studies aimed at exploring this issue. The first study (*n*=276) showed that Facebook users reported on increased social-semantic and mentalizing demands, and that such increases were positively associated with people's level of Facebook use. The second study (*n*=33) theorized on and examined likely anatomical correlates of such changes in demands on the brain. Findings indicated that the grey matter volumes of the posterior parts of the bilateral middle and superior temporal, and left fusiform gyri were positively associated with the level of Facebook use. These results provided preliminary evidence that grey matter volumes of brain structures involved in social-semantic and mentalizing tasks may be linked to the extent of social networking sites use.

Keywords: MRI, voxel-based morphometry, social networking sites, Facebook, social-semantic brain network

---

The use of social networking sites (SNS), such as Facebook, Twitter, WeChat and Snapchat has dramatically increased. Facebook, for example, has 1.71 Billion monthly active users, out of which 1.13 Billion are daily active users (Smith, 2016). Moreover, 66.1% use this website daily to interact with an average of around 150 contacts, spend on average over 20 minutes on this site, and many (56%) visit Facebook multiple times per day; these numbers are much higher for young-adults (Smith, 2016).

This modern way of interaction involves changes in the way people socialize, share information, work, perceive others, and present themselves (Gil-Or, Levi-Belz, & Turel, 2015). These behavioral changes are important as they can, for instance, through "addiction" and problematic behaviors (e.g., using such sites while driving, instead of studying, or during meetings) adversely influence the psychological states, health, wellbeing and work/ academic performance facets of users (Turel & Qahri-Saremi, 2016). Given this broad set of influences on people's lives, recent calls have been issued to examine the brain structures associated with social media use (Meshi, Tamir, & Heekeren, 2015), and several studies already point to neural activation (Meshi, Morawetz, & Heekeren, 2013) and connectivity (Meshi et al., 2016) inter-individual differences that are associated with functions such as "liking" and sharing on social media. Less, though, is known regarding brain morphology associations with social media use levels, especially given the plausible shift in the social-semantic demands (i.e., neural tasks that involve recognizing social group members, retrieving semantic associations for them, and interpreting their states and motivations) that such patterns present to humans. Understanding these possible morphological associations is critical, because it can enhance knowledge regarding social media use and inform future intervention studies aimed at correcting social media related adverse states of some users. Once causality is established, this knowledge could also inform potential use of SNS in therapeutic interventions aimed at slowing down the decline of certain cognitive capacities in specific clinical groups. Hence, this paper makes initial strides toward this objective.

One of the important facets of SNS use is that it is arguably accompanied by an augmentation of the stream of social information a person needs to process and interpret. In the pre-SNS era people's network often included a limited set of social contacts, and their exposure to each member of the network was occasional. In contrast, with SNS individuals need to manage relationships with hundreds of contacts each of which is also connected to hundreds of people. Each one of these contacts often provides an almost constant stream of images, videos and texts that the person needs to process (Noonan et al., 2013). Moreover, the increase in one's social group sizes afforded by SNS is roughly paralleled by a corresponding decrease in the paralinguistic cues and clues that unfold over meaningful slices of time and that set the tone of our ordinary, as opposed to virtual, social interactions (Hayes, Carr, & Wohn, 2016). These two changes can create new demands on socio-semantic circuits in the brain (i.e., brain regions involved in assigning social meaning to one's environment), which may now need to be able to deal with the increased volume and speed of virtual cue interpretation (Hayes et al., 2016), mentalizing (Saxe, Carey, & Kanwisher, 2004), empathizing and systemizing tasks (Baron-Cohen, 2009). SNS use may particularly increase tasks related to identifying and classifying faces, and interpreting others' intentions and states based on image and text streams (Meshi et al., 2015). Such changes in demands on the brain can be associated with morphological differences in grey matter volumes (Draganski et al., 2004), especially in regions that are morphologically flexible (Kanai, Bahrami, Roylance, & Rees, 2012).

We conducted two studies aimed at enhancing the understating of the potential brain morphology associations with SNS (specifically Facebook) use. The first study was behavioral-descriptive. It tested hypotheses based on evidence from market statistics (Smith, 2016) and research (Deters & Mehl, 2013; Maier, Laumer, Eckhardt, & Weitzel, 2015; Meshi et al., 2016;

Meshi et al., 2015; Subrahmanyam, Reich, Waechter, & Espinoza, 2008), which point to substantial changes in the ways humans interact and consequently incur presumed demands on social-semantic brain networks. Based on such insights, we tested the hypotheses that (1) Facebook users face increased social-semantic and mentalizing demands (operationalized as seeing, identifying and classifying more faces of animals and people than before and have an increased need to interpret intentions and emotions on social media), and (2) that these patterns are positively associated with people's levels of Facebook use.

Given the observed increase in social-semantic and mentalizing demands and reported associations between these demands and the morphology of the bilateral middle and superior temporal gyri (Deng, Wei, Du, Hitchman, & Qiu, 2014; Lewis, Rezaie, Brown, Roberts, & Dunbar, 2011; Schneider-Hassloff et al., 2016) and the fusiform gyrus (Garrido et al., 2009; Greve et al., 2013), in Study 2 we hypothesized that the grey matter volumes (GMV) in these areas will be positively associated with the level of Facebook use. Reduction in grey matter volumes of these regions is often associated with social-semantic and mentalizing deficits, for instance in cases of autism, dementia, Alzheimer, psychopathy and prosopagnosia (Garrido et al., 2009; Gregory et al., 2012; Waiter et al., 2004; Wright et al., 2000) as well as with lower cognitive abilities (Mackey et al., 2015). Larger regional volumes can therefore be associated with improved ability to deal with socio-semantic and mentalizing demands, which are associated with Facebook use (as per Study 1). Note that we do not suggest that SNS use is mediated exclusively via these systems (e.g., it can be mediated via linguistic / narrative / conversational paths), but rather imply that the mentioned systems represent a theoretically reasonable starting point for examining links between brain morphology and the social-semantic demands imposed by SNS use.

STUDY 1

Materials and Methods

Participants

Three hundred university students who use Facebook were invited to participate in this study in exchange for bonus points. They signed an informed consent before completing the study, which has been approved by the university's Institutional Review Board. Two hundred and seventy six (123 women, M_{age}= 22.74, SD=4.28, Range=18 to 47) provided complete responses. The only inclusion criterion was Facebook usage. It was met by all respondents ($M_{\text{years on Facebook}}$=6.00, SD=2.7, Range=0.5 to 12).

Measures and Procedures

The participants completed an online survey which captured demographic information (age and sex) and Facebook use information (years on Facebook [open ended], days per week using Facebook [1=rarely/never; 5=almost daily; Range=1-5, *M*=3.88, SD=1.33], and hours per day using Facebook [1=below one hour; 6=more than 8 hours; Range=1-5, *M*=1.71, SD=0.90]. The items are based on common measures of social networking site use (Turel & Bechara, 2016). The product of "days per week" and "hours per day" of Facebook use captured the weekly number of hours a person spends on Facebook, and hence represented the Facebook use construct in this study [Range=1-25, *M*=7.06, SD=5.00].

The survey captured perceived enhancement in social-semantic demand as a result of Facebook use by employing two self-developed scales. The first one captured perceived increase and the second one captured perceived change (compared to before Facebook use) in social-semantic demand. The second one was added since it is potentially less biased; the direction of change (increase) is embedded in the first one.

The increase scale included the following three items: To what extent do you believe the use of Facebook has increased (1) the number of human faces you see, identify and classify on a daily basis?, (2) the number of animal faces you see, identify and classify on a daily basis?, and (3) the facial expressions you need to interpret? Scale anchors were 1=to a very low extent, and 5=to a very large extent. The change scale included the following three items: Does the use of Facebook expose you to more or less, compared to before you joined Facebook (1) human faces you need to identify, classify and interpret? (2) animal (e.g., dog) faces you need to identify and classify?, and (3) need to interpret people's emotions and intentions from their communications. Scale anchors were 1=much less, and 5=much more. These items were self-developed and were pilot-tested with a sample of 50 students. They were reliable in the pilot study (α=0.887 for perceived increase and α=0.860 for perceived change) and were approaching acceptable reliability in the main study (α=0.681 for perceived increase and α=0.773 for the perceived change scale).

Data Analysis

Data were first analyzed with one sample t-tests with scale midpoint (3) as a test value. In addition, one sample Bayesian t-test was applied to increase confidence in the findings. To convert t-tests and sample sizes to Bayes factors, we used Jeff Rouder's Bayes factor calculator (http://pcl.missouri.edu/bf-two-sample) with the recommended Jeffrey-Zellner-Slow (JZS) Prior with the default value of 0.707. We accepted the alternative hypothesis with a JZS $BF_{10} > 3$. Next, partial Pearson correlations (n=276) between the behavioral measures (increase and change in social semantic demands) and Facebook use (calculated hours per week), after controlling for age and sex, were estimated. Results were adjusted for multiple comparisons with Bonferroni corrections.

Results

Changes in Social-Semantic Demands

Averages and standard deviations for the scales were: increase scale: M=3.23, SD=0.051 and change scale: M=3.48, SD=0.045. The findings indicate that Facebook users, on average, believe that the use of Facebook has significantly increased their social-semantic demands (increase scale: $t(276) = 4.77$, $p < .001$, JZS BF10 = 1876.06; change scale: $t(276) = 10.74$, $p < .001$, JZS BF10 = 2.15E18). These results are also depicted in Figure 1. To further validate these results, bootstrapping (1000 re-samples) indicated that the bias-corrected 95% confidence intervals for the increase and change means are [3.130, 3.342] and [3.390,3.582], respectively.

Associations between Social-Semantic Demands and Facebook Use

An association analysis revealed that the calculated self-reported weekly hours a person spends on Facebook was significantly positively correlated with the average scores for the reported increase (r=0.230, p<0.001) and change (r=0.232, p<0.001) in social-semantic demands, after controlling for age and sex. To further validate these results, bootstrapping (1000 re-samples) indicated that the bias-corrected 95% confidence intervals for the "increase" and "change" in social-semantic demands correlations with Facebook use were [0.129,0.326] and [0.130,0.327], respectively.

STUDY 2

Materials and Methods

Participants

Thirty-three participants (21 females, M_{age}= 23.1, SD= 4.56, Range= 18 to 34) who reported using Facebook ($M_{\text{years of experience}}$ = 5.41, SD= 2.26, Range = 0.4 to 10; $M_{\text{number of contacts on Facebook}}$=738.6, SD=528.7, Range= 30 to 2,500) were recruited for this study using a university bulletin board. Exclusion criteria included (1) major neurological and psychiatric disorders (Psychoses, current major depression episode, a history of major depression episodes or major depressive disorder, heavy drinking, substance abuse, pathological gambling, schizophrenia, current and history of anxiety disorders, Bipolar disorder) which were captured using a computerized short version of the Structural Clinical Interview for DSM-IV Disorders (SCID) (2) use of medication that impact the central nervous system, which was captured in a questionnaire, and (3) uncorrected abnormal vision, which was self-reported in a questionnaire . No exclusions were made. All participants gave informed consent to the study procedures, which were approved by the Institutional Review Boards of two American universities.

Behavioral Measures

The level of Facebook use was captured with principal component scores (-1.28 to 2.49) of two items, each of which is a calculated number of weekly hours a participant typically spends on Facebook (α=0.812). The items are based on common measures of SNS use (Turel & Bechara, 2016). The first item was calculated by multiplying open ended self-reported measures of days per week on Facebook by hours per day on Facebook (both reported to the second decimal). The second item used the product of Likert-type questions capturing days per week (1=never, 5=Daily) and hours per day (1=less than 1, 6=more than 8). Means for the first and second items, correspondingly, were 9.78 (SD=7.33) and 12.82 (SD=7.40). The first mean can be directly interpreted; it implies that an average person in our sample used Facebook for almost 1.4 hours a day.

MRI Protocol

After signing the consent form and completing the behavioral interview, screening procedure, and a survey capturing demographics and behavioral measures, participants went through a 30-minute MRI scan. All MRI images were acquired using a 3T Siemens MAGNETOM Tim/Trio scanner at a research university. Participants lay in the supine position on the scanner bed. Foam pads were used to minimize head motion. They were instructed to keep their head very still during the scan. The structural imaging was performed using T1-weighted 3D-Magnetization Prepared RApid Gradient Echo (MPRAGE) sequence, covering the whole brain with the following scanning parameters: TR/TE = 2530/3.39 ms, flip angel = 7°, matrix = 256 x 256, number of sagittal slices = 128, and slice thickness = 1.33 mm.

Voxel-based Morphometry Analysis

Data were analyzed with FSL-VBM, an optimized voxel-based morphometry (VBM) analysis toolbox implemented in FSL. This approach requires no prior information about the location of possible correlates of grey matter, and has been proven to be operator independent. First, structural images were extracted using Brain Extraction tool. Next, tissue-type segmentation was carried out using Fmrib's (Oxford center for Functional Magnetic Resonance Imaging of the Brain) Automated Segmentation Tool 4. Resulting grey-matter partial volume images were then aligned to the grey-matter template in the MNI152 standard space using the affine registration tool Fmrib's Linear Registration Tool, followed by nonlinear registration using Fmrib's Nonlinear Registration Tool, 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 grey matter images were registered using the abovementioned linear and nonlinear algorithms. 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, which represented the GMV, were then smoothed with an isotropic Gaussian kernel with a 4 mm standard deviation.

Lastly, voxel-wise general linear models were used to examine the correlation between Facebook use and local grey matter volumes with age and gender as covariates. Non-parametric permutation methods (Randomise v2.1 in FSL) were used for inference on statistic maps. The null distribution at each voxel was constructed using 10,000 random permutations of the data. Threshold-free cluster enhancement (TFCE) (Smith & Nichols, 2009) was used to correct for multiple comparisons across the regions of focus. Freesurfer *mri_vol2surf* command was used for visualizing the results on brain surfaces (**Figure 2**). The mean GMV in each significant cluster was then extracted for each individual for plotting purposes.

Results

After controlling for age, gender, contacts, and years of Facebook use, we found that the grey matter volume of three clusters: bilateral posterior superior temporal gyrus /middle temporal gyrus (pSTG/MTG), and left posterior fusiform gyrus, positively correlated with Facebook use (Table 1 and Figure 2). As illustrated in Figure 2, the left temporal part was one cluster around the superior temporal sulcus, but the right side was divided into two sub-clusters. The right fusiform gyrus' volume was not associated with use, even after using the ROI approach for extracting it. No region showed negative correlation with Facebook use. Hence, hypotheses regarding the superior and middle temporal gyri were supported; partial support (lateralized to the left) was given to the fusiform hypothesis.

Post-hoc Analyses

Research has shown that the GMV of some of our regions of interest (STG and MTG) is also associated with the number of contacts on the online social network (i.e., social network size, Kanai, Bahrami, Roylance, & Rees, 2011; Lewis et al., 2011). It is therefore possible that social network size mediates the relationship between use (a proxy for social-semantic demands) and brain volume, or that Facebook use mediates the relationship between social network size and brain volume. We ventured to post-hoc test this possibility in order to shed further light on our findings. The number of contacts as well as its log (transformed to normality) did not correlate with use ($p<0.32$ - 0.52), nor did it correlate with the volumes of our ROIs ($p<0.21$ – 0.95). Hence, no mediation was observed.

It is also worth noting that the temporoparietal junction (TPJ) and ventromedial prefrontal cortex (vmPFC) have been implicated in social-semantic processes and specifically the understanding of others' states and intentions (Kanai et al., 2011; Meshi et al., 2015). Prior research did not find the volumes of these regions to be associated with social network size (Kanai et al., 2011). Nevertheless, and especially given the relative independence between social network size and SNS use, as demonstrated in the first post-hoc analysis, it is worth examining if the volumes of these regions are associated with Facebook use. Consistent with Kanai et al. (2011), no correlation between the volumes of these regions and Facebook use was observed (two-tailed tests: mPFC $r=-0.02$, $p<0.89$; leftTPJ $r=0.13$, $p<0.14$, rightTPJ $r=0.27$, $p<0.13$).

DISCUSSION

The results of study 1 suggested that it is likely that the use of SNS imposes new social-semantic and mentalizing demands on the brain and that these demands are enhanced as SNS use increases. Study 2 extended these findings and showed that morphological differences in the GMV of key brain regions of people's social-semantic and mentalizing circuits are associated with the extent of SNS use. The directional causality of these associations has been difficult to decipher (Kanai & Rees, 2011). One possibility is that Facebook use leads to morphological brain adaptations; it is plausible since the regions this study focuses on can be morphologically flexible (Garrido et al., 2009; Gregory et al., 2012; Waiter et al., 2004; Wright et al., 2000). Another reasonable possibility is that existing inter-individual differences in brain structures underlie the reported pattern of Facebook use. According to this view people with certain social-semantic capacities elect to use sites such as Facebook more than others, because they have the ability to do so effectively. A third logical possibility is that there are underlying genetic-environmental predispositions that drive both SNS use and the morphology of our ROIs. We cannot support or refute these possibilities with the current data and hence call for future research to examine these plausible explanations.

Ultimately, the findings of both studies support the need to better understand the cognitive-structural links in social media users' brains (Meshi et al., 2015). They pointed to initial evidence that Facebook use patterns impose changes in social semantic and mentalizing demands among users (study 1), which were associated with brain morphology of regions involved in processing such demands (study 2). Specifically, the imaging results suggested that Facebook use is associated with increases in GMV within a specific neural circuit involved in the perception of emotions in facial stimuli, the recognition of known faces, and the detection of changing characteristics of a face, all of which are relevant to Facebook use. The post-hoc analysis revealed that Facebook use is a behavioral facet which is relatively distinct from previously examined facets (such as social network size) and that it is independently associated with brain morphology. Specific findings and implications are discussed below.

First, positive correlations were revealed between Facebook use and grey matter volumes of both the left and right superior temporal gyri, especially the more posterior parts. The posterior regions of the superior temporal gyri overlap with the lower parts of the inferior parietal lobe, which is included in the “empathy” network. It is involved in the perception of emotions in facial stimuli (Lamm, Decety, & Singer, 2011; Schulte-Ruther et al., 2011), which is a function that is relevant to looking at faces in Facebook. In addition, these same regions are also known from behavioral neurology to help access the meaning of words while reading, i.e., these are regions that connect the visual cortex (for reading) to Wernicke’s area (for understanding language). Brain lesions that selectively include these parts of the posterior MTG on the left lead to pure cases of alexia (Cohen et al., 2003; Kawahata, Nagata, & Shishido, 1988; Sakurai et al., 2000). As such, the positive associations we observed here possibly supplement, reinforce and extend to the SNS use context, prior studies pointing the role of these regions in interpreting facial inputs.

Second, positive correlations were revealed between Facebook use and GMV of both the left and right middle temporal gyri. Although accumulating knowledge about the function of the middle temporal gyrus is still in progress, functional neuroimaging studies suggest that it plays a role in the recognition and classification of known faces (Rossion et al., 2003; Vartanian, Goel, Lam, Fisher, & Granic, 2013), a function that is relevant to Facebook use. Reduction in the volume of these regions is associated with schizophrenia (Onitsuka et al., 2004), which is characterized by reduced and dysfunctional social behavior. In contrast, we showed that increased social behavior on Facebook can be associated with larger volumes of these regions. Thus, our findings provide initial evidence that these notions can be extended to the case of SNS, and plausibly reinforce the importance of left and right middle temporal gyri for social conduct, including online social interactions.

Third, positive correlations were revealed between Facebook use and grey matter volume in the left fusiform gyrus. Functionally, this region could be linked to at least two relevant social-semantic processes associated with social media use: one is recognition of faces (Kanwisher, McDermott, & Chun, 1997), and the other is anterograde memory (Kapur, Friston, Young, Frith, & Frackowiak, 1995). Prosopagnosia in semantic dementia is associated with grey matter volume reduction in the fusiform (Josephs et al., 2008). Here, we showed that a presumed increase in face classification, recognition and interpretation demands may be associated with reverse inter-individual differences; that is, larger volumes of at least the left fusiform gyrus. In addition, the fusiform gyrus is very close to the hippocampus (albeit it is a distinct structure). However, at least functionally, there could be some overlap; both are activated when encoding novel pictures (Stern et al., 1996). Memory is important for Facebook use (Meshi et al., 2015), and its development can be reflected through increased grey matter volume in regions close to, and might be linked to, known regions related to memory formation, such as the hippocampus. Hence, it is possible that the observed positive association between the GMV of the left fusiform gyrus and Facebook use also reflects some aspects of differences in memory.

Lastly, the post-hoc analysis revealed relative independence between social network size and SNS use as related to brain morphology. This may stem from the idea that the decrease in paralanguage that is typical of SNS use has increased the load upon the social features-extracting neurons of the regions pointed out in the manuscript. In other words, the higher demand that has been put on the cerebral social-semantic systems by SNS use may be primarily due to the overall lower paralinguistic content of SNS rather than social network size proper. While this idea is supported by a lack of significant correlations between the GMV changes and social network size, it should be further examined in future research.

Importantly, though, such inter-individual differences can often be modulated and perhaps reversed through interventions such as behavior modification and in severe cases pharmacology, transcranial magnetic stimulation, or surgery (Kanai & Rees, 2011). In most cases, such interventions may not be needed. However, when the use of Facebook adversely affects people's lives and addiction-like symptoms (tolerance, withdrawal, conflict, salience, relapse and reinstatement, mood modification) emerge (the prevalence rate is between 0.7% to 11%) (Turel, He, Xue, Xiao, & Bechara, 2014), interventions, some aimed at reducing the use of the social networking site, may be needed. Hence, the findings presented here can serve as a basis for future studies that examine the efficacy of various interventions geared toward reducing the grey matter volumes in these target regions, as a means to possibly help people alter their social media use patterns.

In addition, one possible interpretation of the findings, which we cannot support or refute with the data, is that people's brains adapt to the social-semantic demands imposed by SNS use. If this is the case (should be tested in future research), then the findings imply at the possibility that social networking site use can improve the social-semantic and mentalizing circuits of people with diseases that affect their social skills, such as dementia and Alzheimer. Prior research suggests that such problems are often associated with reduced GMV in the regions implicated in the current study (Garrido et al., 2009; Gregory et al., 2012; Waiter et al., 2004; Wright et al., 2000). It is possible that reversed influences, that is, growth in GMV, can be achieved through SNS use, as the findings of study 2 suggested. Establishing the efficacy of such approaches, though, requires further research.

Future research may try to establish causality, for instance, through potential use of repeated transcranial magnetic stimulation of target regions. In addition, it can strengthen the validity of our findings by using larger samples, adding a battery of social behavior and functioning measures to see if the observed neuroanatomical differences manifest in changes in social-semantic abilities and conduct beyond Facebook use, and extending the generalizability of the findings to other SNS. Ultimately, since our sample is relatively small, the behavioral analysis lacks control and relies on self-reports of change, and VBM is not sufficient for pinpointing the cognitive workload that is associated with SNS use (it just indicates individual differences in grey matter densities) or for establishing causality, the results should be treated as preliminary. Future research should reaffirm and extend them, for instance by combining them with fMRI studies (see example integration of VBM and fMRI studies in Morishima, Schunk, Bruhin, Ruff, & Fehr, 2012). Moreover, caution should be exercised regarding the interpretation of the results, since the MTG, STG and fusiform gyrus are not specific to social-semantic tasks. Lastly, our sample may be too small for detecting differences between the sexes in terms of morphology associations with social-semantic demands and SNS use; this is something we call future research to examine in depth.

CONCLUSIONS

Overall, the findings suggested that the neuroanatomy of brain regions involved in social-semantic and mentalizing processes can be associated with SNS use. They specifically showed that this use is related to an increase in social-semantic and mentalizing demands, and that these presumed differences in demand (as manifested in differences in social media use) are associated (regardless of social network size) with larger volumes of left and right posterior superior and middle temporal gyri, and larger volume of the left posterior fusiform gyrus. These findings not only indicate possible social media use – brain morphology associations, but also point to potential interventions which can be used for correcting problematic social media use behaviors or the use of social media for correcting volume reductions in the implicated regions. We call for future research to consider and test such interventions.

Acknowledgments

The authors thank (to be completed later) for their help in recruiting participants.

Disclosure statement.

The authors report no conflict of interest. The authors report on no financial interest or benefit that has arisen from the direct applications of this research.

REFERENCES

Baron-Cohen, S. (2009). Autism: the empathizing-systemizing (E-S) theory. *Annals of the New York Academy of Sciences, 1156*(1), 68-80.

Cohen, L., Martinaud, O., Lemer, C., Lehericy, S., Samson, Y., Obadia, M., et al. (2003). Visual word recognition in the left and right hemispheres: Anatomical and functional correlates of peripheral alexias. *Cerebral Cortex, 13*(12), 1313-1333.

Deng, Z., Wei, D., Du, S. X. X., Hitchman, G., & Qiu, J. (2014). REGIONAL GRAY MATTER DENSITY ASSOCIATED WITH EMOTIONAL CONFLICT RESOLUTION: EVIDENCE FROM VOXEL-BASED MORPHOMETRY. *Neuroscience, 275*, 500-507.

Deters, F. G., & Mehl, M. R. (2013). Does Posting Facebook Status Updates Increase or Decrease Loneliness? An Online Social Networking Experiment. *Social Psychological and Personality Science, 4*(5), 579-586.

Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Neuroplasticity: Changes in grey matter induced by training - Newly honed juggling skills show up as a transient feature on a brain-imaging scan. *Nature, 427*(6972), 311-312.

Garrido, L., Furl, N., Draganski, B., Weiskopf, N., Stevens, J., Tan, G. C. Y., et al. (2009). Voxel-based morphometry reveals reduced grey matter volume in the temporal cortex of developmental prosopagnosics. *Brain, 132*, 3443-3455.

Gil-Or, O., Levi-Belz, Y., & Turel, O. (2015). The “Facebook-self”: Characteristics and psychological predictors of false self-presentation on Facebook. *Frontiers in Psychology, 6*(99).

Gregory, S., Ffytche, D., Simmons, A., Kumari, V., Howard, M., Hodgins, S., et al. (2012). The Antisocial Brain: Psychopathy Matters A Structural MRI Investigation of Antisocial Male Violent Offenders. *Archives of General Psychiatry, 69*(9), 962-972.

Greve, D. N., Van der Haegen, L., Cai, Q., Stufflebeam, S., Sabuncu, M. R., Fischl, B., et al. (2013). A Surface-based Analysis of Language Lateralization and Cortical Asymmetry. *Journal of Cognitive Neuroscience, 25*(9), 1477-1492.

Hayes, R. A., Carr, C. T., & Wohn, D. Y. (2016). One Click, Many Meanings: Interpreting Paralinguistic Digital Affordances in Social Media. *Journal of Broadcasting & Electronic Media, 60*(1), 171-187.

Josephs, K. A., Whitwell, J. L., Vemuri, P., Senjem, M. L., Boeve, B. F., Knopman, D. S., et al. (2008). The anatomic correlate of prosopagnosia in semantic dementia. *Neurology, 71*(20), 1628-1633.

Kanai, R., Bahrami, B., Roylance, R., & Rees, G. (2011). Online social network size is reflected in human brain structure. *Proceedings of the Royal Society B: Biological Sciences*.

Kanai, R., Bahrami, B., Roylance, R., & Rees, G. (2012). Online social network size is reflected in human brain structure. *Proceedings of the Royal Society B-Biological Sciences, 279*(1732), 1327-1334.

Kanai, R., & Rees, G. (2011). The structural basis of interindividual differences in human behaviour and cognition. *Neuroscience - Nature Reviews, 12*(2), 231-242.

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience, 17*(11), 4302-4311.

Kapur, N., Friston, K. J., Young, A., Frith, C. D., & Frackowiak, R. S. J. (1995). ACTIVATION OF HUMAN HIPPOCAMPAL-FORMATION DURING MEMORY FOR FACES - A PET STUDY. *Cortex, 31*(1), 99-108.

Kawahata, N., Nagata, K., & Shishido, F. (1988). ALEXIA WITH AGRAPHIA DUE TO THE LEFT POSTERIOR INFERIOR TEMPORAL-LOBE LESION - NEUROPSYCHOLOGICAL ANALYSIS AND ITS PATHOGENETIC MECHANISMS. *Brain and Language, 33*(2), 296-310.

Lamm, C., Decety, J., & Singer, T. (2011). Meta-analytic evidence for common and distinct neural networks associated with directly experienced pain and empathy for pain. *Neuroimage, 54*(3), 2492-2502.

Lewis, P. A., Rezaie, R., Brown, R., Roberts, N., & Dunbar, R. I. M. (2011). Ventromedial prefrontal volume predicts understanding of others and social network size. *Neuroimage, 57*(4), 1624-1629.

Mackey, A. P., Finn, A. S., Leonard, J. A., Jacoby-Senghor, D. S., West, M. R., Gabrieli, C. F. O., et al. (2015). Neuroanatomical Correlates of the Income-Achievement Gap. *Psychological Science, 26*(6), 925-933.

Maier, C., Laumer, S., Eckhardt, A., & Weitzel, T. (2015). Giving too much social support: social overload on social networking sites. *European Journal of Information Systems, 24*(5), 447-464.

Meshi, D., Mamerow, L., Kirilina, E., Morawetz, C., Margulies, D. S., & Heekeren, H. R. (2016). Sharing self-related information is associated with intrinsic functional connectivity of cortical midline brain regions. *Scientific Reports, 6*.

Meshi, D., Morawetz, C., & Heekeren, H. R. (2013). Nucleus accumbens response to gains in reputation for the self relative to gains for others predicts social media use. *Frontiers in Human Neuroscience, 7*.

Meshi, D., Tamir, D. I., & Heekeren, H. R. (2015). The Emerging Neuroscience of Social Media. *Trends in Cognitive Sciences, 19*(12), 771-782.

Morishima, Y., Schunk, D., Bruhin, A., Ruff, C. C., & Fehr, E. (2012). Linking Brain Structure and Activation in Temporoparietal Junction to Explain the Neurobiology of Human Altruism. *Neuron, 75*(1), 73-79.

Noonan, M. P., Mars, R. B., Sallet, J., Dunbar, R. I., Rushworth, M. F. S., & Fellows, L. K. (2013). *Structural and functional brain networks relating to social network size in humans.* Paper presented at the Society for Neuroscience, San Diego, CA.

Onitsuka, T., Shenton, M. E., Salisbury, D. F., Dickey, C. C., Kasai, K., Toner, S. K., et al. (2004). Middle and inferior temporal gyrus gray matter volume abnormalities in chronic schizophrenia: An MRI study. *American Journal of Psychiatry, 161*(9), 1603-1611.

Rossion, B., Caldara, R., Seghier, M., Schuller, A. M., Lazeyras, F., & Mayer, E. (2003). A network of occipito-temporal face-sensitive areas besides the right middle fusiform gyrus is necessary for normal face processing. *Brain, 126*, 2381-2395.

Sakurai, Y., Takeuchi, S., Takada, T., Horiuchi, E., Nakase, H., & Sakuta, M. (2000). Alexia caused by a fusiform or posterior inferior temporal lesion. *Journal of the Neurological Sciences, 178*(1), 42-51.

Saxe, R., Carey, S., & Kanwisher, N. (2004). Understanding Other Minds: Linking Developmental Psychology and Functional Neuroimaging. *Annual Review of Psychology, 55*, 87-124.

Schneider-Hassloff, H., Straube, B., Jansen, A., Nuscheler, B., Wemken, G., Witt, S. H., et al. (2016). Oxytocin receptor polymorphism and childhood social experiences shape adult personality, brain structure and neural correlates of mentalizing. *Neuroimage, 134*, 671-684.

Schulte-Ruther, M., Greimel, E., Markowitsch, H. J., Kamp-Becker, I., Remschmidt, H., Fink, G. R., et al. (2011). Dysfunctions in brain networks supporting empathy: An fMRI study in adults with autism spectrum disorders. *Social Neuroscience, 6*(1), 1-21.

Smith, C. (2016, Aug. 29, 2016). Facebook Statistics and Facts (2016). Retrieved Aug. 30, 2016, from http://expandedramblings.com/index.php/by-the-numbers-17-amazing-facebook-stats/

Smith, S. M., & Nichols, T. E. (2009). Threshold-free cluster enhancement: addressing problems of smoothing, threshold dependence and localisation in cluster inference. *Neuroimage, 44*(1), 83-98.

Stern, C. E., Corkin, S., Gonzalez, R. G., Guimaraes, A. R., Baker, J. R., Jennings, P. J., et al. (1996). The hippocampal formation participates in novel picture encoding: Evidence from functional magnetic resonance imaging. *Proceedings of the National Academy of Sciences of the United States of America, 93*(16), 8660-8665.

Subrahmanyam, K., Reich, S. M., Waechter, N., & Espinoza, G. (2008). Online and offline social networks: Use of social networking sites by emerging adults. *Journal of Applied Developmental Psychology, 29*(6), 420-433.

Turel, O., & Bechara, A. (2016). A Triadic Reflective-Impulsive-Interoceptive Awareness Model of General and Impulsive Information System Use: Behavioral Tests of Neuro-Cognitive Theory. *Frontiers in Psychology, 7*.

Turel, O., He, Q., Xue, G., Xiao, L., & Bechara, A. (2014). Examination of neural systems sub-serving Facebook "addiction". *Psychological Reports, 115*(3), 675-695.

Turel, O., & Qahri-Saremi, H. (2016). Problematic Use of Social Networking Sites: Antecedents and Consequence from a Dual-System Theory Perspective. *Journal of Management Information Systems, 33*(4), 1087-1116.

Vartanian, O., Goel, V., Lam, E., Fisher, M., & Granic, J. (2013). Middle Temporal Gyrus Encodes Individual Differences in Perceived Facial Attractiveness. *Psychology of Aesthetics Creativity and the Arts, 7*(1), 38-47.

Waiter, G. D., Williams, J. H. G., Murray, A. D., Gilchrist, A., Perrett, D. I., & Whiten, A. (2004). A voxel-based investigation of brain structure in male adolescents with autistic spectrum disorder. *Neuroimage, 22*(2), 619-625.

Wright, I. C., Rabe-Hesketh, S., Woodruff, P. W. R., David, A. S., Murray, R. M., & Bullmore, E. T. (2000). Meta-analysis of regional brain volumes in schizophrenia. *American Journal of Psychiatry, 157*(1), 16-25.

TABLES

Table 1: Summary of VBM results

L/R	Brain region	Voxels	Peak Coordinates (*x, y, z*)	Geometric Center Coordinates (*x, y, z*)	TFCE corrected *p*
POSITIVE CORRELATION OF FACEBOOK USE					
L	Posterior STG/MTG	1355	-60, -26, -20	-62.4, -30.7, -3.68	< 0.001
R	Posterior MTG	759	64, -12, -30	64.1, -19.5, -15.7	< 0.001
R	Posterior STG	163	70, -36, 10	66, -32.4, 9.53	0.029
L	Posterior Fusiform Gyrus	43	-32, -24, -26	-26, -33.1, -24.6	0.035
NEGATIVE CORRELATION OF FACEBOOK USE					
NONE					

L: Left; R: Right; STG: Superior Temporal Gyrus; MTG: Middle Temporal Gyrus.

Note: The voxel size in VBM analysis is 2 mm × 2 mm × 2 mm = 8 mm^3.

FIGURE CAPTIONS

Figure 1: The average scores of the perceived "increase" and "change" in social-semantic demands on Facebook. Results suggested that both perceived increase and change of social semantic demands were significantly higher than the midpoint (3). Error bar represents the standard error. ***: $p < .001$.

Figure 2: Grey matter volumes showed positive correlation with Facebook use, including left pSTG/MTG (A), right pSTG (B), left pFG (C), and right pMTG (D). There was no negative correlation between GMV of any region and Facebook use. Color bar represents t values. T maps were mapped to the brain surface using Freesurfer command mri_vol2surf. Grey color represents sulci and bright color represents gyri. pSTG/MTG: posterior superior temporal gyrus/middle temporal gyrus; pSTG: posterior superior temporal gyrus; pMTG: posterior middle temporal gyrus; pFG: posterior fusiform gyrus.

FIGURES

Figure 1

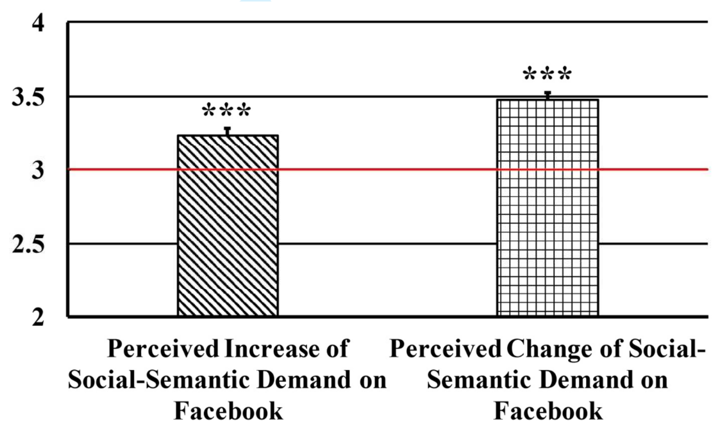
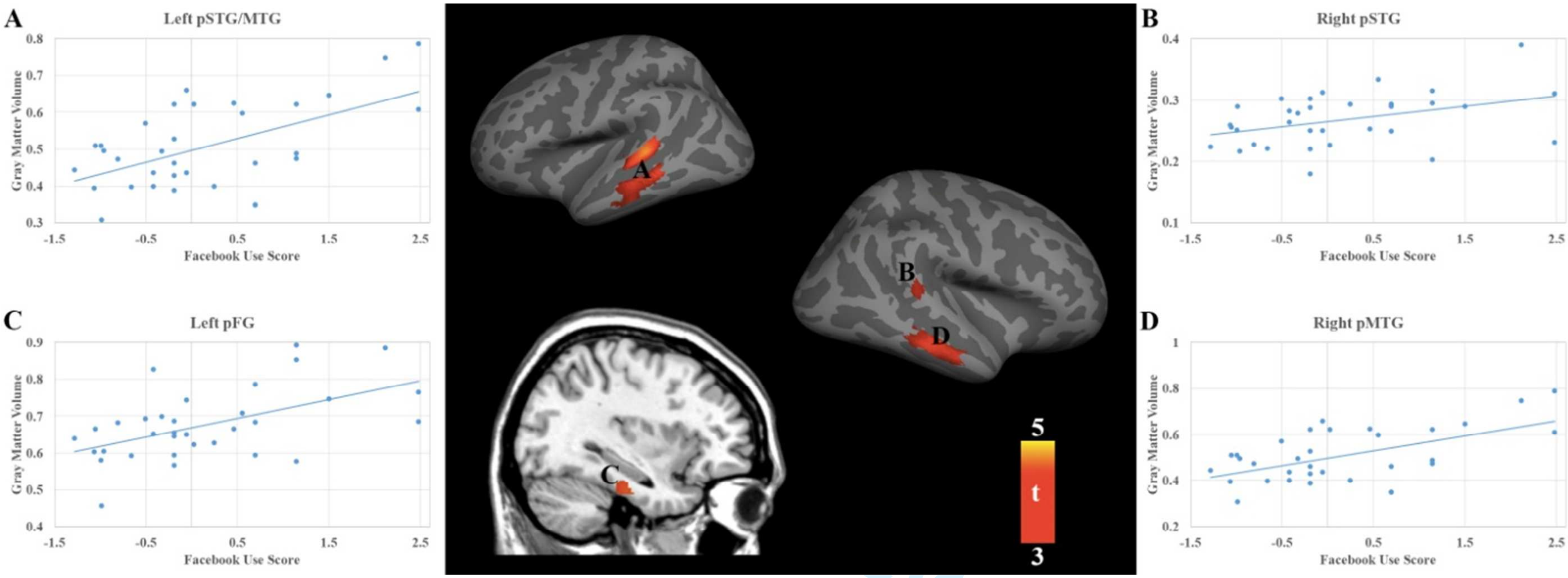


Figure 2


A
Left pSTG/MTG
Gray Matter Volume
Facebook Use Score
B
Right pSTG
Gray Matter Volume
Facebook Use Score
C
Left pFG
Gray Matter Volume
Facebook Use Score
D
Right pMTG
Gray Matter Volume
Facebook Use Score
5
t
3

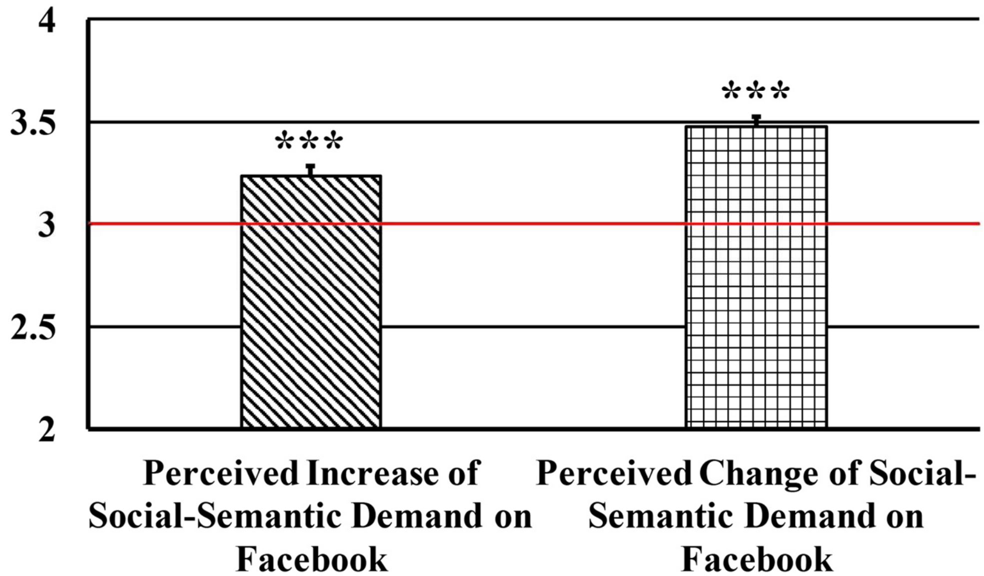


Figure 1: The average scores of the perceived "increase" and "change" in social-semantic demands on Facebook. Results suggested that both perceived increase and change of social semantic demands were significantly higher than the midpoint (3). Error bar represents the standard error. ***: p < .001.

165x98mm (220 x 220 DPI)

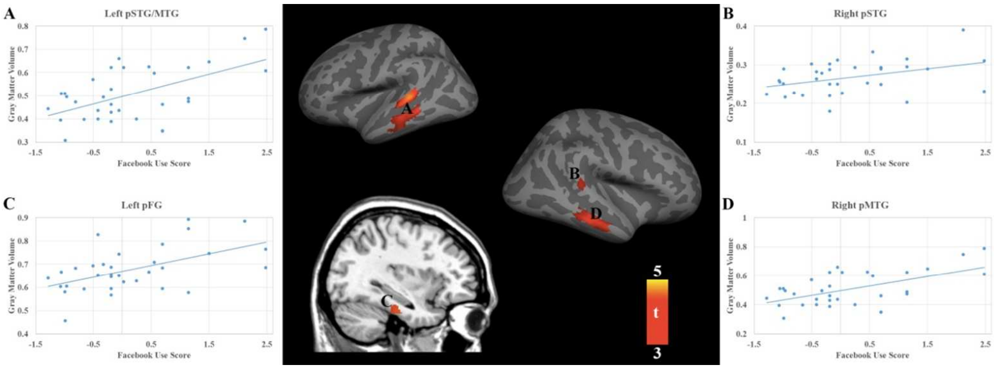


Figure 2: Grey matter volumes showed positive correlation with Facebook use, including left pSTG/MTG (A), right pSTG (B), left pFG (C), and right pMTG (D). There was no negative correlation between GMV of any region and Facebook use. Color bar represents t values. T maps were mapped to the brain surface using Freesurfer command mri_vol2surf. Grey color represents sulci and bright color represents gyri. pSTG/MTG: posterior superior temporal gyrus/middle temporal gyrus; pSTG: posterior superior temporal gyrus; pMTG: posterior middle temporal gyrus; pFG: posterior fusiform gyrus.

165x59mm (220 x 220 DPI)