Gender differences in brain activity when exposed to cyberbullying: Associations between wellbeing and cyberbullying experience using functional Magnetic Resonance Imaging

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ABSTRACT

The role of gender and the associated brain activation when witnessing cyberbullying requires investigation. The current study aimed to determine whether brain responses to cyberbullying differ according to gender and level of wellbeing. We hypothesised that females and males would activate different regions of the brain when witnessing cyberbullying, and that this would be influenced by wellbeing levels and prior cyberbullying experiences. Blood-oxygenation-level-dependent (BOLD) responses were examined in participants (N = 32, aged 18–25 years; 66% female) whilst observing cyberbullying versus neutral stimuli during a functional MRI. Results revealed significant correlations between BOLD signal and achievement scores among males, but not females, with previous experiences of cyberbullying, in regions including the cerebellum, the superior and inferior frontal gyrus, and the precuneus. Furthermore, males who previously cyberbullied others, with higher scores in achievement (a wellbeing sub-category), activated brain regions associated with executive function, social cognition, and self-evaluation, when viewing the cyberbullying stimuli. In addition, despite gender, BOLD signal in the cingulate gyrus was negatively correlated with cyberbullying scores, and BOLD signal in the left dorsal caudate and the precuneus was positively correlated with achievement scores. Taken together, these findings provide insights into brain responses to cyberbullying scenarios and emphasize that there are some significant variations according to gender. The overall finding that males activated brain regions linked to varying aspects of cognition, whereas females more often activated regions linked to emotion processing and empathy is important for future research in this area.

1. Introduction

Given the links between cyberbullying and negative mental health outcomes (Fahy et al., 2016; Le et al., 2017; McLoughlin et al., 2018, 2019), there is an urgent need to better understand the neurobiological underpinnings. Cyberbullying is an aggressive, repeated, intentional act carried out on an individual using electronic forms (Smith et al., 2008), and it remains unclear what role gender may play in terms of the brain response to cyberbullying. We conducted the first functional magnetic Resonance Imaging (fMRI) study (McLoughlin et al., 2020a, b, c) to examine the BOLD response when viewing cyberbullying stimuli. We found that ‘cybervictims’ activated responses across numerous regions of the brain, including those linked to social and emotional processing (McLoughlin et al., 2020c). Females had a greater BOLD response to the cyberbullying stimuli in the right anterior cingulate cortex (R-ACC), which plays a key role in the processing of empathy (Decety and Jackson, 2004; Jackson et al., 2006), and emotion regulation (Stevens et al., 2011). Those with no prior experience of cyberbullying had a greater response in the precuneus, responsible for feeling self-conscious (McLoughlin et al., 2020c). It is important to further explore gender differences in the context of both previous cyberbullying experiences (determined via self-report) and current wellbeing, therefore, this paper extends on our previous work with new hypothesis-driven analyses, taking into consideration these other influential factors. This research aimed to answer the following question: Are there gender differences in the brain when exposed to cyberbullying...
stimuli, and does this differ according to wellbeing and experiences of cyberbullying?

Gender differences in cyberbullying have been researched previously, with most studies reporting that females are more likely to be cybervictims, while males are more likely to cyberbully (and traditionally bully) others (Cross et al., 2009; Hemphill and Heerde, 2014; Li, 2006; Sakellariou et al., 2012). This difference is often attributed to lower levels of empathy among males compared to females (Del Rey et al., 2016; Topcu and Erdur-Baker, 2012). Interestingly, there may also be gender differences in cyberbullyer behaviours. Female cyberbullyers tend to be more likely to support a cybervictim compared to males, who are more likely to reinforce the cyberbully by revealing their amusement with it (Bastiaensens et al., 2014). Conversely, other studies have suggested there are no differences between males and females in terms of helping cybervictims (Jenkins et al., 2018).

A recent review (Crone and Konijn, 2018) highlighted that neuroscience is important in terms of understanding the developmental sensitivities related to adolescents’ media use over time. The authors posit that adolescents are particularly sensitive to acceptance and rejection, and that social media exacerbates this, making adolescents vulnerable to emotional sensitivity and poor cognitive control (Crone and Konijn, 2018). Some research has examined social media use and the brain, reporting that young people respond to social interactions online the same they would offline (Lamblin et al., 2017; Sherman et al., 2016). Yet, there is little research to date that has specifically addressed the role gender may play in the impact of cyberbullying on the brain. A recent study on traditional bullying found that in a group of adolescent bully-victims, there was a significant interaction between experiences of childhood victimization and cortisol which predicted vLPFC area in boys, but not girls (du Plessis et al., 2019). This could indicate that bullying victimization may influence development of brain structure, especially in boys. Interestingly, research suggests some differences between male and female brain development. Well known research by Giedd et al. (1996) demonstrated that males had larger cerebral and cerebellar volumes, with the size of putamen and globus pallidus being larger in males, whereas the relative size of the caudate was larger in females. Furthermore, while lateral ventricular volume increased significantly in males with age, their caudate and putamen volumes decreased longitudinally (Giedd et al., 1996). These differences are particularly important when considering neurodevelopmental impairments and may be useful when addressing cyberbullying and gender differences in the brain.

Researchers have established that cyberbullying is a key area of concern, with serious mental health implications for young people in Australia and abroad (Campbell et al., 2012; Fahy et al., 2016; Kim et al., 2011; Lawrence et al., 2015) reported that one in thirteen (7.7%) adolescents aged 11–17 years met the DSM-IV diagnostic criteria for major depressive disorder in the previous 12 months, highlighting that adolescents are already at risk of mental health problems, and cyberbullying increases this risk. Wellbeing may also be an important factor to consider when trying to disentangle the neurobiology of cyberbullying. For example, low self-reported wellbeing scores in children has been linked to increased likelihood of future cyberbullying victimization (Glenn-Shemesh and Heiman, 2014). Other research has examined the impact of cyberbullying on wellbeing over time and found that increased social connectedness in young people is vital to promoting positive wellbeing and can be protective, particularly in those experiencing cyberbullying and/or cybervictimisation (McLoughlin et al., 2022).

While no studies, to our knowledge, have specifically evaluated cyberbullying, wellbeing and brain changes, there is recent evidence of a link between volume of brainstem structures and levels of self-reported wellbeing in adult twins (Gatt et al., 2018). The authors suggested that this association may be due to environmental factors, which may indicate that this relationship can be influenced by previous experiences (for example during childhood) (Gatt et al., 2018). Thus, the current study aimed to address the above-mentioned gaps in research and determine whether brain responses to cyberbullying differ according to gender and level of wellbeing. Based on our pilot study and the aforementioned literature, we hypothesised that males and females would activate different regions of the brain when witnessing cyberbullying stimuli compared to neutral stimuli, and that brain activation when observing cyberbullying stimuli would be positively correlated to individual scores of wellbeing and negatively correlated to prior cyberbullying and cybervictimisation experiences (determined via self-report). Given that this research is the first of its kind, we are unsure which specific brain regions may be activated, however, based on our previous work, we can hypothesise that regions may include the right anterior cingulate cortex and the precuneus.

2. Method

This study was approved by the University of the Sunshine Coast, Human Research Ethics Committee (Ethics Approval Number: A181135).

2.1. Recruitment

Participants were recruited through the advertisement within the University via social media posts, student newsletters, student support services, announcements in lectures, and word of mouth. Those who expressed interest in participating were sent the information sheet and subsequently asked to provide written informed consent. Inclusion criteria: (i) aged 18–25 years; and (ii) proficient in written and spoken English. Exclusion criteria: (i) major neurological disorder, developmental disorder, intellectual disability, or major medical illness; (ii) head injury (with loss of consciousness >30 min); (iii) deemed unsafe to undergo MRI. Due to the pilot nature of this study, and ethical reasons, young adults were recruited for this project. Future research with younger, adolescent populations is warranted, particular as the current paper, and our previous work, have observed differential fMRI responses to these stimuli, making a replication study highly feasible.

2.2. Participants

A total of 32 participants (aged 18–25 years; 21 female), took part in the study.

2.3. Cyberbullying self report measure

The Berlin Cyberbullying-Cybervictimisation Questionnaire (BCyQ) was used to assess experiences of cyberbullying and Cybervictimisation (Schultze-Krumboh & Scheithauer, 2009, 2011). Participants were asked if they had experienced a list of behaviours over a 6-month period at any time in their life, as well as if they had acted in that way. The scale ranged between 0 “has not happened to me at all”, to 4 “several times a week”. Aggregated scores were then created to allow a total score for both cyberbullying (range = 23) and Cybervictimisation (range = 37), with higher scores indicating greater frequency of either cyberbullying or Cybervictimisation.

2.4. COMPAS-W measure

The COMPAS-W (26 item) scale was used to assess poor to optimal wellbeing and resilience and was originally developed in a cohort of 1669 healthy adult twins (19–61 years) (Gatt et al., 2014). It has also been validated for use in those aged 10 to 17-years, with high inter-rater consistency (Gatt et al., 2020). The scale ranged from 1 “strongly disagree”, to 5 “strongly agree”. Aggregates were created for each of the subscales of wellbeing, with higher scores indicating greater levels of those aspects of wellbeing. The Composure sub-scale (COMPAS-WC)
consists of 4 items and had a range of 11. The Own-Worth subscale (COMPAS-WO) consists of 9 items and had a range of 17. The Mastery sub-scale (COMPAS-WM) consist of 6 items and had a range of 13. The Positivity sub-scale (COMPAS-WP) consists of 5 items and had a range of 24. Lastly, the Wellbeing total (COMPAS-W) consists of 26 items and had a range of 53.

2.5. fMRI design - the cyberbullying picture series (CyPics)

The current study utilised our established fMRI protocol, using CyPics (McLoughlin et al., 2020a), which was developed internally by our group (McLoughlin et al., 2020b) and included a total of 12 scenarios created and designed to mimic a social networking site popular with young people, with nuanced comments associated with them to determine their stimulus condition: cyberbullying or neutral. Full details regarding the development of this fMRI protocol, and the use of it in our initial pilot results, have been published (McLoughlin et al., 2020c). In summary, participants were asked to view negative (cyberbullying) and neutral stimuli whilst undertaking task-based fMRI (tb-fMRI) acquisition. Each block consisted of 30s activation (15 vol) and 18s rest (9 vol), and each stimulus was presented six times, totaling 594s (297 vol). The stimuli included three images depicting a female and three images depicting a male (and each of these were duplicated across the two conditions). The CyPicS task was run via E-Prime (v2.0) (Psychology Software Tools, 2018) and visualised within the scan room on an MR compatible NordicNeuro Inroom Viewing Device (NordicNeuroLab, 2018), which was positioned outside the bore and at the head end of the scanner.

2.6. fMRI protocol

All scans were conducted on a 3-T Siemens Skyra MRI scanner (Germany, Erlangen) with a 64-channel head and neck coil at the Nola Thompson Centre for Advanced Imaging. The MRI protocol consisted of a structural, whole-brain 3D T1-weighted Magnetization-Prepared Rapid-Acquisition Gradient Echo sequence (MPRAGE; scan parameters $TR=2200\text{ ms}$, $TE=1.76\text{ ms}$, $TI=850\text{ ms}$, $FOV=240\text{ mm}$, $256 \times 256$ matrix, spatial resolution $= 0.9\text{ mm}$ isotropic, 208 slices and scan duration $= 4\text{ min}$). The fMRI scans were performed using a T2*-weighted multislice EPI sequence ($TR=2000\text{ ms}$, $TE=30\text{ ms}$, $FOV=224\text{ mm}$; $74 \times 74$ matrix, inplane resolution = 3 mm, IPAT6, SMS acceleration factor 3; transverse plane; slice thickness = 3 mm; 57 contiguous slices acquired top-down, 297 vol, scan duration = 9.54 min), with five dummy volumes at the start. The CyPicS task was then automatically triggered from the first “true” RF pulse of the fMRI sequence. Prior to the tb-fMRI sequence a field map with the same FOV was acquired to aid in correcting image distortion due to field inhomogeneities. Self-report measures assessed previous experiences of cyberbullying. Participants were all given unique individual ID codes which were entered at the commencement of the self-report and before the fMRI scan. This way, participants self-report questionnaire responses could be linked to their fMRI scans using their ID codes.

2.7. Data preprocessing

The fMRI analysis was performed using SPM12 (Neuroimaging, 2014). Before processing, each participant’s scans were checked for data quality; functional and structural data were visually inspected for artifacts, coverage of brain regions, and signal dropout, and all scans had passed the quality check. The preprocessing of fMRI data included (i) two-level of motion correction with initial alignment of all volumes to the first fMRI volume of the sequence; then an average volume was created from aligned volumes and used for the second motion correction as a reference volume; (ii) fMRI images were then co-registered to the 3D T1 structural images, (iii) normalisation to the Montreal Neurological Institute (MNI) space was achieved by a unified framework for normalising the structural T1 images to the MNI template, detailed in Ashburner et al. (1999). The transformation matrix and warp files found in the last step were used to normalise each fMRI scan to the MNI space (Ashburner et al., 1999). Lastly, normalised volumes were smoothed with a $4 \times 4 \times 4\text{ mm}^3$ full width at half maximum Gaussian kernel.

2.8. Statistical analysis

Two-level general linear modelling was used to investigate whether voxel-wise fMRI signal changes were associated with behaviour measures (BCyQ and COMPAS-W) and whether these relationships were different between genders and prior experiences of cyberbullying. The fMRI signal changes associated with each scenario were determined by fitting the convolution of a hemodynamic response function (HRF) and each scene event with the measured BOLD signal changes. The BOLD signal of interest was the differences between the negative and neutral contrast within the fMRI paradigm. A canonical HRF with time and dispersion was used to account for slice timing and individual HRF variances.

The neural correlates of cyberbullying were constructed as the contrast image of BOLD signal changes associated with viewing cyberbullying scenes minus those with neutral scenes. The neural correlates of cyberbullying from the subject level were then used for the second-level group statistics for (i) multiple regressions to test whether BOLD contrasts were related to any of the behaviour measures (BCyQ scores and each COMPAS-W sub-scale), controlling for age and gender ii) two-sample designs that tested for interaction between group (female vs. male) and BCyQ and COMPAS-W scores while age was included as a covariate. The significance of correlations between neural correlates and behaviour measures were tested using family-wise error (FWE) corrected cluster $P$ value ($P_{FWE} < 0.05$) with a cluster forming voxel threshold of uncorrected $P < 0.001$.

3. Results

The results were in support of our hypothesis that males and females would activate different regions of the brain when witnessing cyberbullying stimuli compared to neutral stimuli, and that brain activation when observing cyberbullying stimuli would be positively correlated to individual scores of wellbeing and negatively correlated to prior cyberbullying and cybervictimisation experiences. These findings will now be discussed, specifying which brain regions were activated and which aspects of wellbeing were correlated to BOLD response. It is also important to note that cybervictimization and cyberbullying are highly correlated, in that cyberbullies are also very likely to be cybervictims, and so those with previous experience of cyberbullying others includes cyberbully-victims (those who have experienced both cyberbullying and cybervictimisation).

The mean age of the total sample was 21.56 ± 2.50 years. Table 1 displays the mean and standard deviations of all measures of cyberbullying and the COMPAS-W by gender.

3.1. Multiple regression analysis

The contrast of increased BOLD signal between viewing cyberbullying scenes and neutral scenes showed significant differences in the right (R-) rostroventral anterior cingulate gyrus (ACC). This ACC changes were negatively correlated with the cyberbullying, but not cybervictimisation, scores. In addition, the left (L-) dorsal caudate and bilateral Crus I of the cerebellum were positively correlated with COMPAS-W across all participants, despite gender (Fig. 1, Table 1).
gyrus (BA 44), precuneus (BA 7) (Fig. 2, Table 1).

Correlations between cyberbullying BOLD response and behaviour measures.

| Correlations | Cluster-level | Peak level | Structural labels |
|--------------|--------------|------------|-------------------|
|              | P\text{FWE} | k_E | T | Z | x | y | z |
| Negative correlations between cyberbullying BOLD response and BCyQ scores (all participants) | 0.05 | 107 | 4.98 | 4.2 | 6 | 32 | 4 | R A24ve CG, right rostroventral area 24 of cingulate gyrus |
| Positive correlations between cyberbullying BOLD response and COMPAS-WA scores (all participants) | 0.052 | 0.118 | 5.02 | 4.23 | -10 | -8 | 20 | L dCa Caudate, left dorsal caudate |
| Correlations between BCyQ scores and cyberbullying BOLD response in females are greater than those in males | 0.003 | 180 | 7.53 | 5.52 | 60 | -10 | -8 | R A5TS, right anterior superior temporal gyrus |
| Correlations between BCyQ scores and cyberbullying BOLD response in males are greater than those in females | 0.002 | 193 | 7.17 | 5.36 | -42 | 22 | -28 | R LHipp, left caudal hippocampus |
| Correlations between COMPAS-WA measures and cyberbullying BOLD response in males are greater than those in females | 0.001 | 216 | 6.19 | 4.87 | -20 | -68 | -18 | Cerebellum, left VI |
| 0.003 | 176 | 4.99 | 4.19 | 58 | -50 | 40 | R A40ve IPL, right caudal area 40 in inferior parietal lobe |
| 0.021 | 121 | 4.87 | 4.11 | 48 | 14 | 0 | R A44op IFG, opercular area 44 in inferior frontal gyrus |
| 0.019 | 124 | 4.38 | 3.79 | 2 | -70 | 50 | LR A7m Pcc, medial area 7 in precuneus |

3.2. Interactions of cyberbullying BOLD signal and COMPAS-WA scores between females and males

When measuring the gender effect on the correlations between the BOLD contrast and the COMPAS-WA scores in the males were significantly higher than those in females in the clusters within the left cerebellum, dorsomedial prefrontal cortex (Brodman area (BA) 8 and 9), right supramarginal gyrus (SMG; BA 40), right opercular inferior frontal gyrus (BA 44), precuneus (BA 7) (Fig. 2, Table 1).

4. Discussion

This is the first study to report that BOLD signal, when viewing cyberbullying stimuli, differ significantly between females and males, particularly in regions associated with understanding actions and emotions of others, as well as self-evaluation, self-consciousness, and resilience. More specifically, this study reports that these BOLD signal changes are related to behavioural measures of previous cyberbullying experiences, and feelings of achievement. In addition, cyberbullying...
Fig. 1. Clusters in which cyberbullying signals were significantly correlated with previous experiences of cyberbullying others, and the achievement subscale of wellbeing (COMPAS-WA) across all participants (males: blue dots in scatter plots, females: red dots in scatter plots). (a) The surfaces of cluster were rendered within the “glass” brain generated as triangle mesh of the surface of Montreal Neurological Institute (MNI) 152 brain atlas (left: left lateral view; middle: right lateral view; and right: top view). The clusters were rendered in arbitrary colours for presentation with no biological/statistical meanings. (b) The blood oxygenation level dependent (BOLD) signals in response to the cyberbullying stimuli in the right rostroventral area of cingulate gyrus were negatively correlated with behaviour cyberbullying scores (family-wise error corrected $P_{FWE} = 0.05$, $R^2 = 0.46$). (c and d) The cyberbullying BOLD signal in the left dorsal caudate ($P_{FWE} = 0.05$, $R^2 = 0.47$) and Crus I of cerebellum ($P_{FWE} = 0.03$, $R^2 = 0.45$) were positively correlated with behaviour COMPAS-WA scores. Note each behaviour measure was tested using multiple regression while the rest of behaviour measures were included as covariates, therefore, all the identified correlations were independent. The scatter plots are the cyberbullying BOLD signal change of each individual calculated as averaged contrasts within the cluster against the behaviour measures. The cyberbullying BOLD signal refers to BOLD signal difference between viewing cyberbullying scenes and neutral scenes. The cluster statistics were summarised in Table 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 2. Clusters in which correlations between cyberbullying signals and the achievement subscale of wellbeing (COMPAS-WA) scores are significantly higher in males (blue dots in scatter plots) than those in females (red dots in scatter plots). (a) The surfaces of cluster were rendered within the “glass” brain generated as triangle mesh of the surface of Montreal Neurological Institute (MNI) 152 brain atlas (left: left lateral view; middle: right lateral view; and right: top view). The clusters were rendered in arbitrary colours for presentation with no biological/statistical meanings. (b, c, d, e, and f) Correlations between cyberbullying signals, i.e. blood oxygenation level dependent (BOLD) changes between viewing cyberbullying and neutral stimuli, and behaviour COMPAS-WA scores in the males were significantly higher than those in females in the clusters within the medial area 7 of precuneus (b, family-wise error corrected $P_{FWE} < 0.02$, $R^2 = 0.01$ in females and $R^2 = 0.88$ in males), medial area 8 and 9 of superior frontal gyrus (c, $P_{FWE} < 0.001$, $R^2 = 0.08$ in females and $R^2 = 0.7$ in males), left cerebellum VI (d, $P_{FWE} = 0.001$, $R^2 = 0.005$ in females and $R^2 = 0.85$ in males), right opercular area 44 of inferior frontal gyrus (e, $P_{FWE} = 0.02$, $R^2 = 0.003$ in females and $R^2 = 0.77$ in males), and right caudal area 40 of inferior parietal lobe (f, $P_{FWE} = 0.003$, $R^2 = 0.09$ in females and $R^2 = 0.7$ in males). The cluster statistics were summarised in Table 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)
BOLD signal changes in the ACC were negatively correlated with cyberbullying scores, despite gender, suggesting that the more frequently a participant had cyberbullied others in the past, the lower their BOLD response when viewing the cyberbullying stimuli. Of interest, there appears to be a cluster of male participants at one end of this association (see Fig. 1), suggesting that future research should further examine this relationship more to verify whether it is more specific to males who cyberbully.

It is important to note that multiple brain regions are implicated based on the findings of this study. Whilst cognitive processes, behaviours and actions are the result of numerous neural circuits and interactions among brain structures, we have highlighted functions that have been emphasised in the relevant literature. For ease of interpretation, we suggest some possible explanations for the BOLD responses observed in this study, by drawing comparison to previous research investigating the same structures and other measures implicating their functions.

Regions of the cingulate gyrus have been linked with the processing of emotion (Maddock et al., 2003; Masten et al., 2011; Stevens et al., 2011; Vogt, 2005). Whilst speculative, one explanation for the rostral-ventral ACC BOLD response observed in this study, is that compared to participants with no experience of cyberbullying, those who had previously cyberbullied others have a blunted response to the cyberbullying stimuli witnessed during the fMRI task. Furthermore, such an explanation could infer from functions of the ACC, such as its role in performance monitoring and error detection (Carter et al., 1998). In addition, the ACC is part of the salience network which contributes to emotion processing, autonomic functions, and self-awareness (Critchley, 2005; Heimer and Van Hoesen, 2006). Given the above, we suggest that these fMRI-based observations in our study stem from a range of functions including adjusting to emotions and conflicting behaviors as well as self-awareness of processes that are all impacted by cyberbullying (whether one is experienced or naïve to it).

In addition, cyberbullying BOLD signal was independently and positively correlated with COMPAS-WA (an achievement sub-category of overall wellbeing) scores, indicating that when viewing the cyberbullying stimuli, participants with higher COMPAS-WA scores had a greater BOLD response. Viewing the scatterplots for this finding, the scores appear evenly spread across males and females. The left dorsal caudate and Crus I of the cerebellum have been linked with the processing of emotion, executive function and working memory (Keren-Happuch et al., 2014; Levy et al., 1997; Postle & D’Esposito, 1999; Stoodley and Schmahmann, 2010). Literature showed that the cerebellum is well suited to regulate emotion through the connections to several regions including the amygdala, the hippocampus, and the septal nuclei (Baumann and Mattingley, 2012). Meta-analyses found emotion-related activity in left Crus I and during emotional face processing (Keren-Happuch et al., 2014; Stoodley and Schmahmann, 2009). These studies suggested that Crus I is part of the executive cerebellum that is involved in the cognitive aspects of emotion processing (working memory, attention allocation, emotion evaluation, response selection) or associative learning (Adamaszek et al., 2017).

Furthermore, correlations between cyberbullying BOLD signal and COMPAS-WA scores in males with previous experience cyberbullying others, were significantly higher than those in females with previous experience cyberbullying others. Therefore, when viewing the cyberbullying stimuli, participants who had previously cyberbullied and who had higher COMPAS-WA scores had a greater BOLD response, and this was stronger in males compared to females. The cerebellum is linked to executive function (Stoodley and Schmahmann, 2010), the superior frontal gyrus is responsible for higher cognitive functions and working memory (du Boisguesneuc et al., 2006), the inferior parietal lobe is linked to emotion processing and expression (Canli et al., 2004; Kitada et al., 2010), the inferior frontal gyrus is responsible for a range of cognitive processes including social cognition and inhibition (Aron, 2011; Hartwigsen et al., 2018), and the precentral is associated with self-evaluation and self-consciousness (Kjaer et al., 2002). In addition, these regions are a part of the Default Mode Network (DFM), which has long been researched in relation to depression, negative self-referential processes, and emotional processing (Ho et al., 2015; Sambataro et al., 2014; Sheline et al., 2009), suggesting that males may have less resilience as compared to females in regards to cyberbullying. These results indicate a possible association between feelings of achievement and the activation of these regions in males with previous experience cyberbullying others when viewing cyberbullying stimuli. In other words, these results suggest that males with previous experience cyberbullying others with higher scores of achievement in regard to wellbeing, activated regions associated with executive function, social cognition, and self-evaluation, when viewing the cyberbullying stimuli.

There are limitations associated with the present research which need to be considered. Firstly, future studies should investigate how the response by the ‘cybervictim’ influences how a cyberbystander may react reactions to these scenarios. It is anticipated that a “reply” from the victim may influence how the brain responds to witnessing these scenarios. Secondly, the current sample size was small, and data was cross-sectional. Future research should replicate the present findings with larger samples and longitudinally, as well as with adolescents.

5. Conclusion

The current research findings are important as they provide new insights, albeit preliminary, into the neurobiological responses of cyberbystanders when witnessing cyberbullying conditions, which appear to vary significantly according to gender, past cyberbullying experiences and levels of wellbeing. The results highlighted that those with a greater sense of achievement significantly influenced how the brain responded, particularly in those who had cyberbullied others in the past. In addition, it was evident that males activated brain regions linked to varying aspects of cognition, whereas females more often activated regions linked to emotion processing and empathy. Additional studies are required to confirm gender differences in brain activation, as well as the role of feelings of self-worth. Despite the limitations, this study highlights several key lines of inquiry for future research to better investigate the potential impacts of cyberbullying and the associated brain responses.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

CRediT authorship contribution statement

Larisa T. McLoughlin: Funding acquisition, Writing – original draft, Concept and design, Acquisition, analysis, or interpretation of data, Drafting of the manuscript. Zack Shan: Writing – original draft, Acquisition, analysis, or interpretation of data, Drafting of the manuscript. Abdalla Mohamed: Acquisition, analysis, or interpretation of data. Amanda Boyes: Writing – original draft, Drafting of the manuscript. Christina Driver: Writing – original draft, Drafting of the manuscript. Jim Lagopoulos: Writing – original draft, Drafting of the manuscript. Daniel F. Hermens: Writing – original draft, Drafting of the manuscript.
Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/...
McLoughlin, L.T., Shan, Z., Broadhouse, K.M., Winks, N., Lagopoulos, J., Hermens, D.F., 2020c. Neurobiological underpinnings of cyberbullying: a pilot functional Magnetic Resonance Imaging study. Hum. Brain Mapp. 41 (6), 1495–1504. https://doi.org/10.1002/hbm.24890.

McLoughlin, L.T., Simcock, G., Schwenn, P., Beaufordin, D., Boyes, A., Parker, M., Lagopoulos, J., Hermens, D.F., 2022. Social connectedness, cyberbullying, and well-being: preliminary findings from the Longitudinal Adolescent Brain Study. Cyberpsychol. Behav. Soc. Netw. 25 (5), 301–309.

Neuroimaging, W.T. C.f., 2014. SPM12. In: Wellcome Trust Centre for Neuroimaging.

Sakellariou, T., Carroll, A., Houghton, S., 2012. Rates of cyber victimization and bullying.

Olenik-Shemesh, D., Heiman, T., 2014. Exploring Cyberbullying among Primary Children in Relation to Social Support, Loneliness, Self-Efficacy, and Well-Being. Child Welfare 93 (5), 27–46 https://search.proquest.com/docview/1804902205?accountid=28745, http://unc-eda-primo.hosted.exlibrisgroup.com/openurl/61USC/61USC_SP?url_ver=Z39.88-2004&rfr_id=info:ofi/fmt:kev:mtx:journal&genre=article&std=ProQ:ProQ%3Acriminaljusticeperiodicals&title=Exploring+Cyberbullying+among+Primary+Children+in+Relation+to+Social+Support%2C+Loneliness%2C+Self-Efficacy+and+Well-Being&title=Child+Welfare&volume=930094021&date=2014-09-01&volume=93&issue=5&page=27&as=Olenik-Shemesh%2C+Dorit%3BHeiman%2C+Tal%26isbn%3Djtitle%3DChild+Welfare%26id-info%3Dinfo:doi/.

Postle, B.R., D’Esposito, M., 1999. Dissociation of human caudate nucleus activity in spatial and nonspatial working memory: an event-related fMRI study. Cognit. Brain Res. 8 (2), 107–115.

Sakellariou, T., Carroll, A., Houghton, S., 2012. Rates of cyber victimization and bullying among male Australian primary and high school students. Sch. Psychol. Int. 33 (5), 533–549. https://doi.org/10.1177/0956797611430374.

Sambataro, F., Wolf, N.D., Pennuto, M., Vasie, N., Wolf, R.C., 2014. Revisiting default mode network function in major depression: evidence for disrupted subsystem connectivity. Psychol. Med. 44 (10), 2041–2051. https://doi.org/10.1017/s0033291713002596.

Schultze-Krumholz, A., Scheithauer, H., 2009. Measuring Cyberbullying and CyberVictimization by Using Behavioral Categories - the Berlin Cyberbullying CyberVictimization Questionnaire (BCyQ).

Schultze-Krumholz, A., Scheithauer, H., 2011. The Berlin Cyberbullying-CyberVictimization Questionnaire (BCyQ). Unpublished Questionnaire. Freie Universität Berlin.

Sheline, Y.I., Barch, D.M., Price, J.L., Rundel, M.M., Vaishnavi, S.N., Snyder, A.Z., Mintun, M.A., Wang, S., Coalson, R.S., Raichle, M.E., 2009. The default mode network and self-referential processes in depression. Proc. Natl. Acad. Sci. U. S. A. 106 (6), 1942–1947. https://doi.org/10.1073/pnas.0812666106.

Sherman, L.E., Payton, A.A., Hernandez, L.M., Greenfield, P.M., Dapretto, M., 2016. The power of the like in adolescence: effects of peer influence on neural and behavioral responses to social media. Psychol. Sci. 27 (7), 1027–1035. https://doi.org/10.1177/0956797616645675.

Smith, P.K., Mahdavi, J., Carvalho, M., Fisher, S., Russell, S., Tippett, N., 2008. Cyberbullying: its nature and impact in secondary school pupils. JCPP (J. Child Psychol. Psychiatry) 49 (4), 376–385. https://doi.org/10.1111/j.1469-7610.2007.01846.x.

Spears, B.A., Taddeo, C.M., Daly, A.L., Stretton, A., McLoughlin, L.T., 2015. Cyberbullying, help-seeking and mental health in young Australians: implications for public health. Int. J. Publ. Health 60 (2), 219–226. https://doi.org/10.1007/s00038-014-0642-7.

Stevens, F.L., Hurley, R.A., Taber, K.H., 2011. Anterior cingulate cortex: unique role in cognition and emotion. J. Neuropsychiatry Clin. Neurosci. 23 (2), 121–125. https://doi.org/10.1176/jnp.23.2.jpa121.

Stoodley, C.J., Schmahmann, J.D., 2009. Functional topography in the human cerebellum: a meta-analysis of neuroimaging studies. Neuroimage 44 (2), 489–501. https://doi.org/10.1016/j.neuroimage.2008.08.039.

Stoodley, C.J., Schmahmann, J.D., 2010. Evidence for topographic organization in the cerebellum of motor control versus cognitive and affective processing. Cortex 46 (7), 831–844. https://doi.org/10.1016/j.cortex.2009.11.008.

Tools, P.R., 2018. E-Prime: In: Psychology Software Tools.

Topcu, Ç., Erdur-Baker, O., 2012. Affective and cognitive empathy as mediators of gender differences in cyber and traditional bullying. Sch. Psychol. Int. 33 (5), 550–561. https://doi.org/10.1177/0143034312446882.

van Geel, M., Vedder, P., Tanslon, J., 2014. Relationship between peer victimization, cyberbullying, and suicide in children and adolescents: a meta-analysis. JAMA Pediatr. 168 (5), 435–442. https://doi.org/10.1001/jamapediatrics.2013.1445.

Vogt, B.A., 2005. Pain and emotion interactions in subregions of the cingulate gyrus. Nat. Rev. Neurosci. 6 (7), 533–544. https://doi.org/10.1038/nrn1704.