



# A Systematic Review and Meta-analysis of Electrophysiological Studies of Online Social Exclusion: Evidence for the Neurobiological Impacts of Cyberbullying

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## Abstract

Cyberbullying is an increasingly problematic psychosocial health risk, particularly in youth. Electroencephalography (EEG) is commonly utilized to investigate the potential effects of social behaviors on brain activity. Hence, the current paper provides a systematic review of EEG-related studies that have addressed cyberbullying-like behaviors. Initial searches from 4 databases returned 1150 unique articles, which were screened according to PRISMA guidelines. The 29 articles remaining after full text screening investigated online social exclusion, a method of cyberbullying. Across these studies, there was evidence of links between social exclusion and abnormalities in a range of event related potential (ERP) and EEG measures representative of deviance detection (“N2” ERP), response to detection (“P3” ERP), emotional attention (“late slow wave” ERP) and emotional regulation (“frontal theta” EEG). Meta-analysis demonstrated increased P3 and late slow wave amplitudes in response to social exclusion, as well as increases in frontal-medial theta power, particularly in child and adolescent samples. However, many studies had small sample sizes, and lacked longitudinal insight into the effects of recurrent ostracism on brain function. Future research should explore the effects of a broader range of cyberbullying behaviors on psychophysiology longitudinally, particularly in vulnerable populations such as adolescents.

**Keywords** Cyberbullying · Social exclusion · Ostracism · Electroencephalography · Adolescence

## Introduction

Cyberbullying is becoming an increasingly problematic phenomenon, particularly in young and adolescent age groups, due to increasing rates of social media use and cyberbullying involvement (Twenge et al., 2019; Zhu et al., 2021). Although there has been an abundance of research interest on the effects of cyberbullying behaviors on psychosocial health and functioning, there has been less research on the effects of cyberbullying on brain activity using electroencephalography (EEG) as an imaging method, and this

research has not been assessed systematically. This study aims to address this gap, via a systematic review and analysis of the available literature that investigates the impacts of cyberbullying-like behaviors on psychophysiology, using EEG as the measurement method.

Cyberbullying is defined as intentional, persistent aggression that occurs over electronic means or context and is directed at (an) other individual(s) (Kowalski et al., 2014). Cyberbullying is an iteration of traditional bullying (Smith et al., 2013), which involves an imbalance of power, repetition and intent to cause pain or harm either physically, socially or psychologically (Kowalski et al., 2014). Research has found cyberbullying facilitates relational victimization, which may involve verbal victimization or exclusion from groups (Xiao & Wong, 2013). An example of relational victimization is social exclusion, which is described in Willard (2007) as a cyberbullying method involving blocking or distancing an individual over online means. Other methods of cyberbullying include flaming (a fight over online means), harassment (repetitive, offensive messages) and

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impersonation (posing as another individual); however, this list is not exhaustive (Willard, 2007). Cyberbullying is particularly prevalent in childhood and adolescence (Kowalski et al., 2014), which refers to individuals under the age of 18 (Australian Human Rights Commission, 2023), and the period preceding adulthood (ages 10–19) (World Health Organization, 2023). Students who experience cyberbullying have been shown to experience higher levels of anxiety, depression and social difficulties compared to victims of traditional bullying (Campbell et al., 2012). There are also issues in identifying cyberbullying behavior, potentially due to difficulty identifying the power imbalance between individuals (McLoughlin & Hermens, 2018). Due to the issues identifying cyberbullying, objective measures such as EEG may be useful to assess risk and minimize harm of cyberbullying involvement in vulnerable populations.

There has been a growing research interest in the use of brain imaging methods to investigate the neurobiology of social behaviors. Magnetic resonance imaging (MRI) studies investigating cyberbullying involvement show that certain brain regions may be linked to cyberbullying or ostracism involvement (McLoughlin et al., 2020; Muetzel et al., 2019), and recent studies have also investigated constructs such as social exclusion using EEG (Stead et al., 2022; Xu et al., 2022). This research can provide insight to the neurological processes that underpin the processing of cyberbullying, and how it's involvement may affect the article investigated EEG power brain function and information processing.

### Neurobiology of Social Exclusion

Feeling socially connected is a need considered fundamental to humans' physical and emotional well-being (Baumeister & Leary, 1995). Social situations where an individual's sense of belongingness or inclusion is threatened by others has been referred to in literature using a variety of different terms such as ostracism, exclusion, and rejection (Reinhard et al., 2020). These constructs are all linked to social defeat, which is a broad concept covering social stressors and has been shown to be associated with psychopathology and behavioral issues (Björkqvist, 2001). However, due to the similarities between these constructs and their outcomes in the available empirical research (Williams, 2007), hereafter, this article will refer to all of these constructs as "social exclusion".

Neuroimaging research on social exclusion has mainly employed the Cyberball paradigm (Williams & Jarvis, 2006; Williams et al., 2000). This paradigm involves participants being excluded from a virtual ball-toss game, where two other virtual players' actions are preprogrammed to simulate social exclusion. Participants are generally led to believe that the other two "players" are other people playing the ball toss games, rather than virtual computerized players.

However, sometimes this belief is not facilitated, as research has shown that feelings of exclusion are still reported when participants are aware that the other players are computerized (Zadro et al., 2004). Traditional Cyberball paradigms involve a phase of inclusion or "fair play", where participants receive the ball one third of the time. The second phase is an exclusionary period, where participants do not receive the ball after a brief period of "fair play". Aside from Cyberball, other paradigms such as the Lunchroom task (Kiat et al., 2017), the Eye-gaze paradigm (Wirth et al., 2010), the Island getaway task (Kujawa et al., 2014), and the Scenario reading task (Zhu et al., 2022) have been used to simulate social exclusion and thus have been utilized to examine the neurobiological correlates of social exclusion. Results from exclusionary paradigms suggest that when processing social exclusion, a neural network involved in the processing of physical pain is activated. Furthermore, research has demonstrated an association between social exclusion and activation of the dorsal anterior cingulate cortex, a region which has been previously shown to be activated by expectancy violation (Eisenberger & Lieberman, 2004; Somerville et al., 2006).

Additionally, brain regions such as the anterior cingulate cortex (ACC) and prefrontal cortex (PFC) have been found to be implicated in the processing of social pain (Eisenberger, 2012). Functional magnetic resonance imaging (fMRI) analysis demonstrated increased activity in the right ventral PFC (Masten et al., 2012), bilateral hippocampus, left ventrolateral PFC and left middle temporal gyrus (Bolling et al., 2011) following peer rejection in adults. Additionally, increased activity was observed in the subgenual ACC and ventral striatum in an adolescent sample (Masten et al., 2012). A meta-analysis using fMRI found social exclusion in youth to be associated with activity in prefrontal regions and midline structures, as well as limbic structures in younger adolescents (Vijayakumar et al., 2017). Specifically, during exclusion conditions, activation in ventrolateral prefrontal regions was evident in adolescents, compared to emerging adult samples which exhibited activations in medial prefrontal regions. Additionally, the right ventral striatum was also implicated in exclusion, but only in adolescent samples (Vijayakumar et al., 2017).

### EEG Neuroimaging

EEG is an electrophysiological measurement of electrical brain activity and is a robust measure of central nervous system activity. EEG activity reflects the volume conduction of neurons that fire synchronously and is representative of the combined electrical fluctuations in membrane potentials generated from neuron interaction (Klimesch, 1999). EEG is non-invasive, measuring brain activity from the scalp, and is therefore an ideal research method for investigating brain

activity (Teplan, 2002). Due to EEG's excellent temporal resolution (milliseconds) (Liu et al., 2020), it provides an effective and accurate measure of sensory information processing activities within the brain. Although spatial resolution is a relative limitation in comparison to other brain imaging techniques, multichannel recordings allow researchers to estimate the location of these processes (Picton et al., 2000). The use of EEG can provide insight to the neural aspect of the attentional processing that occurs when processing social exclusion stimuli.

### Event Related Potentials

Embedded in the brain's ongoing EEG activity are phasic responses or Event-Related Potentials (ERPs) that index different aspects of information processing. ERPs are thought to reflect physiological responses to particular stimuli and index cognitive and sensory processes (Sur & Sinha, 2009). ERPs are displayed as waveforms that plot voltage change in response to a stimulus, and are time-locked to that event. The waveforms depict the time between the exogenous and endogenous potentials. That is, the response to the external evoking stimulus, and the brain's internal processing of this external stimulus (Picton et al., 2000). ERPs can be categorized as "early stage" processing, representative of exogenous stimulus parameters, or "late stage" processing, which are dependent on internal, cognitive processes and brain function (Sur & Sinha, 2009).

**ERP Components** ERP components are named according to their latency and amplitude in the ERP waveform. N100 (N1) is a negative deflection between 90 and 200 ms after stimulus presentation (Sur & Sinha, 2009), and is representative of early stage processing, automatic attention and stimulus salience (Zhu et al., 2022). P200 (P2) is a positive deflection in the ERP waveform, peaking between 100 and 250 ms after stimulus presentation (Sur & Sinha, 2009) and is thought to represent early judgement of stimulus perception (Zeng et al., 2021). N200 (N2) is a negative peak that occurs about 200 ms post stimulus and is representative of deviance detection (Sur & Sinha, 2009). P300 (P3) is a late positive peak of an ERP which occurs approximately 300 to 800 ms following the detection of a target stimuli (Themanson et al., 2015), and is theorized to represent information processing associated with memory and attentional aspects of cognition (Polich, 2007). The P3 consists of two subcomponents (P3a and P3b). P3a has an earlier peak latency than P3b (Themanson et al., 2015) and is maximal over frontal sites, and associated with novelty. Whereas P3b is thought to index attentional and contextual updating processes, with larger amplitudes indicating increased top-down attentional control (Polich, 2007). Late slow waves (LSW) are late ERP

components, and are implicated in facilitated emotional attention to stimuli (Cuthbert et al., 2000).

**ERPs in Social Exclusion** Research on social exclusion using ERPs has identified some of the neural patterns that may correspond with the experience of social exclusion. A review article describes the neural processes that occur during social exclusion as intrapersonal processes of detection, appraisal and regulation (Kawamoto et al., (2015). The N2 ERP and activation of dorsal ACC were thought to be involved in stimuli detection, whereas appraisal was thought to be indexed by P3 and dorsal ACC activation. Additionally, regulation was associated with frontal slow waves and ventrolateral PFC activation. This therefore suggests that these neurobiological markers may be discernible during social exclusion paradigms (Kawamoto et al., (2015). Another framework aiming to decipher the neurological processes of social exclusion was developed by Wang et al. (2017). This framework discusses two stages of temporal neural processing; early stage processing and late stage processing. This research proposes that early stages of processing are indexed by P2, N2 and P3, and are reflective of attention, emotion, arousal and appraisal modulation (Wang et al., 2017). Alternatively, late stage processing is representative of regulation of cognitions and emotions and consists of 400 to 900 ms slow waves.

Additionally, experimental research has linked changes in neural activity indexed by EEG in individuals who have experienced social exclusion (McPartland et al., 2011; Themanson et al., 2013). For examples, frontal-parietal N2 corresponds to a neural alarm system that is responsible for monitoring conflict, and occurs in response to a social exclusion (Themanson et al., 2013). Some research has shown overall P3 effects to be decreased in excluded participants, when compared to included participants (Otten & Jonas, 2013), indicating that excluded participants exercise less inhibitory control when responding to emotional stimuli. However, this is contrary to other research that found increased P3 amplitudes in response to exclusion conditions (Crowley et al., 2010). In addition, larger P3b amplitudes in earlier exclusion events, compared to later events suggests heightened early sensitivity to exclusion that dulls over time (Themanson et al., 2013). Reduced P3 amplitudes may be indicative of neurobiological vulnerability, which is present in mental disorders with externalization, such as substance abuse and behavioral disorders (Patrick et al., 2006).

### Power Spectrum Analysis

Spectral analysis or power spectrum analysis is a standard method for quantifying EEG signals (Dressler et al., 2004) as power in frequency domain ( $\mu V^2/Hz$ ) (Xiao et al., 2018). Power spectrum analysis consists of estimating

power spectral density of the EEG signal, which is often divided into distinct frequency bands, thereby also termed as band power analysis. The five most commonly used frequency bands, and their corresponding oscillations or frequency ranges are: delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (14–30 Hz), and gamma (> 30 Hz) (Abo-Zahhad et al., 2015; Teplan, 2002).

Delta waves are the slowest EEG waves, and are thought to be associated with motivational attention and salience detection (Knyazev, 2007). Theta signals have been shown to be associated with emotions such as empathy (Knyazev, 2007), and have been well documented on their role in emotional processing, emotional regulation (Knyazev, 2007; Krause et al., 2000) and memory functions (Mitchell et al., 2008). Alpha waves are involved in inhibitory processes, and also contribute to functions such as attention and memory (Knyazev, 2007). Alpha power has also been linked to motivational processes through frontal asymmetry indexes, with positive alpha asymmetry scores reflective of higher right hemisphere alpha power, and negative scores reflective of higher left hemisphere alpha power (Kawamoto et al., 2013). Differences in frontal EEG asymmetry at resting state (frontal alpha asymmetry), is considered a neurobiological marker of resilience and psychopathology (Kawamoto et al., 2013), due to its role in cognition and emotional regulation (Coan & Allen, 2004). Additionally, beta oscillations have been observed in cognitive tasks, particularly those involving a sensorimotor component (Kilavik et al., 2013). Beta (along with alpha) oscillations are important during attentional maintenance to stimuli (Knyazev, 2007). Gamma waves have strong electrical signals, and are representative of learning, memory and information processing (Abo-Zahhad et al., 2015). Although there is vast research on EEG power bands and how they correspond to cognition and emotion (Klimesch, 1999; Xing et al., 2017), there is limited literature investigating the neurobiology of involvement in social exclusion using EEG power spectrum analysis (Cristofori et al., 2013). However, research has found frontal alpha asymmetry to change from left frontal activation to right frontal activation during social exclusion, suggesting a change from approach motivation to withdrawal (Kawamoto et al., 2013). Additionally, there has been a vast amount of literature investigating the association of frontal alpha asymmetry with psychopathology, including depressive and anxiety disorders (van der Vinne et al., 2017), and experiences of ostracism or exclusion have been linked with alterations in theta and alpha power bands (van Noordt et al., 2015).

## Current Study

There has been a growing research interest in the use of EEG to investigate the changes to neurobiological function that may be associated with exposure to cyberbullying-like behaviors, such as social exclusion. Therefore, this article aims to review and analyze the existing literature investigating cyberbullying-like behaviors using EEG measures, in order to identify and understand the underlying neurophysiological processes implicated in cyberbullying involvement. More specifically, this article will aim to identify how ERP amplitudes are affected by experiencing cyberbullying-like behaviors (Research Question 1), how EEG spectral power is affected by experiencing cyberbullying-like behaviors (Research Question 2). Additionally, this article will conduct a systematic review and meta-analysis of this available literature according to PRISMA guidelines (Research Question 3).

## Methods

### Literature Search Strategy

Online search engines such as Scopus, PubMed, Web of Science and ProQuest were used by the first author to conduct a systematic literature review search in May 2022. The systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Protocols (PRISMA-P) guidelines (Page et al., 2021).

The search strategy used a keyword search string of “EEG” OR “electroencephalography” OR “electrophysiology” OR “neurobiology” OR “ERP”, and also containing “cyberbull\*” OR “bully\*” OR “ostraci\*” OR “social exclusion” OR “victim\*” OR “online aggress\*” (Appendix 1). These key words aimed to broadly search articles containing brain activity, and within those articles search for experiences with any type of bullying behavior. This search strategy was run in 4 databases, including Scopus (title/ abstract search), PubMed (title/ abstract search), Web of Science (topic search) and ProQuest (abstract search) (see Fig. 1).

### Article Screening

All studies with the full text available online at the time of the search were exported into the EndNote citation manager and were assessed for relevance. Duplicates were removed, then remaining articles were assessed for relevance based on the title, abstract, and inclusion and

PRISMA flow diagram demonstrating article screening process

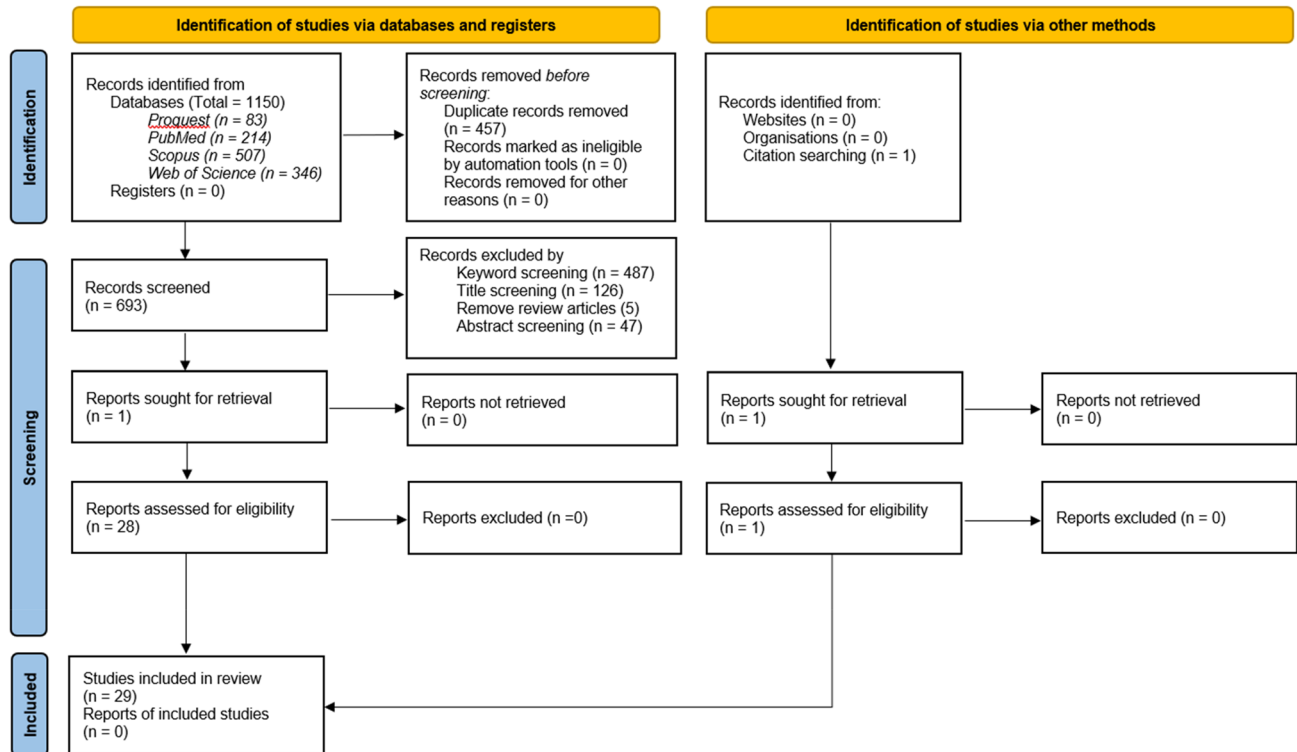


Fig. 1 PRISMA flow diagram demonstrating article screening process

exclusion criteria. Full texts were scoped if further information was required when excluding articles.

### Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were developed by the first author, then discussed with the research team before finalizing the search strategy. Studies were included according to the following criteria: (1) Full text reported in the English language; (2) dated between 2002 and 2022; (3) empirical research articles; (4) included appropriate keyword combinations; (5) investigates participants experiencing cyberbullying directly (are not observers or bystanders); (6) investigates brain activity using EEG; (7) peer reviewed. Studies were excluded based on the following criteria: (1) review articles; (2) full text unavailable in English; (3) student or doctoral theses; (4) studies investigating bullying bystander or witness.

### Selection Process

Literature search and selection process is detailed in the PRISMA flow chart (see Fig. 1) and review protocol (Appendix 1). The initial search resulted in 1150 articles across the four online databases. One additional study was

found through citation and reference searching and was retrieved through University of the Sunshine Coast's institutional library. Screening of articles was conducted independently by the first author. Removing duplicate articles (457) resulted in a total of 693 studies for further screening. This screening then resulted in 487 articles. Further screening by title, then abstract, left 29 studies for critical review. These 29 articles were checked for peer review status, then underwent a final assessment based on inclusion and exclusion criteria and quality assessment.

### Study Selection

Tables 1 and 2 summarize the final cohort of included articles, as well as quality assessment scores. A total of  $k=29$  met inclusion criteria for this review. Studies/findings were categorized based on whether the article investigated EEG power ( $k=7$ ; Table 1) or ERPs ( $k=24$ ; Table 2).

### Risk of Bias

Articles were assessed for quality using the quality assessment tool for observational cohort and cross-sectional studies (National Institute of Health; NIH, 2019). This quality assessment tool evaluated the methodology and sources of



**Table 1** EEG Power Spectra studies included in systematic review

Author(s), year, country	Sample: N, (M/F)	Age (years): M (SD)	Ethnicity (%)	Study aim	Paradigm	Methodology	Key findings	Limitations/Risk of bias	Quality assessment score
van Noordt et al., (2015) USA	33 (16F)	Range: 8–12	91 Caucasian 9 African-American	To understand how theta EEG might be a neural signature of social exclusion in typical children	Cyberball	Inclusion & exclusion conditions; completed NTS via narration following task, while recording EEG	↑ frontal theta in response to exclusion conditions ↑ alpha power in exclusion condition	Small sample size	5
Tang et al. (2021) Canada	Child: 58 (38F) Adolesc: 64 (39F)	Child: 10.83 (0.82) (Range: 10–12) Adolesc: 15.02 (0.98) (Range: 14–17)	91.8 White	To examine associations between shyness and theta EEG in social exclusion conditions	Cyberball	Fair play & exclusion conditions Completed NTS following tasks	Adolesc: ↑ theta in exclusion conditions Child: ↑ theta in rejection (c.f. exclusion) Shy child & adolesc: ↑↑ theta in rejection & exclusion conditions	Subjective measures of shyness Cross-sectional design limits causal inferences	7
Tang et al. (2019) Canada	Child: 58 (38F) Adolesc: 64 (39F) Adult: 79 (47F)	Child: 10.83 (0.82) Adolesc: 15.02 (0.98) Adult: 19.42 (1.92)	69.5 Caucasian 14.5 Asian 13.5 South East Asian 1 Hispanic 0.5 African	Investigate response to social exclusion using EEG analysis, focusing on the theta band	Cyberball	Fair play & exclusion conditions Participants completed NTS following cyberball	↑ theta in children and adolesc in response to exclusion conditions ↑ theta in response to exclusion = ↑ self-reported distress (strongest in adolesc)	Cross sectional design No measure of physical/ pubertal development	7
Stead et al. (2022) USA	64 (40F)	14.45(1.60) Range: 11–17	86.4 White 3.4 Hispanic/Latino 1.1 Indigenous 1.1 Asian 1.1 Black/ West Indian 4.5 Multiethnic 2.3 Other	Examine whether FAA moderated the relationship between BPD and rejection sensitivity during social exclusion	Cyberball	Time 1: Participants undergo psychiatric measures Time 2: Participants do baseline EEG and cyberball task; exclusion and inclusion	↑ Greater relative left frontal alpha asymmetry (at rest) predicted extreme (either high or low) feelings of social exclusion	Biased sample, results not generalizable Region of interest approach – a priori	6

Table 1 (continued)

Author(s), year, country	Sample: N, (M/F)	Age (years): M (SD)	Ethnicity (%)	Study aim	Paradigm	Methodology	Key findings	Limitations/Risk of bias	Quality assessment score
Kawamoto et al. (2013)* Japan	19 (11F)	18.3	NR	Investigate temporal changes in psychological states resulting from exclusion by a computer	Cyberball	Modified cyberball task used to adjust timing for ERP 3 conditions; observation, inclusion & exclusion Following this, survey assessed social pain	Frontal EEG alpha asymmetry: left frontal to right frontal activation in exclusion condition	All female participants All undergraduate students	5
Cristofori et al. (2013) France	15 (5F)	34.8 (Range: 19–51)	NR	Investigate neurophysiological underpinnings of social pain	Cyberball	Modified cyberball task Exclusion/ inclusion conditions Intracranial EEG recording during task	↑ theta during exclusion in multiple regions (AI, PI, sACC, orbitofrontal cortex, supplementary motor area, dlPFC, FFA) ↑ neural synchrony during exclusion for theta waves, ↓ for other FB	Participants were suffering from drug-refractory epilepsy Small sample Note: used intracranial EEG recording (differs from other studies' methods)	5
Peterson et al. (2011) USA	40 (20F)	NR	NR	Investigate the emotional consequences of social exclusion, looking at asymmetrical frontal cortical activity and response dynamics	Cyberball	Exclusion & inclusion conditions Participants reported sadness, distress and positive affect	↑ relative left frontal cortical alpha power (exclusion condition) low control = ↑ mid frontal and frontal central alpha asymmetry (exclusion condition)	All introductory psychology students Lacking demographic information about participants	4

**Table 2** ERP studies included in systematic review

Author(s), year, country	Sample: N, (M/F)	Age (years): M (SD)	Ethnicity (%)	Study aim	Paradigm	Methodology	Key findings	Limitations/ Risk of bias	Quality assessment score
McPartland et al. (2011) USA	ASD: 20 (20 M) HC: 34 (16 M)	ASD: 10.2 (2.94) HC: 11.0 (1.69)	NR	Investigate neural activity in response to peer exclusion, and associated ostracism distress	Cyberball	Inclusion and exclusion conditions, followed by NTS	↑ medial-frontal LSW amplitude in response to exclusion ↓ P2 amplitude in exclusion conditions	Gender-biased sample Use of self-report during exclusion to measure emotional experience	5
Crowley et al. (2010) USA	33 (16F)	10.76 (1.32)	91 Caucasian 9 African-American	Identify patterns of neural activity related to peer exclusion conditions and distress	Cyberball	Inclusion and exclusion conditions, followed by NTS	↑ LSW amplitudes in frontal regions, ↓ in posterior regions ↑ Posterior P3 amplitudes (more positive) in exclusion trials ↑ slow wave cortical activity during exclusion conditions	Small sample size Self-report, subjective data	5
Sreekrishnan et al. (2014) USA	Child: 21 (12F) Mother: 21	Child: 11.0 (1.1) Mother: 45.1 (3.6)	NR	-Investigate neurological phenomena in response to exclusion from kin	Cyberball	Inclusion and exclusion conditions, followed by NTS	↑ P2 and left frontal LSW amplitudes and kin exclusion in response to negative frontal slow wave associated with self-reported social exclusion	Small sample size	5
White et al. (2012) USA	23 (8F)	12.86 (1.30)	91.3 Caucasian 8.7 biracial	Identify links between neural response to exclusion by unknown peers in early adolesec	Cyberball	Inclusion and exclusion conditions, followed by ostracism distress measure (Need threat scale; NTS)	↑ ostracism distress = ↑ left frontal LSW waves in exclusion conditions	Small sample size	7



Table 2 (continued)

Author(s), year, country	Sample: N, (M/F)	Age (years): M (SD)	Ethnicity (%)	Study aim	Paradigm	Methodology	Key findings	Limitations/ Risk of bias	Quality assessment score
Kawamoto et al. (2013)* Japan	19 (11F)	18.3	NR	Investigate temporal changes in psychological states resulting from exclusion by a computer	Cyberball	Modified cyberball task used to adjust timing for ERP 3 conditions; 1 observation, 2 inclusion, 3 exclusion Following this, survey assessed social pain	↑ P3 amplitude fair play > exclusion > observation conditions however ↓ over trial time in exclusion and inclusion conditions	All female participants All undergraduate students	5
Themanson et al. (2015) USA	55 (29F)	Range: 18–22	NR	-Assessing neural activity during both inclusion-ary and exclusionary social interactions by examining ERPs	Cyberball	Inclusion and exclusion conditions Positive/ negative affect scale, state-trait anxiety, depression inventory and NTS completed prior to and also following each task	Greater ACC activation, indexed by ↑ N2 in early exclusion ↑ frontal and central P3 in exclusion conditions ↓ frontal and central P3 over the course of exclusion interaction ↑ frontal and central P3 amplitudes in response to early exclusion	All undergraduate students	5
Themanson et al. (2013) USA	22 (15F)	Range: 18–23	NR	To examine the relationship between neural and behavioral markers of social exclusion	Cyberball	Completed positive/ negative affect scale, NTS, prior to task 3 blocks; inclusion, exclusion, then re-inclusion blocks NTS and PANAS completed after each task	No effect of condition on frontal N2 or posterior P3 ↑ P3 amplitudes = ↑ social distress ↑ posterior P3 and frontal N2 amplitudes in earlier exclusionary stages	Small sample size All undergraduate students	5

Table 2 (continued)

Author(s), year, country	Sample: N, (M/F)	Age (years): M (SD)	Ethnicity (%)	Study aim	Paradigm	Methodology	Key findings	Limitations/ Risk of bias	Quality assessment score
Kiat et al. (2018) USA	20 (10F)	19.90 (1.37)	NR	Investigate differences in anticipatory related activity on the Cyberball task across its inclusion versus exclusion blocks	Cyberball	Inclusion and exclusion conditions	↑ posterior P3 amplitudes in exclusion conditions	Small sample size	7
Otten and Jonas (2013) The Netherlands	32 (22F)	21.8 (Range: 18–35)	NR	Does exclusion directly alter the mental processes that underlie cognitive control	Cyberball	Modified version of cyberball Inclusion and exclusion conditions After the inclusion condition, participants experienced ostracism via an “online chat”. Following this, exclusion condition	↑ N2 and ↓ P3 amplitudes for participants that had experienced social exclusion	Small sample size	5
Xu et al. (2022) China	45 (45F)	20.16 (0.12) Range: 18–24	NR	Examine how social exclusion effects the neural processes involved in social reward processing	Cyberball	Inclusion and exclusion conditions, PANAS	↑ CNV during reward processing during anticipatory stage for exclusion condition	Biased (all female) sample	7

Table 2 (continued)

Author(s), year, country	Sample: N, (M/F)	Age (years): M (SD)	Ethnicity (%)	Study aim	Paradigm	Methodology	Key findings	Limitations/ Risk of bias	Quality assessment score
Crowley et al. (2009) USA	27 (13F)	20.56 (Range: 18–26)	NR	Investigate neural responses to exclusion conditions in relation to ostracism distress	Cyberball	Trials consisted of fair play (inclusion) block and exclusion block. After completing cyberball, participants completed the NTS	Neural responses to exclusion dependent on level of ostracism distress ↑ late positive slow wave in anterior left frontal, medial frontal region is greater in those who experienced less distress	All undergraduate students	5
Weschke and Niedeggen (2016) Germany	15 (10F)	21.7 (2.9)	NR	To examine the relationship between neural and behaviors markers of social exclusion	Cyberball	Participants led to believe the study was investigating visual imagination capabilities, and reaction experiment. Inclusion, exclusion blocks NTS completed retrospectively following the task	↑ midline P3 amplitudes in exclusion conditions No difference in midline N2 amplitudes based on condition	Small sample size	5
Schuck et al. (2018) Germany	84 (55F)	22.3 (4.38)	NR	Investigate behavioral and ERP markers of social exclusion and whether they are replicated in a between-participant design	Cyberball	2 groups; inferior and superior position of avatar low exclusion and high exclusion conditions NTS following task	Groups with higher exclusion had ↑ P3b amplitudes in central and parietal regions, c.f. low exclusion conditions Mean P3b amplitude ↑ for superior positions	Cross sectional only	7

Table 2 (continued)

Author(s), year, country	Sample: N, (M/F)	Age (years): M (SD)	Ethnicity (%)	Study aim	Paradigm	Methodology	Key findings	Limitations/ Risk of bias	Quality assessment score
Niedeggen et al., (2017) Germany	42 (22F)	22.77	NR	Does vertical position in the cyberball game impact the outcome of exclusionary conditions?	Cyberball	3 independent groups; superior, inferior, even 2 blocks for each group; exclusion and inclusion NTS, negative mood scale and estimated ball frequency scale completed immediately following exclusion block	↑ P3 amplitudes in superior positions (c.f. inclusion) ↑ P3 amplitudes during partial exclusion; larger for central and parietal regions (compared to frontal)	- Relatively small sample	6
Weschke and Niedeggen (2013) Germany	30 (17F)	23.6	NR	Investigate whether the credibility of the environmental setting affects the processing of social exclusion	Cyberball	Inclusion and exclusion blocks; 2 conditions: internet and presence	↑ central and posterior P3 amplitudes, ↓ central N2 in exclusion conditions No change in Frontal N2 or P3 amplitudes between conditions	Small sample size	5
Weschke and Niedeggen (2015) Germany	Control: 15 (7F) Exp: 15 (7F)	Control: 25.6 Exp: 24.2	NR	To investigate a potential neural differentiation between outcome expectancy and social needs threat	Cyberball	Inclusion block and exclusion block NTS completed following the task	↓ probability of ball possession leads to ↓ expectancy leads to ↑ P3 amplitudes	Relatively small sample Recruited from a university environment	5

**Table 2** (continued)

Author(s), year, country	Sample: N, (M/F)	Age (years): M (SD)	Ethnicity (%)	Study aim	Paradigm	Methodology	Key findings	Limitations/ Risk of bias	Quality assessment score
Gutz et al. (2011) Germany	24 (14F)	25.4 (2.84)	NR	Investigate whether the social exclusion processing is affected by previous exposure to inclusion and vice versa. Investigate whether ERP effects are related to ostracism distress	Cyberball	Inclusion and exclusion condition Administered NTS following condition	↑ P3 amplitudes in response to social exclusion Frontal-central P3a = affective exclusion processing Parietal P3b = perceived intensity of exclusion ↑ parietal N2 in exclusion conditions	Small sample size All university students	5
Gutz et al. (2015) Germany	BPD = 25 (23F) SAD = 25 (21F) HC = 25 (22F)	BPD = 25 (6.56) SAD = 28 (4.82) HC = 26 (4.44)	NR	Investigate P3 amplitudes among individuals with BPD, SAD	Cyberball	Inclusion and exclusion blocks Post intervention, participants completed NTS and rejection sensitivity questionnaire	Exclusion condition elicited ↑ posterior P3 response across all participants; only BPD participants ↓ P3 amplitudes in inclusion also ↓ difference between P3 amplitudes across conditions = ↑ exclusion expectancy	Predominantly female sample No social control	6
Kiat et al. (2017) USA	24 (13F)	19.80 (1.39)	54 White 46 Black	Investigate how the brain prepares for social exclusion using EEG	Lunchroom task	Participants chose between two options of noun, e.g., Activities, food, clothing etc Outcome of 1 of 4 conditions (neutral exclusion, inclusion, stereotyped exclusion, inclusion)	↓ P3 amplitudes for stereotyped exclusion (c.f. neutral); these results were more present among Black participants	Small sample size All undergraduates	6

Table 2 (continued)

Author(s), year, country	Sample: N, (M/F)	Age (years): M (SD)	Ethnicity (%)	Study aim	Paradigm	Methodology	Key findings	Limitations/ Risk of bias	Quality assessment score
Hudac (2019) USA	28 (15F)	22.71 (5.01)	NR	Do neural correlates of social exclusion and inclusion differ based on amount of involvement prior to exclusionary event	Lunchroom task	Participants chose between two options of noun, e.g., Activities, food, clothing etc Exposed to inclusion/exclusion conditions	↑ medial frontal P3 amplitudes in exclusion ↑ medial central N2 latency during exclusion Amygdala, ACC, superior temporal gyrus more engaged during exclusion conditions (for N2 and P3 windows)	Small sample size No self-report or control for current mood	5
Rappaport et al. (2019) USA	56 (26F)	18.05 (1.01)	57 Caucasian 34 African-American 9 Other	Investigate the relationship between experiences of early vs. recent peer victimization, and the current neural responses to social acceptance/ exclusion in adolescence	Island getaway task	Players vote on whether they want peers to continue playing with them, and they will receive feedback on how players voted Peer victimization measured using Health and Behaviour questionnaire (measured early and recent victimization)	↓ neural response to social acceptance for those with early victimization Similar (although non-significant) result for recent victimization	Parents reported experiences of early victimization (no self-report or other sources of data)	6



**Table 2** (continued)

Author(s), year, country	Sample: N, (M/F)	Age (years): M (SD)	Ethnicity (%)	Study aim	Paradigm	Methodology	Key findings	Limitations/ Risk of bias	Quality assessment score
Leng et al. (2018) China	15 (9F)	Range: 18–21	NR	Investigated ERPs of brain responses to social exclusion	Eye-gaze paradigm	Participants interviewed for university club Participants presented with either direct gaze, closed eye, then either direct or indirect gaze Participants indicate how excluded and distressed they felt	↑ midline P2 amplitudes for exclusion condition ↓ frontal N2 amplitudes for exclusion condition ↑ LPP amplitudes in exclusion at frontal, central and parietal areas	Small sample All freshmen/undergraduates Narrow age range	6
Zhu et al. (2022) China	40 (27F)	19.80	NR	Provide neuro-physiological evidence for early stages of social reconnection after exclusion	Scenario reading task	Participant underwent social exclusion or inclusion priming Participants then matched faces based on “stranger” or “future co-worker” categories	↓ posterior N1 amplitudes for future co-worker vs. stranger face in exclusion (but no inclusion) conditions ↑ reconnection desire = biased face perception and subsequent neural deviation	Small sample size No baseline measure of emotion	7

*Adolesc* adolescents; *AI* anterior insula; *ASD* autism spectrum disorder; *BPD* borderline personality disorder; *c.f.* “compared to”; *CMV* contingent negative variation; *dIPFC* dorsolateral prefrontal cortex; *FAA* frontal alpha asymmetry; *FB* frequency bands; *FFA* fusiform face area; *HC* healthy controls; *NTS* need threat scale; *NAS* positive and negative affect scale; *PI* posterior insula; *sACC* subgenual anterior cingulate cortex; *SAD* social anxiety disorder; *SPN* stimulus preceding negativity. \*studies represented in both Tables 1 and 2  
Higher quality assessment scores = higher level of article quality (Grundy et al., 2001)

bias in the assessed studies (including participant sample, power, and associations between interventions and outcomes; Appendix 3). The total score for each article ranged from 1 to 10 and was categorized as: poor (0–2.5;  $k=0$ ), fair (2.5–5;  $k=1$ ), good (5–7.5;  $k=28$ ) or excellent (7.5–10;  $k=0$ ) quality (Grundy et al., 2001).

## Meta-Analyses

A post-hoc meta-analysis was performed for study outcomes metrics that met each of the following criteria; (1) at least two studies reporting the same metric, (2) sufficient quantitative reporting to calculate effect size (i.e., sample size, and/or group means, test statistic or p-value), and (3) homology of study design and sample characteristics. Accordingly, meta-analyses were conducted for frontal theta power ( $k=2$ ), lateral frontal alpha asymmetry ( $k=2$ ), central P3 amplitude ( $k=2$ ), posterior P3 amplitudes ( $k=3$ ), and frontal LSW amplitudes ( $k=2$ ).

Analyses were conducted using the *Comprehensive meta-analysis (Version 3.3.070)* software (Borenstein et al., 2005), with results provided in tabulated and figure (forest plot) formats (see Fig. 2a–d). Analyses per metric were performed on a region-of-interest basis (e.g., frontal), and standardized mean differences (Hedge's  $g$ ) and 95% confidence intervals were calculated (Appendix 2). Hedge's  $g$  is to be interpreted in the same way as Cohen's  $d$ : 0.2 = small; 0.5 = medium; and 0.8 = large (Cohen, 1988). Results were pooled for the meta-analysis using a random effects model, with  $I^2$  reported as a measure of the proportion of variance in observed effects that reflects true effects, as opposed to that due to sampling error (Huedo-Medina et al., 2006).

## Study Demographics

All 29 studies in this review were experimental with cross-sectional design, with  $k=1$  also containing longitudinal components. The investigated studies looked at a variety of EEG measures, including theta power (14%;  $k=4$ ); alpha power (3%;  $k=1$ ), alpha asymmetry (10%;  $k=3$ ), LSW (21%;  $k=6$ ), N2 (28%;  $k=8$ ), P2 (10%;  $k=3$ ), P3 (52%;  $k=15$ ), N1 (3%;  $k=1$ ) and CNV (3%;  $k=1$ ). The age range of participants ( $N=1320$ ) included in the review was 8–52 years of age, with the exception of  $k=1$  study which did not specify the age of participants. Only  $k=1$  study has a single sex sample (female), with all other studies including a mixed female/male sample. Most studies were conducted in the United States (48%;  $k=14$ ), then Germany (24%;  $k=7$ ), China (10%;  $k=3$ ), Canada (7%;  $k=2$ ), Japan (3%;  $k=1$ ), France (3%;  $k=1$ ), and The Netherlands (3%;  $k=1$ ) (see Tables 1 and 2). Of the studies analyzed, 10% ( $k=3$ ) had clinical subsamples (Borderline Personality Disorder; BPD, Social Anxiety Disorder; SAD, and Autism Spectrum

Disorder; ASD), which were included for results and discussion (Gutz et al., 2015; McPartland et al., 2011; Stead et al., 2022). Sample sizes ranged from  $n=15$  to  $n=201$ , with a total of  $N=1320$  across all 29 studies. The studies identified were published within the years of 2009 and 2022.

## Results

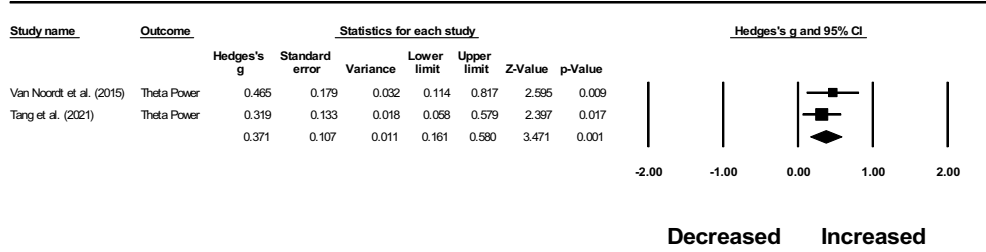
Most studies (59%;  $k=17$ ) investigated young adults, commonly undergraduate students in the age range of 18–25 years. However, some studies (28%;  $k=8$ ) examined child and adolescent age groups. Tables 1 and 2 are ordered from youngest (top) to oldest (bottom) in sample ages. Of the 29 studies included in this systematic review, 24% ( $k=7$ ) investigated EEG power (Table 1) and 79% ( $k=23$ ) investigated ERPs (Table 2), with 3% ( $k=1$ ) of studies investigating both EEG and ERPs (Kawamoto et al., 2013; marked\* in Tables 1 and 2). A total of 24 studies (83% of all studies; 100% of the EEG studies) utilized the Cyberball paradigm, and the remaining 5 studies (all ERP only) utilized other paradigms including the Lunchroom task ( $k=2$ ), the Island getaway task ( $k=1$ ), the Eye gaze paradigm ( $k=1$ ) and the scenario reading task ( $k=1$ ).

## EEG Power Results

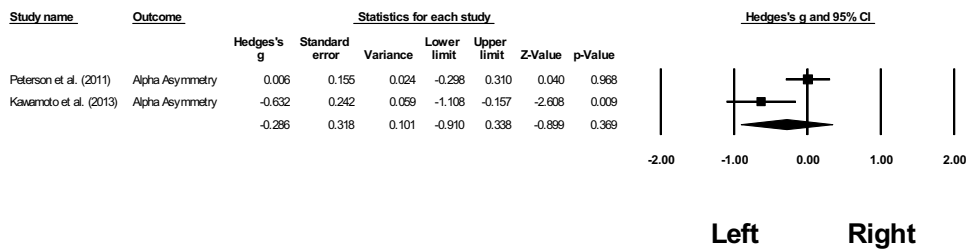
Studies examining EEG (Table 1) have revealed associations between social exclusion and EEG spectral power across several brain regions and frequency bands. Of the 7 EEG studies, 43% ( $k=3$ ) investigated theta power, one of which also investigated alpha power. Participation in the exclusion conditions of the Cyberball paradigm were associated with increases in mediofrontal theta power in children (Tang et al., 2021; van Noordt et al., 2015) and adolescents (Tang et al., 2019, 2021). Additionally, increased theta power in these frontal medial regions in response to rejection was predictive of greater ostracism distress (van Noordt et al., 2015). There was also evidence of increased frontal alpha power in exclusion conditions (van Noordt et al., 2015). Frontal EEG alpha asymmetry in response to social exclusion in Cyberball paradigms was examined in 43% ( $k=3$ ) of studies. More specifically, two studies found that increased left frontal alpha asymmetry was associated with increased emotional response to exclusion conditions (Peterson et al., 2011; Stead et al., 2022). Kawamoto et al. (2013) investigated observation, inclusion and exclusion trials as two halves, and found a shift from left frontal to right frontal alpha asymmetry, with right frontal activation present in the second half of trials in the exclusion condition. Additionally, intracranial EEG research investigating social pain found increased theta power in several brain regions, including the anterior insula, orbitofrontal cortex and FFA (Cristofori

Output and forest plots from conducted meta-analyses (a-e)

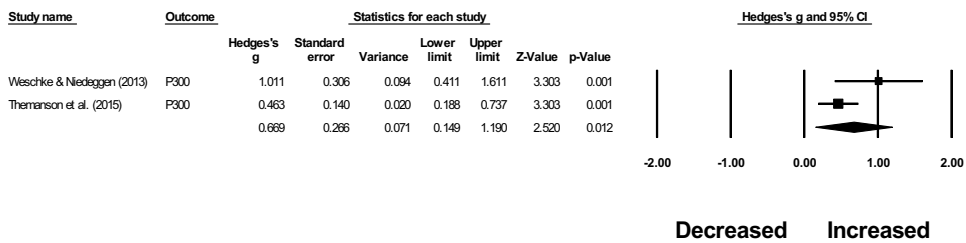
Frontal Theta Power (a)



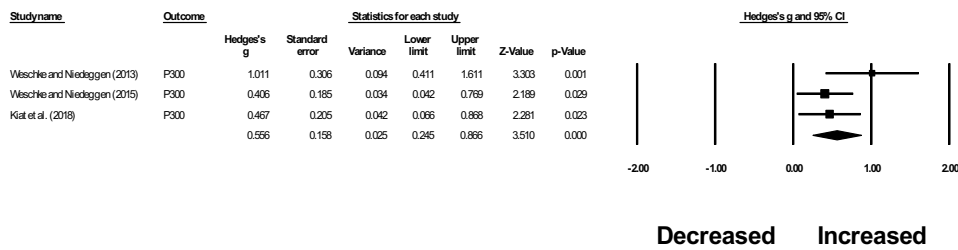
Lateral Frontal Alpha Asymmetry (b)



Central P300 Amplitudes (c)



Posterior P300 Amplitudes (d)



Frontal LSW Amplitudes (e)

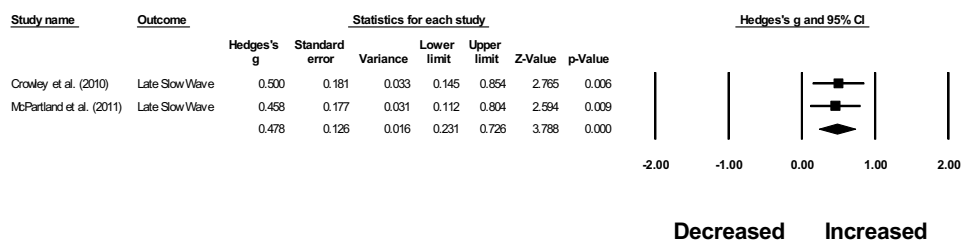


Fig. 2 Output and forest plots from conducted meta-analyses (a–e)

et al., 2013). There was also a finding of increased “neural synchrony” (i.e., increased power) within the theta band during the exclusion condition, whereas delta, alpha and beta band powers decreased (Cristofori et al., 2013).

## ERP Results

While 3% ( $k=1$ ) of studies investigated both EEG power and ERP results during social exclusion, 79% ( $k=23$ ) investigated ERP responses to social exclusion. Of these 23 studies, 78% ( $k=18$ ) used a Cyberball exclusion paradigm, 9% ( $k=2$ ) used a Lunchroom exclusion task, 4% ( $k=1$ ) used the Island getaway exclusion task, 4% ( $k=1$ ) used an Eye gaze exclusion paradigm, and 4% ( $k=1$ ) used a scenario reading task.

Overall, results show that early ERP components were present in response to exclusion stimuli (41%;  $k=12$ ). P2 amplitudes were larger (more positive and pronounced) during social exclusion conditions in  $k=2$  studies (Leng et al., 2018; Sreekrishnan et al., 2014), however amplitudes were reduced in exclusion conditions in  $k=1$  study (McPartland et al., 2011). Studies investigating N2 (28%;  $k=8$ ) found larger N2 amplitudes were present during exclusion conditions in medial central regions (Hudac et al., 2019), frontal regions (Themanson et al., 2013) and parietal regions (Gutz et al., 2011; Otten & Jonas, 2013). However, some studies found no impact of exclusion on N2 amplitudes (Weschke & Niedeggen, 2016), or reduced N2 amplitudes in frontal (Leng et al., 2018; Weschke & Niedeggen, 2013) and central areas (Weschke & Niedeggen, 2013). Overall, results show that late ERP components were present in exclusion conditions (52%;  $k=15$ ). Specifically, P3 amplitudes were greater during exclusion conditions in central (Niedeggen et al., 2017; Schuck et al., 2018; Themanson et al., 2015; Weschke & Niedeggen, 2013), posterior (Crowley et al., 2010; Gutz et al., 2011, 2015; Kiat et al., 2018; Niedeggen et al., 2017; Themanson et al., 2013; Weschke & Niedeggen, 2013), parietal (Niedeggen et al., 2017; Schuck et al., 2018) and frontal (Hudac et al., 2019; Themanson et al., 2015) regions, when compared to inclusion or baseline measures. However, in an exclusionary Cyberball task, smaller P3 amplitudes have been observed in exclusion conditions (Kawamoto et al., 2013), where larger N2 amplitudes are observed (Otten & Jonas, 2013). Slow wave effects were found in 21% of studies ( $k=6$ ), with increased frontal slow wave amplitudes found in all six studies (Crowley et al., 2009, 2010; Leng et al., 2018; McPartland et al., 2011; Sreekrishnan et al., 2014; White et al., 2012). Additionally,  $k=1$  study also found increased amplitudes in parietal areas (Leng et al., 2018).

## Meta-Analyses

Pooled effect estimates found significantly increased frontal theta power (Fig. 2a; Hedge's  $g=0.371$ ,  $p=0.001$ , 95% CI: 0.161 to 0.580,  $I^2=0\%$ ), central P3 amplitude (Fig. 2c; Hedge's  $g=0.669$ ,  $p=0.012$ , 95% CI: 0.149 to 1.190,  $I^2=62.29\%$ ), posterior P3 amplitude (Fig. 2d; Hedge's  $g=0.556$ ,  $p<0.001$ , 95% CI: 0.245 to 0.866,  $I^2=33.61\%$ ), and frontal LSW amplitude (Fig. 2e; Hedge's  $g=0.478$ ,  $p<0.001$ , 95% CI: 0.231 to 0.726,  $I^2=0\%$ ), in response to exclusion conditions. In contrast, no significant difference in lateral frontal alpha asymmetry was found in response to exclusion conditions (Fig. 2b; Hedge's  $g=-0.286$ ,  $p=0.369$ , 95% CI: -0.910 to 0.338,  $I^2=79.69\%$ ).

## Discussion

Due to increasing rates of social media use, particularly in young and adolescent age groups Twenge et al., 2019; Zhu et al., 2021) cyberbullying and other like behaviors are becoming a problematic mental health issue (Campbell et al., 2012). Although there has been research interest on the effects of social behaviors on psychosocial health and functioning, there has been less research on the effects of cyberbullying on brain activity, particularly using EEG as an imaging method. This systematic review and meta-analysis aimed to determine how EEG power in different frequency bands and ERP amplitudes are affected by online exclusionary behaviors.

## ERP Effects

### Early ERP Components

Additionally, ERP data identified early ERP components (200 to 300 ms) as P2 and N2. Exclusion events were generally indexed by increases in P2 amplitudes. However, McPartland et al. (2011) found reduced frontal P2 amplitudes in exclusion conditions. This effect was more present in ASD participants, compared to healthy controls (McPartland et al., 2011). When comparing rejection by kin to rejection by peers, P2 was increased, whereas greater ostracism distress elicited smaller P2 peaks. (Sreekrishnan et al., 2014). Results suggest that frontal P2 is more pronounced during social exclusion, due to increased attention allocated to perception and processing of focal stimuli (Sreekrishnan et al., 2014).

Across many studies, increased N2 amplitudes were found in response to exclusion conditions (Gutz et al., 2011; Hudac et al., 2019). However, some studies found no change in N2 amplitudes across conditions (Weschke & Niedeggen, 2016), or a decrease in amplitude (Leng et al., 2018; Weschke &

Niedeggen, 2013). Additionally, N2 amplitudes were greater when inhibiting a response during exclusion (Otten & Jonas, 2013). Considering N2 is argued to correspond to a neural alarm system that is responsible for monitoring conflict, this suggests the studies that showed a lesser effect may have less conflict present for participants in their study design.

### Late ERP Components

Late ERP components (300 to 400 ms) were indexed by P3 amplitudes. Individual studies reported increased P3 amplitudes in response to exclusion in a variety of regions across the brain (Crowley et al., 2010; Hudac et al., 2019; Schuck et al., 2018; Themanson et al., 2015). This was supported by the meta-analyses in central and posterior regions. However, participants with BPD displayed this P3 indexation throughout inclusion conditions as well as exclusion conditions (Gutz et al., 2015). Results also found increased P3 amplitudes during partial exclusion conditions, particularly in central and parietal brain regions (Niedeggen et al., 2017). Generally, P3 amplitudes increased in response to exclusion, however some results suggest a decrease in amplitudes (Kawamoto et al., 2013; Otten & Jonas, 2013). However, this may be due to variation in study methodology and use of paradigm.

Larger P3b amplitudes during exclusion conditions were also found to be correlated with positive affect and decreased cognitive control (Themanson et al., 2013). Research suggests P3a and P3b to be representative of different neural processes (Polich, 2007). P3a is related to negative mood induced by social exclusion (Gutz et al., 2015); P3b is thought to index stimulus evaluation and processing (Gutz et al., 2015; Weschke & Niedeggen, 2015). Results also found increased P3a amplitudes in response to exclusion in early trials, and progressively decreasing P3b amplitudes during exclusion conditions (Themanson et al., 2015). However, this may be attributed to study design; once participants realize that they are going to receive the ball, in the Cyberball paradigm (inclusion), they prepare a motor response to throw the ball again. These cognitive processes are not required for exclusionary events, but do require control processes that may be indexed by P3b. In addition, excluded participants exhibited a smaller P3 amplitude when inhibiting a response, indicating that excluded participants had less inhibitory control than included participants (Otten & Jonas, 2013).

Results suggest that exclusionary events may be indexed by larger P3 amplitudes and late positive potentials (LPPs) (Crowley et al., 2010). Based on the salience of exclusion stimuli, it may be suggested that P3 and LPPs mark the cognitive processing behind distribution of attention (Crowley et al., 2010). Gutz et al. (2011) further investigated the processes behind interpreting exclusion events, and

distinguished between early fronto-central P3a and late parietal P3b. Aligning with existing research, these results suggest that P3a indexes a frontal attention mechanism during processing of external stimuli, while P3b indexes an internal attention mechanism in the parietal region (Polich, 2007).

Results from some studies suggest that lower ball reception probability leads to decreased expectancy, resulting in higher P3 amplitudes (Schuck et al., 2018; Weschke & Niedeggen, 2015). Other studies investigating the effects of expectancy of ERP effects found that increased P3 demonstrates expectancy violation. Interestingly, previously experiencing exclusion increased the expectation of incurring future rejection events (Gutz et al., 2011). Position of the players avatars on the screen was also influential on ERP effects, with those in a superior position on the screen eliciting a greater mean P3b amplitude than those who were in lower (inferior) or even positions (Schuck et al., 2018). The use of different paradigms to research social exclusion may influence P3 amplitudes. However, only a few studies have investigated ERP effects of social exclusion outside the Cyberball task. Research using the Lunchroom paradigm to investigate the effects of social dynamics on ERPs found that participants with greater self-reported cognitive reappraisal have larger P3b amplitudes from inclusion to exclusion (Kiat et al., 2017).

### Slow Wave Components

ERP components (from 400 to 900 ms) in frontal regions demonstrated LSW effects (Crowley et al., 2009, 2010; Leng et al., 2018; McPartland et al., 2011; Sreekrishnan et al., 2014; White et al., 2012). Notably, the meta-analysis found significantly increased frontal LSW amplitude in response to exclusion conditions. The late positive slow wave (400–900 ms) has been shown to reflect emotional regulation, with negative frontal slow waves reflective of the evaluative processes (Crowley et al., 2010). Additionally, later processing stages involve frontal theta modulation, which has been closely linked to distress and anxiety. This frontal theta activity is suggested to be related to higher and more stable levels of anxiety (Themanson et al., 2013).

Late positive potentials (580 – 900 ms) in interior left prefrontal and medial frontal brain regions have been found to be associated with exclusion and self-reported ostracism distress (Crowley et al., 2009). Additionally, frontal slow waves in the medial frontal region are more negative in response to rejection events, and more positive in the posterior occipital-parietal region. For rejection events only, distress was associated with increased negativity in frontal slow waves and a larger late positive slow wave (Crowley et al., 2010). These results suggest that frontal slow waves may mark processes associated with cognitive regulation of negative emotion in response to exclusion events.



## EEG Power

In response to exclusion events, neural oscillations in the frontal cortex showed increased theta power (Kawamoto et al., 2013; van Noordt et al., 2015), as well as the insula, subgenual anterior cingulate cortex (subACC) and fusiform face area (FFA) (van Noordt et al., 2015). fMRI studies have suggested that the dorsal ACC is reflective of secondary cognitive processes, associated with conflict monitoring, emotional awareness and decision making (Bolling et al., 2011; Somerville et al., 2006). Increased activity in the subACC has previously been recognized as a marker or predictor for depression. Specifically, it reflects higher levels of negative emotions induced by social exclusionary events (Masten et al., 2012). Increased theta power in frontal regions of the brain has also been found in response to social pain in intracerebral EEG data (Cristofori et al., 2013). Additionally, increased theta power in frontal medial regions has been shown to be predictive of greater ostracism distress (van Noordt et al., 2015). Results showed that medial frontal theta activity was greatest during social rejection in comparison to control trials, and is representative of ostracism distress in the late wave window (400–800 ms). However, research suggests that frontal theta activity may be reflective of expectancy violation of ball reception, and the processing of not receiving the ball in Cyberball (van Noordt et al., 2015).

In exclusion conditions, low control was associated with frontal cortical asymmetry, with relative increased left frontal cortical activity associated with increased emotional response to social exclusion (Peterson et al., 2011). As alpha power is inversely related with cortical activity (Davidson, 2004), lower frontal alpha asymmetry index scores are representative of greater left frontal activation (or relative left activation). Research by Harmon-Jones (2004) suggests that emotions such as anger are related to greater left frontal cortical activity in frontal cortical asymmetry. This activity is present in emotions that are negatively valent, and have approach motivational rather than withdrawal motivational tendencies. Additionally, research has found a change from approach to withdrawal motivation as social exclusion continues, evidenced by a change from left frontal to right frontal alpha asymmetry in the second half of the exclusion condition (Kawamoto et al., 2013).

## Vulnerable Populations

Neural processes of attention and perception in early stage processing may be influenced by factors such as ASD or other psychological conditions. Participants with ASD have decreased engagement and attention to social cues, and this is reflected neurologically by reduced P2 amplitudes in response to rejection events (McPartland et al., 2011). Participants with ASD also have greater difficulty making

critical distinctions based on social cues or contexts. This is indexed at late stage processing, with the absence of a differential slow wave (McPartland et al., 2011). In contrast to this, participants with borderline personality disorder (BPD) had increased parietal P3b amplitudes, which were not differentiable between exclusion and inclusion conditions (Gutz et al., 2011). This suggests a negative perception of both inclusion and exclusion events in this subject sample. Stead et al. (2022) had similar findings, in that participants with greater relative left frontal activity have more extreme (both high and low) rejection sensitivity scores, moderated by the presence of high or low BPD features (respectively). These results suggest that individuals with BPD diagnoses or symptoms experience heightened rejection sensitivity, indexed by neurological markers such as increased left frontal activity or amplified P3b in task-based EEG.

## Children and Adolescents

Research using MRI has shown that increased activation of the ventrolateral PFC is demonstrative of acquired emotional regulation strategies when comparing an adult sample to adolescents (Sebastian et al., 2011). Therefore, adolescents may be at an increased risk for negative outcomes, as they are less equipped to deal with negative emotions caused by adverse social interaction. The transition period of adolescence can be relatively seamless for some, despite extensive biological and psychological changes occurring during this period. However, for others, this transition can cause emotional turbulence and see the emergence of behaviors that are often problematic for the individual's mental health and psychosocial functioning (Steinberg, 2013). Synaptic formation and pruning that occurs during this time makes adolescence a critical developmental period (Steinberg, 2005). Changes in regions of the brain coordinating emotional regulation and inhibition may contribute to emotional and behavioral changes. This may help explain the notable increase in adolescent affectual problems, risk-taking behaviors and impulse inhibition (Steinberg, 2005). These changes may also help explain intense variability in emotions and issues with emotion regulation, which may provide an explanation for an increased risk for psychological disturbances and suicide in the adolescent demographic (Casey et al., 2010).

Additionally, research suggests that child and adolescent populations may have heightened rejection sensitivity and therefore increased theta power in mediofrontal brain regions (Tang et al., 2019, 2021). Increased frontal medial theta power as a response to social exclusion was found in child and adolescent populations (Tang et al., 2019). Additionally, research has found that children had greater theta power in rejection (compared to exclusion) events, and adolescents had greater theta power in both rejection and exclusion events (Tang et al., 2021). This result was replicated



in children that were classified as shy based on self-report scores. This suggests children may have greater functional role in negative cue appraisal, or a role in distress regulation, which may explain the increase in theta power (Tang et al., 2021). These results suggests that youth may have a heightened sensitivity to social cues, including social exclusion or other types of ostracizing behavior. Adolescents have been identified to have impaired ability in regulating negative emotion when compared to other age groups (Sebastian et al., 2011), and therefore may have difficulty coping with rejection. Due to this, youth may be considered a high risk group for neurophysiological effects of social exclusion, and may therefore be more susceptible to ongoing neurophysiological effects of online exclusionary behaviors that may impact social and emotional development. Literature so far has investigated and provided evidence for the negative effects of cyberbullying on mental health, social functioning, and academic success (Kowalski et al., 2014; Nishina & Juvonen, 2005). Additional research examining the neurobiological response to social exclusion may lead to better understanding of the factors that contribute to mental health and psychosocial functioning in adolescence.

## Limitations

Although the literature was systematically searched to find electrophysiological studies that investigate social exclusion or cyberbullying studies, there were no cyberbullying specific studies discovered in the search results; all investigated the broader key construct of social exclusion or ostracism, with the vast majority (83%;  $k = 24$ ) using a Cyberball paradigm. This may be due to cyberbullying being a relatively new construct (compared to traditional schoolyard bullying), as well as potential ethical and validity complications regarding replication of cyberbullying scenarios and behaviors. Although there were no studies on cyberbullying specifically, it was important to include cyberbullying specific search terms in order to ensure the literature was searched exhaustively. Additionally, the results from Cyberball/social exclusion studies are relevant and translatable to cyberbullying experiences, as online exclusionary behaviors by definition are a method of cyberbullying behavior, and therefore contribute sufficiently to cyberbullying literature. However, this does uncover a gap in the literature; future research should focus on using a cyberbullying specific index to investigate the neurophysiological effects of all aspects of the broader cyberbullying.

Research has shown that the Cyberball paradigm is an effective way to investigate neural processing of social exclusion and social pain (Crowley et al., 2009; Gutz et al., 2011; Otten & Jonas, 2013; Schuck et al., 2018). However, it has

been suggested that participants may perceive themselves to be accepted or rejected after a period of time, which may influence rapid response ERP components. Additionally, there is evidence for order effect of the Cyberball paradigm in self-report and EEG data, with earlier inclusion experiences influencing exclusion processing, and vice versa (Gutz et al., 2011). In comparison, the Eye-gaze paradigm (Wirth et al., 2010) uses eye gaze as a non-verbal exclusion cue, and may deliver exclusion and inclusion cues more immediately than Cyberball (Leng et al., 2018). Additionally, the Cyberball paradigm may be less appealing to adults, which may impact the generalizability of the data (Leng et al., 2018). Despite these limitations, the selected studies have examined different neural oscillations and ERPs during online social exclusion and found consistent results between studies.

Of those studies included in the current review, only 2–3 studies per EEG component were deemed permissible for conducting a meta-analysis, which reflects the significant heterogeneity within the literature. Additionally, this was the first meta-analysis of EEG/ERP studies of social exclusion, and therefore highlights the need for future research to adhere to thorough reporting of statistical parameters. From the five meta-analyses conducted, exclusion conditions found significant increases for frontal theta power, central P3, posterior P3 and frontal LSW. Without sufficient studies, the pooled effect size estimates for N2 and P2 could not be quantitatively investigated. Once sufficient further research in this area has been published, a meta-analysis of these EEG metrics in the context of social exclusion must be re-visited.

In addition, a large proportion of included studies had small sample sizes, and the results from such studies may therefore lack the sufficient power to draw informed conclusion from the data. Additionally, only  $k = 8$  (28%) of studies reported sample ethnicity, and therefore this review could not draw conclusions on potential impacts of race or ethnicity. Future research should report ethnicity, and should use larger sample sizes with appropriate statistical power analyses in order to make sure the data is more reliable and therefore more generalizable to the target population.

Additionally, the paradigms reviewed in this article were administered with EEG, and therefore report a high temporal resolution to examine the effects of time-matched exclusionary and inclusionary events (Liu et al., 2020). However, the reviewed articles fail to examine the any long-term effects that social exclusion may have on resting state neural oscillations or task-based ERPs. Research has shown that repeated exposure to traumatic environments or certain behaviors can impact brain structure and function over time (Meyer et al., 2018). Therefore, investigation into the longitudinal effects of social exclusion should be explored.

## Conclusion

Although there is an array of literature investigating the psychosocial impacts of online exclusionary behavior, there has been less research interest in the neurobiological underpinnings of such behavior. Therefore, this article aimed to better understand the potential neurophysiological impacts of social exclusion in online environments by conducting a systematic review and meta-analysis of the available, albeit limited literature on this topic. Overall, it was found that in response to social exclusion conditions participants showed increased N2 amplitudes, elevated P3 amplitudes, more negative frontal LSW, and increased frontal theta power. Respectively, these findings are suggestive of heightened deviance and stimulus detection responses, as well as increases in emotional attention and emotional regulation. Meta-analyses were conducted for 2–3 studies for each EEG component and were restricted according to brain region and availability of statistical parameters, evidencing a need for consistency in methodology and reporting in future research. The overall findings here are important to our understanding of how social exclusion may affect the brain. Such evidence has important implications for interpreting the neurobiological underpinnings of cyberbullying, which is becoming an ever-increasing threat to the developing psychological health of high-risk groups, such as children and adolescents.

## Appendix 1

### Protocol—Systematic Review and Meta-analysis of Electrophysiological Studies of Online Social Exclusion Overview

Title of the review	Systematic Review and Meta-analysis of Electrophysiological Studies of Online Social Exclusion
First author	Lia Mills
Co-authors	Christina Driver, Larisa T. McLoughlin, Toomas Erik Anijärvi, Jules Mitchell, Jim Lagopoulos, Daniel F. Hermens
Systematic review guidelines	In line with PRISMA 2020 guidelines (Page et al., 2021)

## Background

Background	Cyberbullying is becoming an increasingly problematic phenomenon, due to increasing rates of social media use and cyberbullying involvement particularly in young and adolescent age groups (Twenge et al., 2019; Zhu et al., 2021). Research has found cyberbullying facilitates relational victimization, which may involve verbal victimization or exclusion from groups (Xiao & Wong, 2013). An example of this is social exclusion, which is described in Willard (2007) as blocking or distancing an individual over online means. Other methods of cyberbullying include flaming (a fight over online means), harassment (repetitive, offensive messages) and impersonation (posing as another individual), however this list is not exhaustive (Willard, 2007). Although there has been a lot of research interest on the effects of cyberbullying like behaviors on psychosocial health and functioning, there has been less research on the effects of cyberbullying like behaviors on brain activity using EEG as an imaging method, and this research has not been assessed systematically
Aim(s)	Review and analyze the existing literature investigating cyberbullying like behaviors using EEG measures, in order to identify underlying neurobiological processes that may be important to understand the neurophysiology underlying cyberbullying
Specific objectives	1. Investigate how ERP amplitudes are affected by experiencing cyberbullying like behaviors 2. Investigate how EEG spectral power is affected by experiencing cyberbullying like behaviors

## Inclusion Criteria

Population of interest	Participants of all ages
Language	The record is reported in the English language
Date range	Research is dated between 2002 and 2022
Study designs	Empirical research articles only
Interventions or exposures	Exposure to cyberbullying-type behaviors (including online ostracism, social exclusion, and online aggression)
Outcomes of interest	Any effects of social exclusion on brain activity, including measures of EEG power bands and asymmetry, or event-related potential data
Peer-reviewed	Article has been peer-reviewed

## Exclusion Criteria

Study design	Review articles
Full-text availability	Full-text of the record is not available
Peer review	Student or doctoral theses
Interventions or exposure	The study looks at cyber bystander or observer behavior only

## Search methods

Electronic databases	ProQuest PubMed Scopus Web of Science
Other methods used for identifying relevant research	Review reference list (citation searching) of included records to identify additional relevant records for consideration
Search fields	Title, abstract, keywords
Keywords	<i>Keywords relating to cyberbullying</i> K1 cyberbull* K2 bull* K3 victim K4 ostracis* K5 “social exclusion” K6 “online aggression” K7 (K1 OR K2 OR K3 OR K4 OR K5 OR K6) <i>Keywords relating to EEG</i> K8 EEG K9 electroencephalography K10 electrophysiology K11 neurobiology K12 ERP K13 (K8 OR K9 OR K10 OR K11 OR K12) <i>Proposed search strategy: K7 AND K13</i>

Database searching results

Database	Unique results from each database
ProQuest	83
PubMed	214
Scopus	507
Web of Science	346

Database	Unique results from each database
Total articles (before removing duplicates)	1150

Review methods

Reference manager	Endnote
Quality assessment	Quality assessment tool for observational cohort and cross-sectional studies (National Institute of Health; NIH, 2019)
Data extraction	Data extraction form in Microsoft Word LM to extract data If necessary, second reviewer to resolve uncertainties
Narrative synthesis Details of what and how synthesis will be done	Identify and summarize influences of social exclusion on brain activity Discuss how these factors may influence adolescent brain activity and development

Presentation of results

How to present findings in final paper	PRISMA flowchart Data extraction tables
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## Appendix 2

Additional output from meta-analyses, demonstrating heterogeneity values and tau-squared.

### Frontal Theta Power (a)

Model		Effect size and 95% confidence interval					Test of null (2-Tail)		Heterogeneity				Tau-squared			
Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
Fixed	2	0.371	0.107	0.011	0.161	0.580	3.471	0.001	0.433	1	0.511	0.000	0.000	0.035	0.001	0.000
Random	2	0.371	0.107	0.011	0.161	0.580	3.471	0.001								

### Lateral Frontal Alpha Asymmetry (b)

Model		Effect size and 95% confidence interval					Test of null (2-Tail)		Heterogeneity				Tau-squared			
Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
Fixed	2	-0.179	0.131	0.017	-0.435	0.077	-1.371	0.170	4.923	1	0.026	79.689	0.163	0.288	0.083	0.403
Random	2	-0.286	0.318	0.101	-0.910	0.338	-0.899	0.369								

### Central P300 Amplitudes (c)

Model		Effect size and 95% confidence interval					Test of null (2-Tail)		Heterogeneity				Tau-squared			
Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
Fixed	2	0.558	0.127	0.016	0.308	0.807	4.378	0.000	2.652	1	0.103	62.288	0.094	0.212	0.045	0.306
Random	2	0.669	0.266	0.071	0.149	1.190	2.520	0.012								

### Posterior P300 Amplitudes (d)

Model		Effect size and 95% confidence interval					Test of null (2-Tail)		Heterogeneity				Tau-squared			
Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
Fixed	3	0.530	0.125	0.016	0.284	0.776	4.230	0.000	3.013	2	0.222	33.613	0.026	0.077	0.006	0.160
Random	3	0.556	0.158	0.025	0.245	0.866	3.510	0.000								

### Frontal Late Slow Wave (e)

Model		Effect size and 95% confidence interval					Test of null (2-Tail)		Heterogeneity				Tau-squared			
Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
Fixed	2	0.478	0.126	0.016	0.231	0.726	3.788	0.000	0.027	1	0.869	0.000	0.000	0.045	0.002	0.000
Random	2	0.478	0.126	0.016	0.231	0.726	3.788	0.000								

## Appendix 3

See Table 3.

**Table 3** Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (n=29)

Citation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total score
van Noordt et al. (2015)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Tang et al. (2021)	Y	Y	NR	Y	Y	N	N	NA	Y	N	Y	CD	NA	Y	7
Tang et al. (2019)	Y	Y	NR	Y	Y	N	N	NA	Y	N	Y	CD	NA	Y	7
Stead et al. (2022)	Y	Y	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	6
Kawamoto et al. (2013)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Cristofori et al. (2013)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Peterson et al. (2011)	Y	N	NR	N	N	N	N	NA	Y	N	Y	CD	NA	Y	4
McPartland et al. (2011)	Y	CD	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Crowley et al. (2010)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Sreekrishnan et al. (2014)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
White et al. (2012)	Y	Y	Y	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	7
Themanson et al. (2015)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Themanson et al. (2013)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Kiat et al. (2018)	Y	Y	Y	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	7
Otten and Jonas (2013)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Xu et al. (2022)	Y	Y	NR	Y	Y	N	N	NA	Y	N	Y	CD	NA	Y	7
Crowley et al. (2009)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Weschke and Niedeggen (2016)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Schuck et al. (2018)	Y	Y	NR	Y	Y	N	N	NA	Y	N	Y	CD	NA	Y	7
Niedeggen et al. (2017)	Y	CD	NR	Y	Y	N	N	NA	Y	N	Y	CD	NA	Y	6
Weschke and Niedeggen, 2013	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Weschke and Niedeggen (2015)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Gutz et al. (2011)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Gutz et al. (2015)	Y	Y	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	6
Kiat et al. (2017)	Y	Y	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	6
Hudac (2019)	Y	N	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	5
Rappaport et al. (2019)	Y	Y	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	6
Leng et al. (2018)	Y	Y	NR	Y	N	N	N	NA	Y	N	Y	CD	NA	Y	6
Zhu et al. (2022)	Y	Y	NR	Y	Y	N	N	NA	Y	N	Y	CD	NA	Y	7

Y Yes; N No; CD Cannot determine; NA Not applicable

### Key Criteria

1. Was the research question or objective in this paper clearly stated?
2. Was the study population clearly specified and defined?
3. Was the participation rate of eligible persons at least 50%?
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?
5. Was a sample size justification, power description, or variance and effect estimates provided?
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed? (e.g., categories of exposure, or exposure measured as continuous variable)?
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome.

9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
10. Was the exposure(s) assessed more than once over time?
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
12. Were the outcome assessors blinded to the exposure status of participants?
13. Was loss to follow-up after baseline 20% or less?
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?

**Authors' Contributions** LM participated in protocol design, searching, screening and drafting of manuscript; CD participated in protocol design, drafting of manuscript and data analysis; LMc participated in protocol design, screening and drafting of manuscript; TEA participated in drafting of manuscript; JM participated in data analysis and revision of manuscript; JL participated in drafting of manuscript; DH participated in protocol design, drafting and revision of manuscript. All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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**Data availability** Data is contained within the article or supplementary material, or this is available from the corresponding author upon reasonable request.

## Declarations

**Conflicts of interest** The authors report no conflict of interests.

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