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Exploring Neural Correlates of Social Media Use: A Review of BOLD fMRI Studies Utilizing in-scanner Social Media Exposure

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Abstract:

The goal of this project is to synthesize articles that provide a new look into the neural correlates of social media use by utilizing BOLD fMRI and in-scanner social media stimuli. Seven articles that matched the criteria were selected for this paper: (n=6) task-based BOLD fMRI utilizing social media stimuli and (n=1) resting-state fMRI included to show the importance of longitudinal research design in the same field. Results include a discussion of the convergence and divergence amongst the studies, the importance of imaging techniques (resting state, whole brain) that could potentially benefit similar studies, the importance of longitudinal study design, and what future studies could look like. The paper is limited by the small amount of eligible literature available, so conclusions should remain tentative. As mentioned by five of the seven articles included, more longitudinal research is needed to assess the neural and behavioral correlates of social media use.

Contents

“The psychological rule says that when an inner situation is not made conscious, it happens outside, as fate. That is to say, when the individual remains undivided and does not become conscious of his inner opposite, the world must perforce act out the conflict and be torn into opposing halves."

- Dr. Carl Jung

I. Introduction

When I first came to Duke, I had very little idea of what to study for this master's project – and that sounds very silly. Even in liberal studies, I felt an immense pressure to know the exact path to take. Of course, generally when vying for higher academia it is to hone what you already have some knowledge of – however in my case, I needed some more exploring – and that was daunting. It is scary to be in a place full of academic rigor if you are unsure what path to go down, where those around you seem to have full maps planned out (though that is often not the case, as true as it may feel). Inevitably after a long search however, I found a home in emerging technology and philosophy, and in essence that is what led me here.

I realize that is broad, but Sarah Rispin's class, Digital Intelligence, keyed me into the many ways that technology is developing, and the many ways that it can change humanity's course, for better and worse. Unethical tech implementation, untested algorithms, privacy violations, bias in courtroom automation - I found a great interest in seeing how to better the flawed technology that, at the same time, seems to make our lives so much easier.

It was sometime after Sarah Rispin's class when I decided to take a neuroscience class with Dr. Edna Andrews, focused on language, music, and dementia. This course blew me away, not only with the research articles worthy of a class dedicated to themselves and Dr. Andrews' immense knowledge rooted in real experience, but also with the life lessons she taught me during the class. I learned a great deal about essentialism and about how to better integrate work into my life: I will always remember her saying "If you don't enjoy your work, something is wrong". That rings true to me still to this day, and I still check myself whenever I find myself begrudgingly doing something I used to enjoy. I should enjoy the process, not just the end result.

It is because those great neurological and life lessons that I chose Dr. Andrews' to help with me on my project, even with my limited neuroscience background.

The following semester I took a neuroscience and philosophy course with Dr. Watkins, and this is where my interests began to narrow the most. This course introduced me to the idea of the "unconscious brain" (Nisbett and Wilson 1997) which states that we can never be fully aware of why we do what we do because there are so many "invisible causes" in our mind that guide our actions. Whether from genetics or our environmental stimuli, the theory goes that we can never fully comprehend ourselves. As someone who must always understand why I'm feeling the way that I'm feeling, I became annoyed. This led me down the path of doing what I can to understand my actions, to find these invisible causes, to understand my human self as much as possible. Combining these ideas with technology, and one of the most ubiquitous technologies of our time, social media, I found more to understand. In a slightly self-indulgent way, I have projected my need to understand myself into this work.

While I would consider it self-indulgent to some degree, my desire to contribute to this discipline is rooted in the ways I have known social media to affect people. Not only by the news articles I see every day about its detriments to our well-being (see here and here for great ones), but how it has affected the lives of those close to me. I struggle to find any one of my friends whose self-image hasn't been harmed by being exposed to the comparison inherent in the structure of social media.

While the stigma around social media, I would argue, is not a positive one, there are many upsides to it. A report from the Mayo Clinic reports the supportive nature that social media can have, especially with those that are in marginalized groups – and how social media can help

people. It gives people the ability to express themselves, connect with other people across long distances, and talk openly about topics such as mental health (Mayo Clinic).

However, beyond personal anecdotes, the research speaks for itself to the detriments social media can present. Even though it is still relatively new, social media has been linked to decreased attention, memory, addiction, and learning abilities (Crone & Konijn, 2018; Firth et al., 2019; Ophir, Nass, & Wagner, 2009; Koc and Gulyagci, 2013, Berail et al. 2019). The Mayo Clinic also cited some potential risks associated with social media use in America: higher risk of mental health concerns for 12–15-year-olds, non-realistic body standards, disrupted sleep, exposure to online predators and exposure to cyberbullying (Mayo Clinic). Large bodies of literature are also dedicated to analyzing the affects social media have on adolescence from a sociological standpoint (He et al. 2024).

According to a 2018 report, 45% percent of teens say they use the internet almost *constantly* (Anderson and Jingjing, 2018). A vast majority of young people's daily smartphone use, like mine, is spent on social media, but most popular of these in the United States are Instagram, Snapchat, and TikTok (Anderson and Jingjing, 2018; Smith et al., 2018). Because of the intense amount of time spent on social media, the immense user base, and the potential harm that can be caused (particularly to adolescents) it is imperative that we understand the neurocognitive, social, and emotional underpinnings. And because social media is screen-based, it can be recreated fairly accurately within the confines of an fMRI. As Sherman et al. (2016) puts it:

> Social media provide a compelling opportunity to examine social interaction in an ecologically valid context. Typically, in the confines of an MRI scanner, social interaction is limited and artificial. Because social media exist on a screen, however,

they can be effectively imported into the scanner environment. (Sherman et al. 2016: 1034)

Throughout the course of writing this piece I found myself continually asking "what is my contribution here?". Sure, I'm connecting the dots between these new study paradigms, but I felt as if I needed some large contribution to give, some "aha!" moment. Yet it was during a meeting with a colleague that reminded me just what a literature review is for. My goal is to connect the dots. By and large, my motive here is to discuss these articles using a similar and relatively new fMRI task-based paradigm, see their convergence, their differences, and how I might suggest a change, because down the line I hope to be doing the same research. This is simply a piece of a larger puzzle, and I implore the reader to see this paper in that light.

II. Neuroimaging

Much of this paper will be analyzing and critiquing several research articles that all utilize functional magnetic resonance imaging (fMRI), and to comprehend this analysis one must first have a competent grasp of the science. We will begin by going over major techniques that are relevant for this paper, and then home in on the space that fMRI occupies, including how it compares to other imaging technologies, its strengths, its limitations, and how researchers have responded to those limitations. Other neuroimaging will be mentioned to give context to why fMRI was the chosen focus of this review.

The long-lasting endeavor of mapping the brain is no small feat, and it is today still a puzzle that researchers have been attempting to put together. Today, there are several types of neuroimaging, including position emission topography (PET), electroencephalography (EEG), magnetoencephalography (MEG), near infrared spectroscopy (NIRS), and transcranial magnetic stimulation (TMS). For neuroimaging there must be some form of physiological underpinning, and each of these imaging techniques attempts to image some aspect of the brain to garner a better understanding of it. *Functional* neuroimaging is a science that "attempts to localize different mental processes to different parts of the brain, in effect creating a map of which areas are responsible for which processes" (Huettel et al. 2009: 3). While we look at this neuroimaging methods keep in mind: neuroimaging technique can be evaluated with a few simple criteria: what quantity does it measure, how sensitively can it measure that quantity, how precisely in space does it measure that quantity, and how often can it make that measurement (Huettel et al. 2009: 6).

i. Electrophysiological

A primary form of neuroimaging is electrophysiological neuroimaging, an imaging science that relies on electrical activity and potentials. Electroencephalography (EEG), a form of electrophysiological imaging, measures electrical activity as clusters of neurons become active. The EEG, discovered by Hans Berger in 1929, is a powerful form of neuroimaging and that can be partially attributed to its high temporal resolution – it is able to measure very rapid changes in electrical potentials (Tudor et al. 2005; Huettel et al 2009: 1, 5). A primary limitation of this technique, however, is its low spatial resolution and the difficulty of measuring electrical activity changes deeper inside the brain, though this is an area where hemodynamic imaging tools such as PET and fMRI fair better, vis a vis their higher spatial resolution and ability to see deeper into the brain (Crosson et al 2011: 2).

ii. Hemodynamic

Hemodynamic neuroimaging is a form of neuroimaging that measures a quality of the blood, instead of the electrical activity and potentials as electrophysiological (Huettel et al. 2009: 3, 23). Before fMRI, the most common form of neuroimaging was the PET (positron emission tomography) that measures changes in the brain via radioactive tracers that are injected into the blood (Huettel et al. 2009 3). The changes measured by the PET include glucose metabolism and/or blood flow and by using these metrics researchers would identify parts of the brain metabolically associated with a given perceptual, motor, or cognitive function (Huettel et al. 2009: 3).

The discovery of the fMRI in the 1980's is normally attributed to Seji Ogawa, a research scientist at Bell Laboratories who discovered BOLD contrast (Huettel 2009: 160-162). A

fundamental feature of nearly all fMRI is that it measures the changes in deoxygenated hemoglobin in the blood flow of the brain through a blood-oxygenation level dependent (BOLD) contrast, no radioactive tracer required (Huettel et al 2009: 5). When a neuron becomes active, it requires more oxygen for the demands, requiring more blood flow – and because deoxygenated hemoglobin is paramagnetic (has a significant magnetic moment) it is able to be picked up by the scanner. That being said, there stand a few caveats with this fMRI scanning method. First, there is the fact that the scanner does not pick up neuronal activity itself, or even the blood flow like the PET, but rather an aspect of the blood (the deoxygenated hemoglobin). Huettel et al (2009: 128) states:

> "It is important to recognize that BOLD contrast is a consequence of a series of indirect effects. It results from changes in the magnetic properties of water molecules, which in turn reflect the influence of paramagnetic deoxyhemoglobin, which is a physiological correlate of oxygen consumption, which itself is a correlate of a change in neuronal activity evoked by sensory, motor, and/or cognitive processes."

Since the fMRI only measure correlates of neuronal activity, fMRI cannot discern between excitatory or inhibitory firing patterns (Andrews 2014: 148). Also importantly, the blood flow and subsequent deoxygenated hemoglobin change that is incited via neuronal activity is inherently a slower hemodynamic response: it lags behind the initiating neuronal activity (Huettel et al. 2009: 178).

An upside to fMRI usage is its high spatial resolution, which refers to the ability to be able to distinguish small details, often up to a few millimeters. As one can imagine, being able to look at hemodynamic response with a greater degree of accuracy is a valuable asset for

functional neuroimaging. If we are to draw a comparison between hemodynamic and electrophysiological neuroimaging, EEG measures in centimeters, while fMRI can measure down to millimeters (Crosson et al. 2011: 16).

While fMRI has many strengths and has proved pivotal to our understanding of the functional brain, it also has some limitations that need to be kept in mind when analyzing and comparing studies. As I mentioned earlier, low temporal resolution is a limitation that plagues fMRI – this is due in part to the aforementioned hemodynamic response time. For processes that require temporal information in the order of milliseconds, techniques akin to EEG may be the better option (Crosson et al. 2011: 7).

In regard to technique, there are commonly refractory artifacts when stimuli are introduced in rapid succession, which is pertinent for the social media stimuli articles we will focus on. This is more of a caveat than a detriment, but to limit the "confounding factors" (Huettel et al. 2009: 290) one must ensure that there is adequate time between stimuli so that one can make signal recovery before the next stimulus. This is commonly seen through a fixation-cross on a solid background.

Significant scanner noise is another limitation of fMRI. Task-related BOLD signal change is already very small relative to the spatial and temporal variability, and significant noise in the scanner can make it even harder to see the signals: thermal sources in the subject and electronics, head motion, cardiac and respiratory noise, and variations in baseline natural metabolism are all contributors to this noise (Glover 2012; Huettel et al 2009: 4, 219). Any subject in the scanner must stay incredibly still for accurate results, as the volume is acquired in "slices" and generally around 32 make up the whole image, there is always a certain amount of time between slices (Glover 2012: 3). As you will see in the studies later in the paper, there are

participant practices as well as correctional algorithms and software packages to combat these limitations, but even those packages have their own nuances and inherent limitations.

iii. Problems of Interpreting Activation

Integrating neuroimaging findings with established theoretical frameworks is essential for advancing our understanding of the complex organization of the mind and its underlying cognitive processes: “Imaging generates data no more no less and data are only usable and useful insofar as they have an interpretation in the context of a theory about how the mind is organized” (Poeppel 2008: 22).

There is the desire in neuroimaging to map certain functions to localized areas in the brain. This seems and feels intuitive, is often correct, and has captured the imaginations – however this is correct only in part and reflects only a small part of the full picture (Poeppel 2013: 2). This approach of strict localization of functions in the brain is only partially accurate and provides an incomplete understanding of the brain's organization. As highlighted by Poeppel (2013), while certain functions may indeed correlate with specific brain regions, the brain operates through complex networks and distributed processing. Many cognitive functions involve intricate interactions between multiple brain regions rather than being confined to discrete anatomical areas. Therefore, it is beneficial to consider both localized functions and the dynamic interactions between brain regions across distributed networks.

Raichle et al. (2001) made an important discovery by establishing the appropriate baseline condition via oxygen extraction fraction (OEF) which Raichle et al. 2001 define as “the ratio of oxygen used by the brain to oxygen delivered by flowing blood and is remarkably uniform in the awake but resting state (e.g., lying quietly with eyes closed)” (Raichle et al. 2001:

676). Deviations from this baseline OEF acquired via the resting state help give meaning to decreases: “Defining the baseline state of an area in this manner attaches meaning to a group of areas that consistently exhibit decreases from this baseline, during a wide variety of goal-directed behaviors” (Raichle et al. 2001: 676). Raichle observed the brain regions that continually showed less activation during task-based stimuli than in resting state, and this led him to the discovery of 7 unique resting-state neural networks: default mode, auditory, visual, sensorimotor, executive control, salience, and dorsal attention (Raichle 2010, 2015).

iv. Ecological Validity

An important criterion when examining this literature is its use of ecological validity. Ecological validity is described by Huettel as “The degree to which the processes studied in an experiment are similar to those produced in the natural environment” (Huettel et al. 2009: 382). To obtain information that is applicable to real-life scenarios, having a high degree of ecological validity is necessary.

v. Longitudinal and Cross-Sectional

Another crucial aspect of fMRI studies is whether they utilize cross-sectional or longitudinal study design. Both types of study design have their merit; however there are certain limitations that are inherent to cross-sectional design that needn’t affect longitudinal studies. For instance, longitudinal studies allow a participant to be their own control. Individual subject differences, including those that change or develop over time, are not observable in cross-sectional studies (Andrews and Swaine 2024: 5).

vi. Software Packages

The discrepancy between software packages is one that is not trivial. fMRI is a data collection machine, and that data must be run through software (the pipeline is listed in Fig. 1). However, the many different software packages used to disseminate that data (FSL, AFNI and SPM are fairly common) can vary the results in a significant manner. To demonstrate this, Bowring et al. 2019 used three different software packages, Analysis of Functional Neuro Images (AFNI), FMRIB Software Library (FSL), and Statistical Parametric Mapping (SPM), and applied them to the results of the same three fMRI research studies. After comparing the studies with the separate software packages, Bowring et al. found that the location of significant activation was substantially different for each of the studies (2019: 3373).

Also, because there are distinct differences in the spatial normalization paradigms and algorithms it is extremely difficult to compare activation across studies (Andrews 160). The two most common brain templates are the Talairach atlas and the Montreal Neurological Institute (MNI) templates and, because of the differences between the two, "correction" software is often applied to aid in comparing activation, but even those are not standardized (Laird 2010: 1).

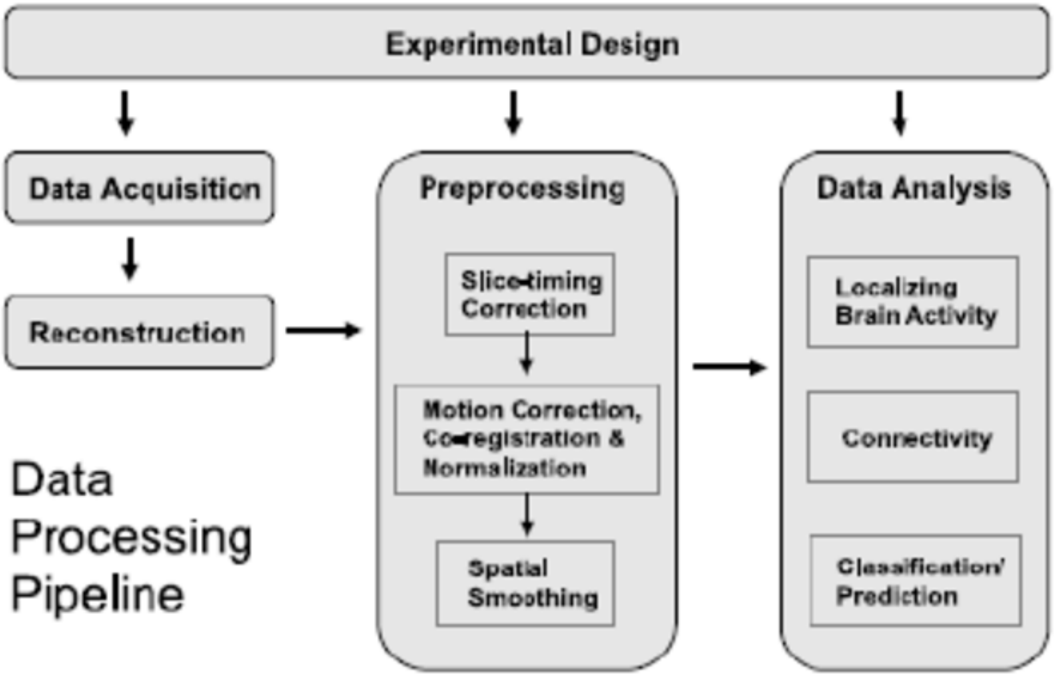

Fig. 1. fMRI data pipeline

Table 2.1 Neuroimaging comparison (Lystad, R. P., & Pollard, H. 2009: 63)

	PET	EEG	fMRI
Measure of neuronal activity	Indirect	Direct	Indirect
Invasiveness	Invasive	Non-invasive	Non-invasive
Spatial Resolution	Good/excellent (4mm)	Poor (1 cm)	Excellent (2mm)
Temporal Resolution	Poor (1-2 min)	Excellent (<1 sec)	Reasonable (4-5s)

III. Method

i. Article Selection

Six articles were selected for this review. The inclusion criteria for the studies were as follows: (i) Peer-reviewed (ii) utilized picture stimuli of social media in the scanner (iii), and are accessible through Duke University Libraries (JSTOR, PubMed, Scopus, Oxford Scholarship Online, Web of Science). Articles were not included if they (i) focused on social media from a marketing perspective or (ii) did not investigate the functional correlates of social media use in an MRI-based way. Titles and abstracts were read to screen for relevance. One study (Bo et al. 2022) did not show picture based social media stimuli in the scanner, but was included as it showed the effect of resting state fMRI and is pertinent to describing how valuable those additions are to task-based fMRI studies. Another study (Achterberg et al. 2016) did not attempt to recreate a current form of social media, but instead relied on making an online profile that peers reacted to which subsequently showed in the scanner, and because this is relevant to nearly all forms of social media, the research was included.

ii. Data Extraction

Data which was deemed relevant to the study was taken from the articles and summarized, then put into tables for ease of consumption. The variables included in the tables and summaries are as follows: author name, year of publication, study design, number of participants, age of participants, mean age, gender, methods, and key findings.

IV. Results

i. Task-based fMRI Studies

Six research articles were included that met the criteria listed. All of the following use task-based fMRI data to analyze the neural correlates of social media use. We will go through an overview of each article, including background information, methods, analysis, key findings, and future directions recommended by the authors in this section.

ii. Sherman et al. 2016

a. Research type and Background

Sherman et al. 2016 presented participants with a mock Instagram (popular social media app) images and functions in an fMRI scanner. The purpose of the study was to see how adolescents' brains respond to peer influence and feedback on social media via recreating the popular "Like" feature within the scanner, and this study was groundbreaking in the fact that it is the first, to their knowledge, to recreate social media use within an MRI scanner (2016: 1028).

The *like*, a near ubiquitous feature of social media, is a form of quantifiable social endorsement. The feature works by allowing a user to *like* an image, text, or other piece of information and the number of users who have *liked* is shown beneath the image as a number, the information is then measured and showed beside the photo (shown in Fig. 1).

In Los Angeles, Sherman et al. 2016 placed 34 participants (18 female, 16 male) in the age range of 13 to 18 in an fMRI and gave them the task of giving and receiving *likes* on a replica of Instagram in the scanner to examine brain activation (2016: 1028). ROI is based on previous research that suggests peer presence heightens nucleus accumbens response and that the nucleus accumbens have a role in social evaluation and sharing information of the self. Sherman et al.

2016 hypothesized viewing one's own photos with many *likes* would elicit greater nucleus accumbens activity (Chein et al, 2011; Meshi, Morawetz, & Heekeren, 2013; Tamir & Mitchell 2012; Sherman et al. 2016: 1028).

b. Methods

In the scanner, the participants were shown picture stimuli of their own photos which they had submitted prior, attached with a certain number of varying *likes*. Afterwards, they were then shown a series of photos and determined whether to "Like" the photos or hit "Next" to show the next photo (Fig. 1). In total, there were three types of photos: (1) neutral images, (2) images representing risk-taking behaviors, and then (3) the images submitted by the participants (2016: 1028). Each photo was shown on an Instagram-like social media feed to provide a more accurate social media experience. Each of these photos were only shown for 3 seconds with interstimulus fixation cross on a white background in between that varied between 1 and 11 seconds to avoid refractory artifacts (2016: 1029).

Fig. 2

Two examples of stimuli shown. Innocuous photos of everyday objects on the left as a "neutral" photo and a "risky" photo behavior stimulus on the right (2016: 1030).

c. Analysis

The scanner used was a 3-T MRI scanner (2016: 1029). The fMRI data gathered was preprocessed and analyzed using AFNI and the FMRIB Software Library (FSL) software packages to account for software package differences (2016: 1030). The main contrast of interest for Sherman et al. 2016 modeled tasks for which the participants selected "Like" or "Next". BOLD signal responses for "Like" and "Next" were compared, as well as the contrast for when participants received many *likes* on their images compared to when they received few *likes* (2016: 1031).

d. Results and further instruction

Neural responses differed according to the participants' own photos shown with *many vs. few likes*. With *many > few likes* shown on the participants' own photos, significantly greater activity was observed in several regions that are implicated in social cognition, such as precuneus, medial prefrontal cortex and hippocampus (Mars et al., 2012; Zaki & Ochsner, 2009), as well as reward learning and motivation, including the nucleus accumbens, caudate, putamen, thalamus, ventral tegmental area, and brain stem (Haruno & Kawato, 2006; Schott et al., 2008). *Few > many likes* on the participants' own photos showed no significant activation in the whole brain (2016: 1031). Sherman et al. 2016 associates their ROI analysis of the nucleus accumbens with the experience of receiving positive feedback on one's own images and viewing other images that have been endorsed by peers (2016: 1033).

For further research, Sherman et al. 2016 suggests building on their work and investigating how individual differences in neural response map onto behavioral outcomes, noting there may be an association between the neural responses and conformity. (2016: 1034).

iii. Wikman et al. 2022

a. Background and Research Type

Excessive social media use has been associated with an increase in mental health problems and cybervictimization in adolescents (2022: 1). Understanding the social, emotional, and neurocognitive aspects of social media usage, particularly in young people, is crucial and the driving force behind the study (2022: 1). The socio-cognitive functions of humans undergo substantial neural development during the adolescent years (no source cited), with heightened sensitivity to social feedback from peers. The maturation of brain regions involved in social behavior, and the fact social media platforms offer frequent opportunities for peer feedback, which strongly activates brain areas involved in socio-emotional processing, is what the study is predicated on (Sherman et al. 2018).

Wikman et al. 2022 hypothesized they would replicate the previous findings showing enhanced activity in the insula and medial prefrontal cortex in response to emotion-evoking stimuli, in addition to seeing activity in the anterior cingulate cortex, lateral prefrontal cortex, and anterior insula in response to negative peer feedback (2022: 3). With these factors in mind, Wikman et al. 2022 conducted a study utilizing task-based fMRI poised to test how the emotion-evoking aspects of social media are associated with brain activity, and whether individual differences have a role in neural responses (2022: 2).

b. Methods

At the University of Helsinki and Tampere, Wikman et al. 2022 gathered 92 participants to utilize task-based fMRI imaging (2022:3). The task used was one focusing on the comment function of a Facebook post. In the scanner, using picture stimuli, participants were presented with statements: “Helsinki is the capital of Finland” or “Abortions should be illegal” and they were then made to select a “agree” or “disagree” button (2022: 4). The participants’ subsequent agreement or disagreement would then be made into a post into a Facebook group, which they then watched as four comments appeared beneath it containing statements resembling “I totally agree with you.” or “What a stupid opinion!”, though neutral statements were followed with only neutral comments (Fig. 2) (2022: 4).

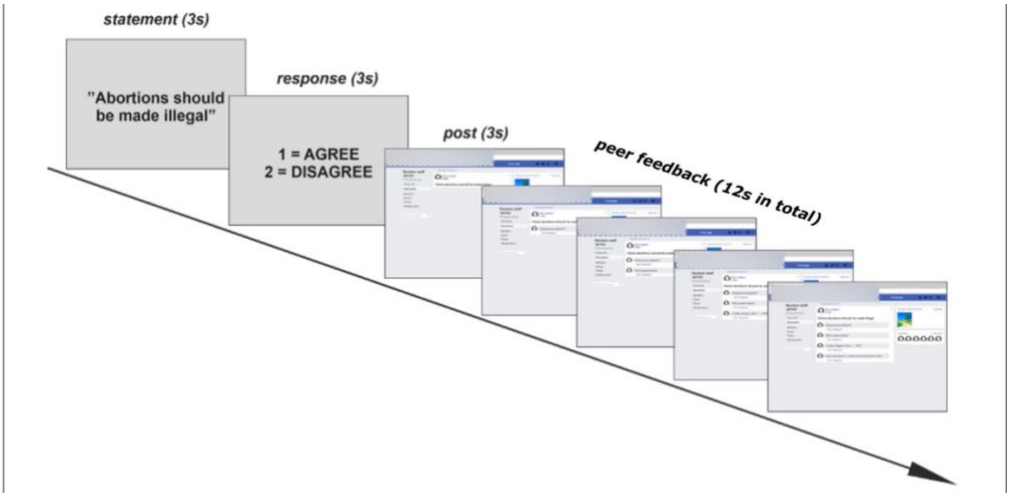

FIGURE 2 | A schematic illustration (translated from Finnish to English) of the procedure of the study. In the sequence of an example trial, where the participants are presented with a controversial statement, they respond with “agree,” and then receive negative peer feedback from peers.

(Fig 3. Wikman et al. 2022: 5)

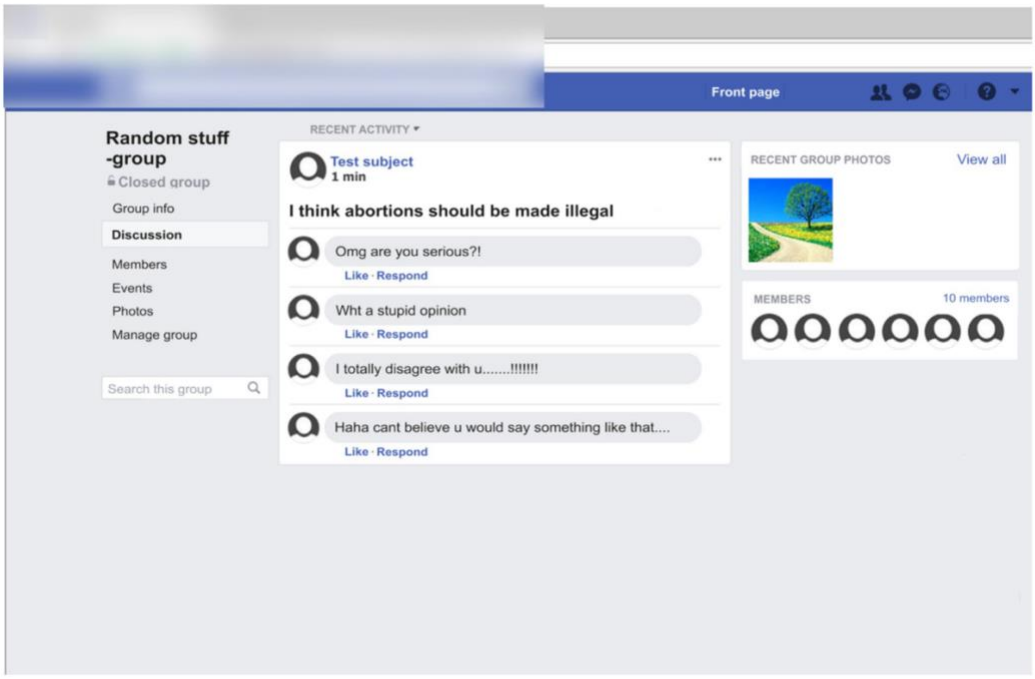

FIGURE 1 | An example screenshot (translated from Finnish to English for descriptive purposes) of the mock Facebook environment used in the study. The response of the participants to a controversial statement is presented as a "post" in a generic Facebook group. The post is followed by four comments from perceived peers. In this example, the participant has responded with "agree" to a controversial statement and has received negative peer feedback to their "post" from peers.

Fig 4 Wikman et al. 2022: 5

Each block consisted of 18 trials, six for each of the following three conditions: (i) a neutral statement with neutral peer feedback, (ii) a controversial statement with positive peer feedback, and (iii) then a controversial statement with negative peer feedback. At the end of each block, a fixation cross in the middle of the screen would appear for 40 seconds. The orders of the trials were randomized, and comments appeared under the post in random order in intervals of 2, 2.7, 3.3, or 4 seconds (2022: 4).

c. Analysis

Imaging was conducted with a 3 T MAGNETOM Skyra whole-body scanner. The focus of analysis is the extent to which neural sensitivity to negative peer feedback was associated with social media use. To avoid correcting for searching the whole volume and increasing the

likelihood of Type II errors, Wikman et al. 2022 chose to analyze the mean signal changes specifically in brain regions involved in the processing of peer feedback based off their whole brain analysis and also prior research done by Schneider et al. 2017, Somerville et al. 2006, and Sherman et al. 2018. Preprocessing of data was done with SPM12. ROIs were chosen based on the contrast of *valenced peer feedback* > *neutral feedback*: superior temporal, inferior frontal, and medial frontal in the left and right hemisphere; and a bilateral occipital ROI (2022: 6). The measure was then put through a mixed-measure analyses of variance (mixed ANOVAS), including number of active social media contacts, time spent on social media, and popularity on social media (2022: 7). Age and gender were also regarded as covariates that could affect fMRI results.

d. Results and Further Instruction

The results of the study showed that neutral peer feedback elicited activation clusters in the ventrolateral prefrontal cortex, medial prefrontal cortex, superior temporal gyrus and sulcus and occipital cortex (2022: 8). Negative feedback was shown to activate greater activity in the ventrolateral prefrontal cortex and medial prefrontal cortex and anterior insula when compared to neutral feedback (2022: 8). However, it should be noted that such negatively charged feedback ("What a stupid opinion!") can produce confounding factors that should make one view results with more pause. Wikman et al. 2022 calls for further investigation into the neural mechanisms behind the emotions that stem from virtual peer interaction, as this may further our understanding as to why adolescents are so intensively involved with social media (2022: 11).

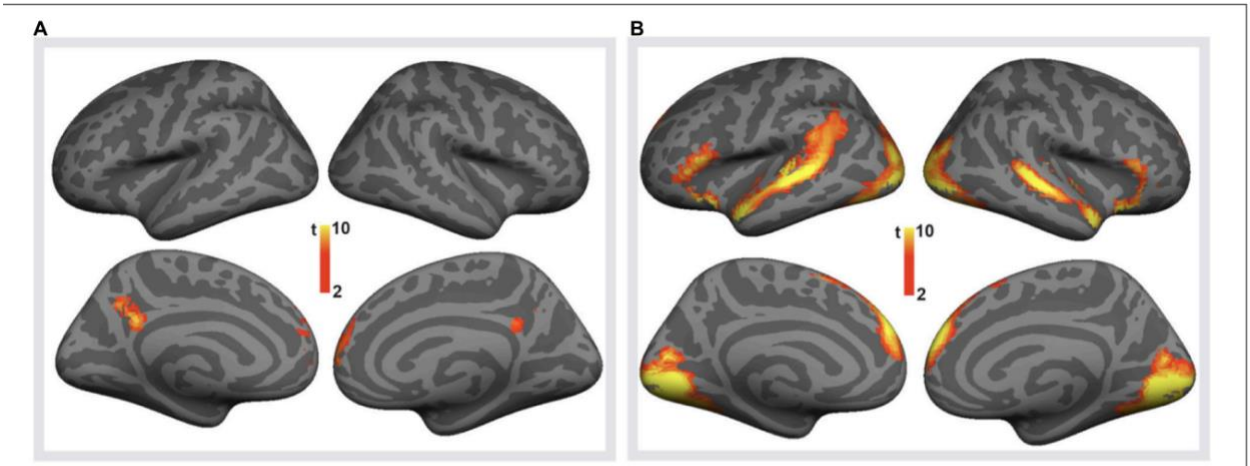

FIGURE 3 | Brain responses to emotionally valenced vs. neutral stimuli. **(A)** Brain regions showing significantly stronger activity in response to viewing controversial (valenced) statements than to viewing neutral statements. **(B)** Brain regions showing on average significantly stronger activity in response to positive or negative peer feedback (i.e., valenced feedback) than to neutral feedback. Voxel-level family-wise error corrected $p < 0.05$, cluster size > 100 voxels for both.

Fig. 4 Wikman et al. 2022: 9

iv. Achterberg et al. 2016

a. Research Type and Background

In the swirl of feedback that we receive on social media, it is understood that a significant portion of feedback will be negative or undesirable. Negative feedback on social media has been found to generate aggressive feelings and behavior. While studies have been conducted into the neural basis of negative social feedback, the underlying neural mechanisms surrounding aggression regulation stays relatively understudied. Achterberg et al. 2016 uses fMRI imaging in conjunction with noise-blast in order to discover those neural mechanisms. A noise-blast is a loud sound imagined to be "electronically" sent to a peer as a form of retaliation. The technique is predicated on the work done by Twenge et al. 2001 and Chester et al. 2014 who both included a noise-blast with social-rejection tasks. By exposing the participant to negative social feedback in the scanner, Achterberg et al. 2016 hypothesized that negative social feedback, in regard to their created profile, would cause reactive aggression (signified by longer noise blast), and that less aggression would be related to increased activation in the lateral prefrontal cortex, also in

response to negative feedback (2016: 713). Based on prior research, it was also hypothesized that positive social feedback would result in increased activation in the subgenual anterior cingulate cortex and ventral striatum (2016: 713) (Guyer et al. 2009; Davey et al. 2010; Gunther Moor et al. 2010).

b. Methods

Achterberg et al. 2016 gathered 15 participants for this study, aged between 18 and 27. The participants IQ was estimated using the 'similarities' and 'block design' subsets of the Wechsler Intelligence Scale for Adults, third edition, and all fell within normal to high range (2016: 713). The researchers made use of the Social Network Aggression Task (SNAT) which was adapted from the social evaluation paradigm. Before scanning, participants completed a profile page at home, which was submitted a week before the fMRI session (2016: 714). The profile contained info on favorite sports, things that made them happy, and their biggest wishes. The SNAT would present participants with pictures and feedback from peers of the same age in response to their personal profiles. Positive feedback would be represented by a green thumbs up, negative feedback would be a red thumbs down, and neutral feedback would be a grey circle. Unbeknown to the participants, all feedback was fabricated, and their profiles were not truly judged (2016: 714).

Once reviewing the feedback participants received on their profiles, they were then made to respond with a noise blast that they imagined would be "sent" to the peer responding to their profile, a visual cue would indicate how loud the noise blast being sent would be (participants were exposed to the noise blast in a pre-scan brief, no noise was played in the scanner). Participants could click a button to indicate how loud they want the noise blast to be but they

were informed the noise blast would not actually be sent to the peer. Participants were told to imagine it would be. There were 60 trials in total separated into two blocks of 30 trials, with 20 trials for each social feedback condition (positive, negative, neutral), and the order was semi-randomized so that no condition was presented more than three times in a row (2016: 715). The order was as follows: fixation cross (5 sec), social feedback (25 sec), fixation cross (3-5 sec), noise screen with volume bar (5 sec), fixation cross (0-11.6 sec).

c. Analysis

Imaging was done with Philips 3.0 Tesla scanner. Data gathered from fMRI in the study were analyzed with SPM12. Analyses were made using a general linear model, with the fMRI time series being modeled as two events convolved with the hemodynamic response function (HRF) (2016: 715). The beginning of the social feedback was considered as the first event with zero duration with separate regressors for the positive, negative, and neutral peer feedback. Contrast images were subject-specific and used for group analysis. A factorial analysis of variance (ANOVA) with three levels (positive, negative, neutral) was used to investigate the neural responses to the peer feedback on the participants' profiles (2022: 715). Achterberg et al. 2016 used a conjunction analysis on ROIs that were activated both after negative and positive social feedback in order to explore the main effect of social evaluation. Results were False Discovery Rate (FDR) cluster corrected.

d. Conclusion and further direction

Achterberg et al. provided insight into the neural responses associated with online peer feedback. Longer noise blasts were associated with receiving negative feedback, especially when compared to neutral feedback (2016: 716) (Fig. 4). Noise blast duration was also greater in neutral feedback as opposed to positive feedback. The main contrast for the fMRI analysis was

the *positive > negative feedback*, which showed activation with local maxima in the bilateral occipital lob, left post central, and in the right and left striatum, extending into subgenual anterior cingulate cortex. *Negative > neutral feedback* resulted in activity in the bilateral include and medial prefrontal cortex. *Positive > neutral feedback* revealed greater widespread activation in the bilateral insula and medial prefrontal cortex, and activity in the ventral striatum, subgenual anterior cingulate cortex, and occipital lobe (2016: 718). The results suggest that, consistent with prior studies, that there was increased activity in the ventromedial prefrontal cortex and the striatum after positive feedback. Achterberg et al. 2016 also reinforces the notion that positive evaluations and social acceptances activate similar brain regions that are activated by the primary feelings of reward (2016: 717). The data also suggests that the lateral prefrontal cortex is an important neural regulator of social aggression. Achterberg et al. 2016 recommends that future research should further validify the noise blast as a measure of aggression by including additional measure of aggression (2016: 718).

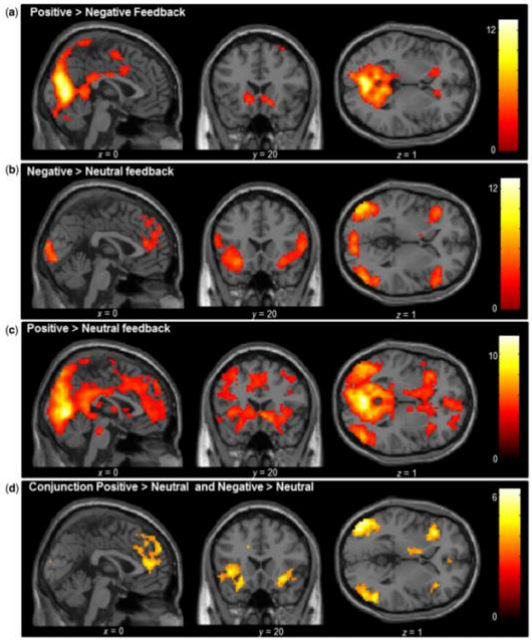

Fig. 2. Whole brain full factorial ANOVA conducted at group level for the contrasts (a) Positive > Negative feedback, (b) Negative > Neutral feedback, (c) Positive > Neutral feedback and (d) the conjunction of the Positive > Neutral and Negative > Neutral feedback contrasts. Results were FDR cluster corrected ($P_{FDR} < 0.05$), with a primary voxel-wise threshold of $P < 0.005$ (uncorrected).

Fig. 5 Achterberg et al. 2016: 717

v. Su et al. 2021

a. Research Type and Background

The aim of Su et al. (2021) was to address why people easily indulge in watching personally recommended short form content, and their focus was on the popular social media app TikTok. To do this, Su et al. (2021) looked into the algorithms deployed by TikTok to obtain content to use as stimuli in an fMRI scanner. In 2020, TikTok was downloaded 1.5 billion times and research was being released on problematic short video watching behaviors. Su et al. (2021) cites Hasan et al. (2018) who reported algorithms "recommending" content for users to watch and a lack of self-control contribute to individuals' excessive use and thus involvement with video streaming services (Hasan et al. 2018). Because the default mode network is implicated in self-referential processes and autobiographical memories, Su et al. (2021) hypothesized that recommended videos could elicit activation of the default mode network.

b. Methods

Su et al. (2021) began by giving participants a questionnaire determining Problematic TikTok Use and a Brief Self-Control Scale (Tan and Guo 2008), then they recruited 30 (14= female) participants from Zheijiang University. Twenty of the participants had reported using TikTok for at least a year 14 reported they spent more than one hour a day watching videos on TikTok.

There were two forms of stimuli presented in the fMRI: generalized recommended videos and personalized recommended videos. The generalized recommended videos were gathered by creating a new TikTok account and recording the first 6 minutes of use = 29 short music videos that ranged from 5 seconds to 21 seconds. The same was done for personalized recommended videos, however those were taken from the first 6 minutes on the participants own account, allowing the videos to be personalized uniquely to them.

c. Analysis

A Siemens 3.0-T scanner was used to capture data. Between every two video clips, there was a white fixation cross on a black background for 30 seconds (2021: 2). The study used a block design for stimuli with three conditions: general videos, personalized videos, and interval/break. Each condition had 6 blocks with each block lasting 1 minute. SPM 12 was used for preprocessing along with being normalized to the Montreal Neurological Institute (MNI) atlas.

d. Conclusions and further direction

The brain regions that were activated by personalized videos and generalized videos showed overlap in the following areas: bilateral primary and secondary auditory and visual cortices, fusiform gyrus, parahippocampal gyrus, superior and inferior temporal cortices, inferior prefrontal, premotor cortex, dorsal posterior cingulate cortex, precuneus, inferior parietal lobule, orbitofrontal cortex, dorsolateral prefrontal cortex, and caudate (2021: 4). Higher activation was revealed during personalized videos in the bilateral superior and middle temporal gyri, temporal pole, ventral posterior cingulate cortex, medial prefrontal cortex, and angular gyrus, which were collectively considered as part of the default mode network (2021: 4). When comparing personalized videos to generalized ones, the fMRI results showed higher activation in the ventral tegmental area, lateral prefrontal cortex, anterior thalamus, and cerebellum. Su et al. 2021 suggest these findings can help shed light on how recommendation algorithms for short videos are able to keep the user's attention to suggested content (2021: 8).

vi. Nasser et al. 2020

a. Research Type and Background

Similar to Sherman et al. (2016), Nasser et al. 2020 aimed to recreate an Instagram mockup within the scanner to see participants' neural response to positively valenced, negatively valenced, and neutral Instagram content. A primary differentiating factor from Sherman et al. (2016) is that this study also analyzes and categorizes participants based on their problematic Instagram use, or lack thereof. Nasser et al 2020 justifies this by noting Instagram's increased prevalence, its association with psychiatric disorders, and risk-taking behaviors (2020: 2). Based off prior research that suggests the dopaminergic reward network (ventral striatum, caudate nuclei, hippocampus, insula, nucleus accumbens, precuneus, and amygdala) explains the brain's response to behavioral addictions (Wang et al. 2016; Syed Nasser et al. 2019a) the team hypothesized that subjects with problematic Instagram use would exhibit increased activation in areas associated with the dopaminergic reward system compared to healthy controls when presented with Instagram themed cues (2020: 2-3).

b. Methods

Nasser et al. 2020 gathered 30 undergraduate students and had them participate in behavioral test such as Barrett's impulsivity test, and the Depression, Anxiety, and Stress Scores assessment test. Then the Smartphone Addiction Scale-Malay version questionnaire and the Modified short Instagram Addiction questionnaire were also utilized. The subjects were then separated into a healthy control (n=15) and problematic Instagram use (n=15) groups based on their overall performance.

The fMRI paradigm used a block-based structure and presented the subjects with a recreation of the online environment of Instagram. The participants were then shown pictures that were valenced as one of the following: risky (selfie taken from great heights with high number of *likes*), neutral (grayscale inanimate objects and scenery with a low number of *likes*), or positive (pleasant, colorful pictures taken from the participants' own Instagram with high or low number of *likes*) (2020: 4).

There were eight blocks per condition, with the three conditions being present. Each cue was shown for 6 sec. with a block lasting 30 sec. and after each block, a fixation cross on a black background was displayed for 30 sec. The block presentation with the fixation cross lasted about 24 minutes total. Using an MRI compatible response box, participants would decide whether to "Like" or "Pass" on each picture shown.

c. Analysis

Imaging was conducted using a 3.0 Tesla Siemens MAGNETOM MRI Scanner. Preprocessing of fMRI data was done with SPM 12 mapping and normalized to the standard Montreal Neurological Institute (MNI) atlas. Nasser et al. 2020 used a general linear model for examining activation in negative vs. truly neutral, positive vs. truly neutral, and negative vs. positive valence (the degree to which something is positive or negative) contrast were calculated (2020: 5). Six ROIs involved in the dopaminergic reward system and executive control network seeds were chosen: amygdala, anterior cingulate cortex, precuneus, orbitofrontal cortex, dorsolateral prefrontal cortex, and medial prefrontal cortex (Everitt and Robbins, 2005; Pierce and Kumaresan, 2006; Ko et al., 2009; Haber and Knutson, 2010; Liu et al., 2011; Starcke et al., 2018; Wegmann et al., 2018).

d. Conclusions

It was found that participants regarded as having problematic Instagram use *liked* far more "risky" pictures than the control group. Also, when viewing the risky photos, the problematic Instagram use group exhibited increased activations in regions of the prefrontal cortex: superior occipital gyrus, left medial occipital gyrus, left inferior occipital gyrus, right fusiform gyrus, parietal lobe, right superior and left inferior parietal lobule, and the right medial occipital gyrus (2020: 7). Within the problematic Instagram use group, negatively valenced photos compared to positive photos elicited significant activations in the left precuneus node of the dopaminergic reward network (Fig. 6) – for the same comparison amongst the healthy control group no significant node activations were detected. Compared to the control group, the problematic Instagram use group showed relative activation in the executive control network when presented with the addiction-specific stimuli, specifically in the dorsolateral prefrontal cortex, medial prefrontal cortex, and orbitofrontal cortex (2020: 9).

As for the ROIs gathered a priori that were being measured, the dorsolateral prefrontal cortex and left medial prefrontal cortex among the problematic Instagram use group (2020: 7).

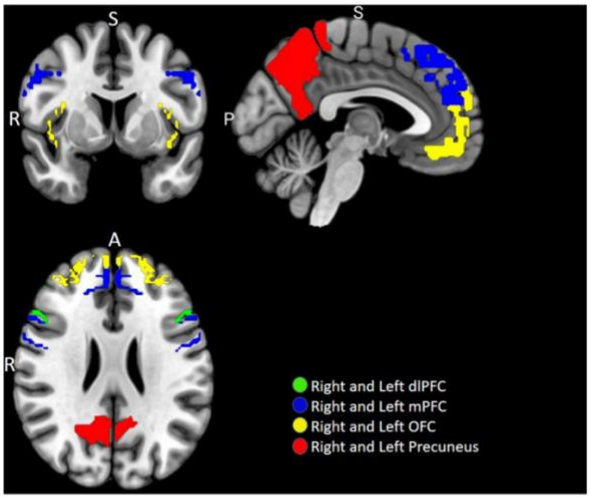

FIGURE 3 | Multi-slice axial view of brain functional image subtraction in PIGU > Control group contrast, when presented with negative emotional valence cues.

Fig. 6 Nasser et al. 2020: 10

vii. Tashjian and Galvan 2020

a. Research Type and Background

In an era dominated by social media, the impact of emotionally-charged content on neural and cognitive functions is increasingly scrutinized. Using task-based fMRI, Tashjian and Galvan 2020 investigate whether exposure to negative, discriminatory tweets affects executive functioning. The researchers hypothesized that tweets that included negative, discriminatory content would interfere with performance on a spatial reasoning task as well as reduced activation in dorsal executive regions associated with worsening affect during tweet presentation would relate to worse performance task.

b. Methods

Tashjian and Galvan 2020 recruited 57 adults aged between 18 and 29 years (38 female). All participants were fluent in English at least between the ages of 18 and 30 and right-handed.

Participants also received a mental rotation (MR) test and received auditory and written instruction (2020: 776).

All participants were exposed to picture stimuli while in the fMRI scanner in one of two conditions: negative or neutral. The task consisted of 5 task blocks in the following order: (1) pre-tweet MR trials, (2) affect ratings, (3) tweet presentation, (4) affect ratings, (5) post-tweet MR trials (2022: 776).

The mental rotation (MR) trials pertained to subjects being shown a pair of objects, with one being modeled relative to the other, however half of the pairs were matches and half of them were not. The shapes were tilted in space and two angle disparities were used, 100 and 150 degrees. All shapes were white and presented on a black background for 11 sec. The participants were asked if the objects were the same shape, requiring the participant to perform a mental rotation of the shape. The participants were not told if they chose the correct answer. Jittered interstimulus intervals (ISIs) displayed a white fixation cross on a black background for a period between 0.5 and 4 seconds (it is not mentioned if this occurred between stimuli). As previously mentioned, these were given before and after the tweet trials (2022: 776).

The tweet trials had participants reading either a set of actual tweets that have been negatively valenced and are inclusive of discriminatory language (negative) or a set of actual tweets related to general topics rated as neutrally valenced (neutral) (2022: 778). Tweets used were selected from actual tweets to preserve ecological validity of the stimuli. The tweets were shown during the task for 12 sec.

c. Analysis

Imaging was done via a 3T Siemens Magnetom Prisma scanner. Preprocessing of data was conducted using FSL and BET (Brain Extraction Tool) and put into an MNI space. To investigate the main effects of the task, Tashjian and Galvan 2020 formed a GLM (general linear model) defined by 6 regressors: task instructions, MR stim presentation (pre and post), MR decision screen (pre), MR decision screen (post), affect rating screens (pre and post), and tweet presentation (2022: 778).

d. Conclusions

Tashjian and Galvan 2020 study shown to elicit greater activation in distributed regions that were previously identified as relevant to emotional response and regulation (bilateral amygdala, orbitofrontal cortex), memory encoding (bilateral hippocampus, middle and superior temporal gyrus), and language processing (inferior frontal gyrus, precentral gyrus) (2022: 780). Tweets also seemed to perpetuate deactivation in regions of the executive control network and default mode network compared to baseline (2022: 780).

Mental rotation decisions post-tweet elicited greater activation compared to baseline in regions associated with working memory and attention (dorsolateral prefrontal cortex, anterior cingulate cortex, bilateral insula, middle frontal gyrus) and spatial cognition (precentral and postcentral gyrus and parietal lobule) (2022: 779).

Tashjian and Galvan 2020 found that exposure to negative content on social media led to worsened mood, which was associated with changes in neural activity in the dorsolateral prefrontal cortex, a region linked to cognitive control (2022: 284). Participants exposed to negative tweets experienced greater habituation in the dorsolateral prefrontal cortex, which affected their performance on a spatial reasoning task. This suggests that emotional distraction

reallocates cognitive resources, impacting cognitive processes (2022: 783). The study's use of actual tweets enhances ecological validity, and assessing neural activation corresponding to self-reported mood changes reduces assumptions about arousal, advancing understanding of emotion-cognition interactions.

viii. Resting-state MRI studies

The sole study in this section is meant to convey the practicality of resting-state MRI studies, as well as comparing results in multiple normalization paradigms. It takes only a few minutes to conduct a resting-state MRI study (see Fig. 7 for atlas comparison).

ix. Bo et al. 2022

a. Background and Research Type

As society becomes increasingly immersed in social media platforms, there is a growing interest in understanding the impact of social media usage on the human brain and cognition. Numerous studies have linked social media use to various cognitive effects, including decreased attention, memory, and learning abilities, as well as structural and functional changes in the brain. However, many of these studies have been limited by their cross-sectional design, making it challenging to determine causality. Therefore, it remains unclear whether social media use induces changes in the brain or if individuals with certain biological traits are predisposed to using social media. Bo et al. 2022 conducted research into this causal relationship as it is crucial for informing interventions and guidelines aimed at mitigating potential negative effects of social media use. The researchers used fMRI based functional connectivity (FC) aimed at finding if social media can influence cerebral FC, even under a short period (2022: 2263).

b. Methods

Bo et al. 2022 gathered two group of subjects for a total of 30 supposed high social media (HSM) use participants and 21 low social media (LSM) use participants (2022: 2263-2264). The HSM use group and LSM use groups were defined by questionnaires given to potential participants. Social media refers to Tiktok, Microblog, and Kwai, the most common social media apps in China (2022: 2264). All participants were given a baseline multi-modal fMRI scan. The LSM participants were then instructed to use social media at least 2 hours per day for a period of 4 weeks. Participants were also given a cognitive test, the Stroop color and word test and a continuous performance task. After this period, the participants were scanned again (2022: 2264).

c. Analysis

Preprocessing was done with SPM12 and mapped onto the brain atlas Montreal Neurological Institute (MNI) (Bo 2022: 2264). Interestingly enough, to account for differences imposed by different brain atlases, Bo et al. (2022) chose to map their data onto three different atlases: AAL, Brodmann, and Yeo to compare results (2022: 2269). For the data, Bo et al. 2022 made use of intersubject correlation (ISC) which allows one to measure similarity across experimental conditions. ISC allowed investigation into the similarity of FC of heavy social media users, low social media users at baseline state, and the low social media users after the "heavy" social media usage test (2022: 2263). The researchers also used brain-region ISC to locate brain regions that were most affected by social media and investigated the relationship between those FC and cognitive function (2022: 2267).

d. Conclusion and Further Directions

Bo et al. 2022 found correlations between selective attention and functional correlates that were most affected by social media as well as illuminated the causality between social media use and biological traits (2022: 2272). The study shows the functional connectivity of the low social media user group became more like the high social media use group after the four-week social media task. The team also found that the FC characteristics of over half the brain region could be structured by four-weeks of heavy social media use, involving almost all major brain networks (limbic, somatomotor, visual, cerebellum, default mode networks) (2022: 2270). Bo et al. 2022 theorized that the fact almost all networks were affected could be due to the nature of social media containing very diverse stimuli. After comparing the data from the different atlases, Bo et al. 2022 found the results consistent (Fig. 3). For future research, Bo et al. suggests having a larger sample size than the one they gathered, and also recommends letting the task of 2 hours of social media use per day run for longer than just four weeks (2022: 2273).

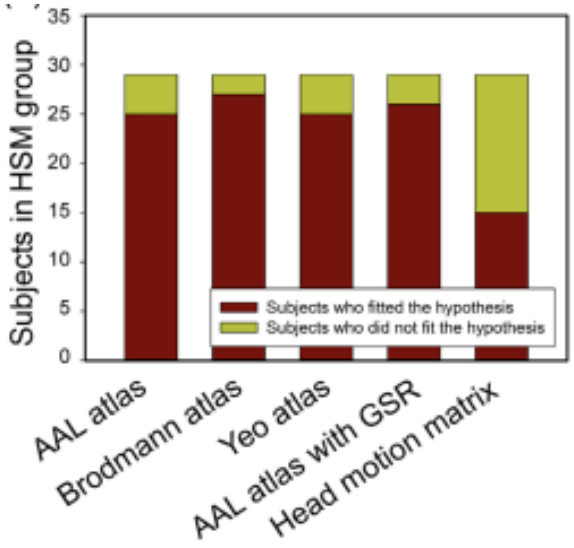

Fig. 7. Three different atlases to compare results: [left to right] AAL, Brodmann, and Yeo (Bo et al. 2022: 2269)

Table 2.1

Authors (Year)	**Block design**	**Event-Related Design**	**Time in Scanner**	**Network Analysis**
Sherman et el. 2016		X	11min 48s	
Achterberg et al. 2016	X		Not mentioned	
Tashjian and Galvan 2020	X		Not mentioned	X
Wikman et al. 2022			1 hr	X
Nasser et al. 2020	X		24 min	X
Su et al. 2021	X		Not mentioned	X

Table 2.2 Imaging Technique – all used BOLD fMRI

Authors (Year)	**Sample**	**Mean Age**	**Design**	**Main Results**
Sherman et al. 2016	32 Instagram users (18 females)	16.8	- Instagram was simulated in the scanner. - Photos were shown in the Instagram simulation attached with a high or low	- Greater activation in bilateral nucleus accumbens when viewing own photos with many *likes*. - Viewing photos with a high number of *likes* attached showed increased activation in

			number of *likes*, including participants' own photos. - Participants decided whether to 'Like' or 'Skip" each photo.	the medial prefrontal cortex, left temporal pole, lateral occipital cortex, hippocampus, nucleus accumbens, caudate, putamen, and thalamus. - Decreased activity in areas linked with cognitive control when participants viewed risky photos.
Achterberg et al. 2016	30 subjects (female = 15)	22.6	- Participants created a basic online profile, and their profile received peer feedback in the scanner (neutral, negative, or positive). - Participants were then instructed to send a "noise-blast" to their peer with the intensity they desired.	- Positive and negative peer feedback were associated with greater activation in the medial prefrontal cortex and bilateral insula.
Tashjian and Galvan 2020	57 subjects (female = 38)	20.9	- 'Tweet Task' Paradigm. Participants would be shown negatively valenced tweets or neutral tweets. - Participants performed a spatial reasoning task pre- and post- tweet.	- Worsened cognitive performance for the spatial reasoning task was shown in the negative condition compared to neutral. - Post-tweet, parametric reductions were shown in left dorsolateral prefrontal cortex.
Wikman et al. 2022	92 subjects (female = 52)	18.7	- Participants completed a Facebook like task. - Participants would agree/disagree with controversial/neutral statements and then received positive or negative feedback on their opinions in the form of a Facebook group.	- Positive feedback elicited greater activity in regions including the posterior insula, temporal parietal junction, precuneus, and posterior cingulate cortex. - Negative feedback was associated with increased medial prefrontal cortex, ventrolateral prefrontal cortex, and anterior insula activity.
Nasser et al. 2020	30 Instagram users. 15 characterized as problematic users (female = 5) and 15 as	21.9	Participants viewed positively or negatively valenced Instagram photos as well as neutral landscape images.	- Negative cues elicited increased activation of precuneus in problematic users. - A negative and moderate correlation was found amongst problematic users with their Instagram addiction score and

	healthy control (female = 8).			right medial prefrontal cortex activation.
Su et al. 2021	30 TikTok users (female = 14).	23.7	Participants were shown a collection of generalized and personalized TikTok short videos, without seeing any of the videos prior.	- Personalized and generalized videos enhanced connectivity in the DAN-FPN-DMN pathway, and both video types resulted in reduced coupling between the SN and VAN.

Table 2.3 Software Packages and Atlas

Authors (Year)	Atlas	Software Package
Sherman et al. 2016	MNI	AFNI/FSL
Achterberg et al. 2016	MNI	SPM8
Tashjian and Galvan 2020	MNI	FSL
Wikman et al. 2022	MNI	SPM12
Nasser et al. 2020	MNI	SPM12
Su et al. 2021	MNI	SPM12

V. Article Synthesis

All of the articles analyzed provide a unique look into examining the neurological correlates of social media use by using ecologically social media use case in the bore of the scanner. This section will provide a look into the differences, overlap, convergence, and methodological differences.

As mentioned previously, social media is relatively new, and peer reviewed data surrounding it are even newer. These are some of the select few studies (Wikman et al. 2022, Tashjian and Galvan 2020, Sherman et al. 2016, Su et al. 2021) that show stimuli nearly identical to modern social media in the scanner, so viewing any overlap or discrepancy is important as this new research is fleshed out.

i. Methodological Comparison

Save for Bo et al. 2022, all of the studies selected for this paper use picture stimuli to recreate social media in fMRI in some fashion. Of the six studies, four focus on text based social media (Sherman et al. 2016, Tashjian and Galvan 2020, Wikman et al. 2022, Nasser et al. 2020) two are Instagram based (Sherman at al. 2016, Nasser et al. 2020), and only one focuses on social video media (Su et al. 2021). No task-based studies also utilize resting-state fMRI or longitudinal study design.

a. Peer Feedback Studies

Four of the studies in this paper investigate peer-feedback in regard to social media, two utilizing an amount of "*Likes*" on participants' own post (Sherman et al. 2016, Nasser et al. 2020), one on negatively valenced comments on participants' post (Wikman et al. 2022) and another on the general reaction to the participants online profile (Achterberg et al 2016).

All of these studies utilized picture-based stimuli in the scanner to recreate aspects of social media (all but one recreated the UI elements, Achterberg et al. 2016 used a user-made profile). As mentioned previously, creating a more realistic recreation of social media improves ecological validity, but there a couple of things to note here.

The extent to how applicable Wikman et al. 2022 is to real-world social media usage is questionable. The study exposes participants to multiple rude comments on social media, though only through a comments section on a Facebook post and doesn't test for positive valence. I would argue that the number of people who consistently use social media, post polarizing content, and receive multiple negative comments without any positive comments is quite low; however, there is not much research done into the number of negative comments social media users receive on their own posts. The comments also are full of derogatory language, which presents confounding factors of emotional stimuli.

Achterberg et al. 2016 data may also not be applicable to real-world scenarios. Achterberg et al. 2016 uses a noise blast in their study, which they note needs to be further validified through more testing (2016:718).

b. Social-Media Stimuli

Su et al. 2022 and Tashjian and Galvan 2020 both exposed participants to social media content, TikTok and Twitter respectively. Su and colleagues chose to screen-record personalized and generalized videos through TikTok to replicate more accurate usage. Tashjian and Galvan 2020 opted to show a series of neutral or negatively valenced tweets. Similarly to Wikman et al. 2022, Tashjian and Galvan used tweets with derogatory language, which while is common on Twitter, can present confounding factors through emotional stimuli.

ii. Brain Region Analysis

In this section, we review brain regions of interest that are commonly implicated in social media use via the dopaminergic reward network, executive control network, and other networks through studies mentioned (Everitt and Robbins, 2005; Pierce and Kumaresan, 2006; Ko et al., 2009; Haber and Knutson, 2010; Liu et al., 2011; Starcke et al., 2018; Wegmann et al., 2018). These areas include the ventral striatum/nucleus accumbens, prefrontal cortex (lateral, medial, and orbitofrontal), cingulate cortex, precuneus, cingulate cortex, and insula. It should be noted again, however, that the larger trend occurring in neuroimaging research is moving away from *localization as explanation* (Poeppel 2008). Localization is still useful in understanding more about brain function, but looking for a dynamic-system level provides us with more contextual and concise information (Andrews 2014: 158).

a. Ventral Striatum/Nucleus Accumbens

As many of the articles in this review have suggested, the ventral striatum and in particular the nucleus accumbens are regions heavily involved in emotional processes (Salgado and Kaplitt 2015). The nucleus accumbens are commonly known to be a key component in the natural reward system, which includes modulation of motivations and incentivized learning (2015: 81). This brain region is also said to be a key player in a positive emotional pathway, which is counterbalanced by a negative emotional pathway that is regulated by the amygdala (2015: 81). Neurosurgical intervention into the nucleus accumbens have led to finding that suggest the nucleus accumbens play a vital role in addiction (2015: 81) and because social media has been shown to be addictive to adolescents, this brain region has been expected to have

neuroadaptations in regard to social media use. In the articles selected for this paper, that does seem to be the case. Sherman et al. 2016 and Achterberg et al. 2016 found significant nucleus accumben activation when participants were exposed to various stimuli in social media.

Sherman et al. 2016 found greater activation in the nucleus accumbens when participants received a higher number of *likes* on their own pictures and also when viewing a picture (risky or neutral) with a higher like count. Sherman et al. 2016 believes their findings suggest this region is implicated in the experience of receiving positive feedback online as well as viewing content that has been endorsed by peers (i.e. by a high number of *likes*) (2016: 1033).

Achterberg et al. 2016 found increased activation in the striatum and nucleus accumbens after positive peer feedback compared to neutral (2016: 717). Su et al. 2021, though they chose the nucleus accumbens as a ROI, found no significant activation when participants viewed both personalized and generalized video recommendations (2021: 9). This is of interest because they did find activation in the ventral tegmental area, a region encompassing the nucleus accumbens, when exposed to personalized videos (2021: 4).

b. Prefrontal Cortex

The prefrontal cortex can be divided into three large regions that make up its parts: the lateral, medial, and orbitofrontal regions. The lateral prefrontal cortex has been implicated in several functions of the brain including language, attention, memory, novelty processing, and creativity (Siddiqui 2008). The media prefrontal cortex has been found to be connected with self-referential processing, motivation, and decision making while the orbitofrontal section is integrated into aspects of emotional behavior, response inhibition, and reward processes (expectations, value, and pleasantness) (2008: 202). As one can imagine, self-referential

processing, inhibition, emotions, etc; play a vital role in participation in social media – all of these regions are shown to have significant activation in the studies.

In Sherman et al. 2016, when participants were shown their own photos with many *likes* (compared with few) or *neutral images* > *risky images*, the medial prefrontal cortex showed significantly more activation. In fact, for all three types of photos with many *likes* (risky, neutral, and the participants' own photos) participants would show greater brain activity in the medial prefrontal cortex. However, when the images were *risky* > *neutral*, participants showed less activation in the bilateral prefrontal cortex. Sherman et al (2016: 1033) believes this suggest adolescents perceive information in a qualitatively different way when they believe that this information is valued more highly by their peers (2016: 1033).

Achterberg et al. 2016 found that both positive and negative feedback given to participants in regard to their online profile would elicit activation in the medial prefrontal cortex. It was also found that the dorsolateral prefrontal cortex showed more activation when comparing *negative* > *neutral*. Positive feedback also elicited increased activity in the ventral medial prefrontal cortex (2016: 713). Similar to Achterberg et al. 2016 findings, after presenting participants with negative tweets and having them do a mental rotation test, Tashjian and Galvan (2020) found greater activation in areas associated with working memory and attention, including the dorsolateral prefrontal cortex (2020: 780).

Wikman et al. 2022 study into social media-based peer feedback found a sweep of activation in the prefrontal cortex. Positive and negative peer feedback activated clusters in the ventrolateral prefrontal cortex and medial prefrontal cortex, with negative feedback showing even greater activation than positive (2022: 11).

When comparing Instagram users with problematic Instagram users that were exposed to negatively valenced content, Nasser et al. 2020 found that the control group showed increased activation the medial prefrontal cortex while the problematic Instagram use group had reduced activity in the same region. Nasser et al 2020 argues this is due to the problematic Instagram use group's impaired decision-making ability, but they say the small sample size and correlative nature warrants caution in interpreting the data (2020: 10).

Su et al. 2021, when exposing participants to personalized TikTok videos, noticed higher activation in the medial prefrontal cortex, being a part of the default mode network. The study also found that the dorsal media prefrontal cortex was more active during personalized videos as compared to generalized videos.

c. Cingulate Cortex

The cingulate cortex, particularly the anterior cingulate cortex, has been implicated in emotion, noting punishment, and reward information which are all tied to emotional response and behavior (Rolls 2019: 1). In this line, Sherman et al. (2016) noted that, when presented with risky images as opposed to neutral images, participants showed significantly less activation in the cingulate cortex and other areas implicated in the network of cognitive control and response inhibition (2016: 1031).

Achterberg et al. (2016) also found the anterior cingulate cortex to be involved in emotional response, when showing participants positive feedback on their created profiles, higher activation was seen (2016: 713). Similarly, Nasser et al. 2020 found their problematic Instagram use group exhibited increased activation in the cingulate cortex following positive valenced Instagram post (2020: 6). Somewhat differently, Wikman et al. (2022) found that the anterior

cingulate cortex response was dependent on the type of valence of peer feedback, showing greater activity for positive feedback (2022: 2).

Su et al. 2021 found that the dorsal and ventral anterior cingulate cortex and the dorsal posterior cingulate cortex were deactivated when participants viewed either generalized or personalized videos on TikTok (2022: 4).

d. Precuneus

The precuneus has been associated with self-referential cognition, visuo-spatial memory, and playing a role in default-mode network and is thus shown to be implicated in studies that show deviations in the default-mode network (Cavanna and Trimble 2006: 129). It can be reasonably assumed that whenever you are presenting your own content on social media, changes in the precuneus can be expected, and that is what happened. Sherman et al. 2016 noted significant precuneus activation when participants viewed their own submitted photos with many *likes* compared with few (2016:1031). Negatively valenced peer feedback to neutral peer feedback on the Facebook group post in Wikman et al. 2022 showed greater activation in the precuneus, and positive feedback compared to negative feedback also elicited significant activation in the precuneus (2022: 9). Nasser et al. 2020 reports similar findings to Wikman et al. (2022) by reporting increased precuneus activity when exposing participants to negatively valenced compared to positive valenced comments in the problematic Instagram group.

Nasser et el. 2020, before correction, also showed significant activation difference between the left and right precuneus when it came to *negative > positive valenced* stimuli. Similar to the cingulate cortex, Su et al. 2022 al. also found deactivations in the precuneus when participants viewed either personalized or generalized videos.

e. Insula

The functions probable to the insula are still being investigated, but a few lesion-based studies have found the insula to be implicated in socio-emotional processing Calder et al. 2014. This notion is perpetuated by Wikman et al. 2022, Tashjian and Galvan et al. 2020, Su et al. 2021 and Achterberg et al. 2016 who all reported activation of the insula with their emotion invoking stimuli.

Wikman et al. 2022 noted greater recruitment of the anterior insula when exposing participants to negative feedback (as opposed to positive). They believe that these observations likely reflect an increased amount of a negative affective state and increased need for emotion regulation, and that holds true for Tashjian et al. 2020 who made similar findings after showing participants to negatively valenced tweets.

However, Achterberg et al. 2016 found that the insula would generally respond to socially salient feedback without regard to whether it was positive or negative, which is in contrast to Wikman et al. 2022, which is further validified by the fact they both use MNI atlas and SPM software packages (though Wikman et al. 2022 uses a newer version, see table x).

iii. Network Analysis

One of the most important findings in recent times in regard to fMRI is the use of resting state fMRI that led to the finding of 7 major brain networks: default-mode network, auditory, visual, sensorimotor, executive control, salience, and dorsal attention (Raichle 2010). Resting-state fMRI gives more context to the relatively small signal change apparent in task-based BOLD

fMRI, and the network analysis provides a more complete picture to the brain function. Other than Bo et al. 2022, no study incorporated resting-state fMRI into their study.

Tashjian and Galvan 2020, Nasser et al. 2020, Wikman et al. 2022, and Su et al. 2021 all included analysis and background information of major brain networks and analyzed the activation in the larger context of the networks.

Tashjian and Galvan 2020 noticed deactivations in regions of executive control network and default mode network when exposing participants to negative or neutral tweets. Wikman et al. 2022 did not have networks distinguished a priori but did notice a wide-spread network of brain regions activated by valenced peer feedback (Fig. 8) (2020: 9).

Based on a priori knowledge, Nasser et al. 2020 chose ROIs involved in the dopaminergic reward network and executive control network seeds. They found deactivation in areas involved in executive control network and activations in areas involved in the dopaminergic reward system when presenting negatively valenced Instagram post to their problematic Instagram use group (compared to the control group) (2020: 9).

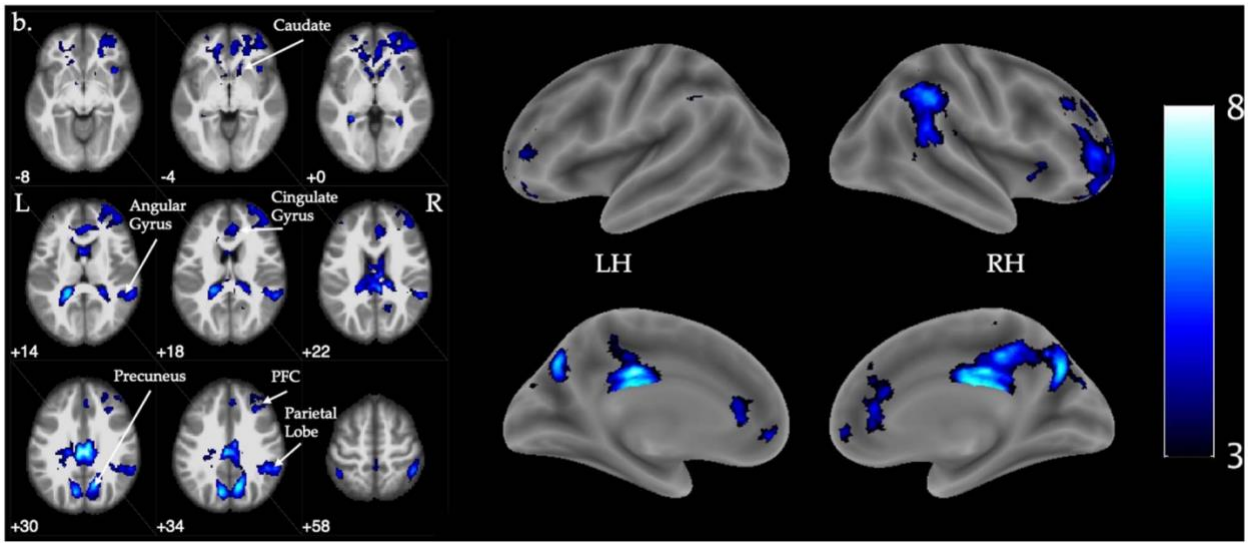

Fig. 8 Deactivations in the executive control network in contrast of tweets versus baseline (Tashjian and Galvan 2020:782)

Similarly to Nasser et al 2020, Su et al. 2021 also chose ROIs involved in brain networks a priori, primarily the default mode network. Su et al. 2021 points out that, though the default mode network was initially identified as a set of brain regions that were deactivated with externally oriented cognitive task (Raichle et al. 2001), studies also suggest that the network can be activated during a wide range consisting of cognitive task, including self-reference, social cognition, and autobiographical memory (Gusnard and Raichle, 2001; Sestieri et al. 2011; Spreng et al. 2009). Utilizing this knowledge, Su et al. 2021 found that the default mode network was activated when showing participants personalized videos as opposed to non-personalized videos on TikTok (2021: 9). These new studies making use of network-based analysis is indicative of a larger trend in the field of task-based fMRI studies to look at not only region specific, but connectivity between brain regions.

iv. Other Observations

It was noted by four out of the six articles that further longitudinal research is needed to help verify their findings on shed light on the relationship between social media use, behavior, and the brain. Also, none of the studies in this paper (besides Bo et al. 2022) utilize resting-state fMRI, which would have given more context to their individuals' brain activation, though many studies did utilize network level analysis in addition to localized brain regions (Tashjian and Galvan 2020, Wikman et al. 2022, Nasser et al. 2020, and Su et al. 2021).

It was noted by Sherman et al. 2016 and Su et al. 2021 how they are the first studies to replicate their prospective social media in the scanner (Instagram and TikTok). This is fundamental groundwork being done as new studies begin to emerge utilizing these present studies as frameworks to build off of.

The last thing to note is how all studies utilize the same brain atlas, and many share SPM (only Sherman et al. 2016 and Tashjian and Galvan 2020 used different software packages) making comparing activations across studies more consistent.

VI. Conclusions and Further Direction

In this paper, we have looked at a new method to examine neural correlates of social media use by exposing the participant to social media within the scanner. In these studies, we have examined brain activation in regard to peer feedback, neutral/positive/negative content, personalized/generalized content, and comparisons amongst them. We have also gone over the importance of not just looking at localized activation, but also at network-based activation analysis as it informs us about brain function. Ecological validity was also brought up in regard to the studies to analyze their real-world applicability. Further research in this area could focus on less emotion arousing stimuli, include longitudinal study design, focus on ecological validity and be network focused.

To bring us back to the top, the psychological and philosophical idea of "invisible causes" I mentioned earlier seems to ring true in this paper. All of these studies examine (activations are problematic, require processing) activation or change in the brain (or change in functional connectivity as we saw in Bo et al. 2022) suggesting that the stimuli surrounding us has a way of affecting us that we are still discovering. These invisible causes bring about effects in our behavior and life, and in the case of social media, can be detrimental if one is not careful.

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