A Narrative Review of the Role of Social Observation on Error Monitoring

*Olivia A. Stibolt[1,2], Jeremy W. Pettit[1,2], and George A. Buzzell[1,2]

[1]Department of Psychology, Florida International University, 11200 SW 8th St, Miami, FL 33199, USA

[2]Center for Children and Families, Florida International University, 11200 SW 8th St, Miami, FL 33199, USA

Contact information of corresponding author:

Olivia Stibolt

410-570-9856

ostibolt@gmail.com

Abstract

Error monitoring is the process by which the brain self-evaluates whether responses are correct and in line with achieving task goals. The error-related negativity (ERN), a neural marker of error monitoring, is influenced by the motivational significance of errors. For example, making a mistake while being observed can be more salient than when alone. The current narrative review assesses whether error monitoring is consistently upregulated within the presence of others. Additionally, we explore the possible influence of paradigm-related factors, such as deception and feedback, and individual factors, such as age and anxiety, on relations between social observation and the ERN. We find that use of deception or feedback may increase ERN amplitudes under social observation. In contrast, presence of an authority figure and whether an observer is physically (or virtually) present do not appear to impact effects of social observation. Specific subconstructs of anxiety, such as fear of negative evaluation, may more strongly influence the ERN under social observation. We also find that the ERN increases under social observation for both youth and adults, although potentially more consistently among youth. We conclude by providing methodological recommendations and propose future directions for this burgeoning area of research.

Key words: error monitoring, error-related negativity, ERN, social observation, social context

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Making an error in front of others can have important implications for one's personal and professional goals. Humans monitor and adapt their behavior to achieve task goals and avoid errors, including during social situations (Bartholow, 2010; Buzzell et al., 2020; Zaki et al., 2010). One way that the need for further control is determined is through error monitoring, which refers to the ability to self-monitor and self-detect one's errors (Gehring et al., 1993; Ullsperger et al., 2014). One common way to index error monitoring is via the error-related negativity (ERN), a negative deflection in the electroencephalogram (EEG) that peaks within 100 ms after making an error (Falkenstein et al., 1991; Gehring et al., 1993).

The ERN is associated with individual factors like age and anxiety (Davies et al., 2004; Kang et al., 2021; Meyer, 2022; Michael et al., 2021; Moser, 2017) and varies as a function of paradigm-related factors, including whether a task requires one or two hands for responses, and the presence/frequency of feedback (Buzzell et al., 2024; Olvet & Hajcak, 2009). Importantly, the ERN can be modulated by factors that impact the motivational significance of errors (Hajcak et al., 2005), including reward (Stürmer et al., 2011), punishment (Riesel et al., 2012), and competition (Van Meel & Van Heijningen, 2010). Of particular relevance for the current review, social observation can likewise increase motivational significance and heighten the ERN (Hajcak et al., 2005).

Humans are a social species (Baumeister & Leary, 1995), and thus social contexts hold great importance to our success as individuals, from physical wellbeing (Holt-Lunstad, 2021) to productivity and satisfaction in the workplace (Holt-Lunstad, 2018). Humans learn even as young children to adjust behavior to initiate and maintain relationships (Rubin et al., 2007) and social concerns increase through adolescence (Nelson et al., 2005; Somerville, 2013). Because instances of social observation (social contexts) are so prevalent in everyday life and integral to the way humans interact with the world, there is great utility in understanding how they shape the brain and behavior. With this review, we aim to synthesize what is currently known about

how error monitoring is influenced by social observation, to highlight the importance of investigating such relations, and to encourage new lines of research in this domain.

Scope

In this narrative review, we assess whether error monitoring, as measured by the ERN, is consistently upregulated under social observation. Moreover, we explore how paradigm-related factors and individual factors influence relations between social observation and the ERN. To these ends, we define social observation as occurring in any situation in which the participant performs a task in the presence of at least one other person, real or fictitious. Accordingly, we use the term “participant” to denote the person performing a task while being observed, and “observer” to denote the person watching the participant perform the task.

To focus the scope of this review, we limit the reviewed studies to those that directly compared the ERN under a social observation condition with a condition in which the participant was alone and not observed. As such, articles reporting on studies in which a social observation condition was assessed, but that did not have a comparison alone condition, such as those examining cooperative vs. competitive contexts (de Bruijn et al., 2020; García Alanis et al., 2019), were not included. Papers examining error monitoring in the observer (Castellar et al., 2011; de Bruijn et al., 2009; Musco et al., 2023) were also not included. Reviewed studies were required to report the effect of social context on the ERN, measured on error trials. However, we also annotated the results of related measures, when present, to include: 1) correct-related negativity (CRN), 2) ΔERN (error-related negativity minus correct-related negativity), and 3) behavioral measures (RT, accuracy, and post-error slowing). For select studies, we also assessed the results of related ERN metrics that were reported, including the “social-effect ERN” (social ERN minus nonsocial ERN) and the “social-effect residualized ERN” (residual variance after social ERN regressed onto nonsocial ERN).

A literature search was conducted using Google Scholar and Web of Science between March 2024 and June 2025 to identify relevant articles from any publication year. Searches were restricted to articles in English. Approximately 70 articles were deemed potentially relevant. All articles were screened by at least one author to determine relevance for inclusion in the narrative review. This process resulted in the identification of eleven studies that examined the ERN in a social vs. alone condition; details regarding these selected studies are reported in Tables 1-3, including summaries of their respective participant samples (Table 1), paradigms (Table 2), and results (Table 3). Due to the small number of resulting studies, we chose to conduct a narrative review rather than a meta-analysis.

In the following sections, we review and synthesize the results of the eleven identified studies. We begin with a general overview of the reported results, to assess whether the ERN is consistently increased under social observation. We then move to an examination of whether specific paradigm-related factors (use of physical/virtual observation, deception, authority, and feedback) influence relations between social observation and the ERN. Similarly, we assess whether individual factors (anxiety and age) impact relations between social observation and the ERN. We also briefly consider whether social observation influences the CRN or associated behavioral measures. Finally, we conclude by providing methodological recommendations and suggest important avenues for future research in this domain.

Table 1: Description of study populations included in review

Journal article	Sample size (Final)	Sex (Final)	Youth/adult	Age (Final)
Barker et al., 2015	43; 22 HSA, 21 LSA	22 female, 21 male (HSA: 11 female, 11 male; LSA: 11 female, 10 male)	Adult	HSA: *M* = 19.77, LSA: *M* = 19.51
Barker et al., 2018	62	Female only	Youth	8.67 - 17.14, *M* = 11.87 (full sample)
Buzzell, Troller-Renfree, et al., 2017	107	58 female, 49 male	Youth	*M* = 13.8
Clayson et al., 2025	125; 66 couples	65 female, 60 male	Adult	Female: *M* = 24, male: *M* = 25
Hajcak et al., 2005	18	7 female, 12 male (full sample)	Adult	Undergraduates, age not reported
Kim et al., 2005	20; 11 observation, 9 alone	7 male, 13 female (observation: 3 boys, 8 girls; alone: 4 boys, 5 girls)	Youth	7 – 11
Masaki et al., 2017	28; 14 HSPA, 14 LSPA	15 female, 13 male (HSPA: 7 female, 7 male; LSPA: 8 female, 6 male)	Adult	HSPA: *M* = 20.5; LSPA: *M* = 21.4
Niu et al., 2023	23	10 male, 13 female	Youth	15.68 - 17.91 (full sample)
Palmwood & Simons, 2021	28	8 male, 20 female	Adult	*M* = 19.04
Schillinger et al., 2016	18	Female only	Adult	18 - 32, *M* = 21.06
Voegler et al., 2018	44; 22 SAD, 22 HC	28 female, 16 male; (SAD: 9 male, 13 female; HC: 7 male, 15 female)	Adult	SAD: *M* = 24.73, HC: *M* = 23.00

Note: HSA indicates high socially anxious, LSA indicates low socially anxious, HSPA indicates high sport anxiety, LSPA indicates low sport anxiety, SAD indicates Social Anxiety Disorder, HC indicates healthy controls, Final indicates that the described statistic is the breakdown of the analyzed sample. The sex breakdown for Hajcak et al. (2005) and the age breakdown for Barker et al. (2018) and Niu et al. (2023) are based on the full sample, as the breakdowns for the final samples were not reported.

Table 2: Summary of paradigms included in review

Journal article	Task	Social condition	Observation type	Authority	Deception	Feedback type
Barker et al., 2015	Arrow flanker	An additional participant (confederate) watched for response time and accuracy via computer and marked each mistake on a clipboard. The confederate was seated at a 90-degree angle from the participant.	Physical	No authority figure	Deception	Block-level
Barker et al., 2018	Arrow flanker	Participants interacted in a fictitious virtual chatroom (deception) before the experiment started. In the social condition, participants were told the "peers" from the chatroom would monitor them via webcam and provide feedback on their performance. In actuality, the feedback was computer-generated.	Virtual	No authority figure	Deception	Block-level
Buzzell, Troller-Renfree, et al., 2017	Arrow flanker	Participants interacted in a fictitious virtual chatroom (deception) before the experiment started. In the social condition, participants were told the "peers" from the chatroom would monitor them via webcam and provide feedback on their performance. In actuality, the feedback was computer-generated.	Virtual	No authority figure	Deception	Block-level
Clayson et al., 2025	Arrow flanker	The participant engaged in two social observation conditions, once while observed by a member or the research team and once while observed by their spouse. For both conditions, observers heard a “ding” every time the participant made a mistake via headphones. Observers were seated behind and to the left of the participant so they could see the screen and responses.	Physical	Authority figure/No authority figure	No deception	None
Hajcak et al., 2005	Arrow flanker	Experiment 2 was included in this review, as it examined social vs. alone conditions. The participant was seated .5 m from a male research assistant. Participants were told the research assistant would evaluate their performance via a computer with info about their speed and accuracy and that they would be told how they compared to other students.	Physical	Authority figure	No deception	None

Kim et al., 2005	Go No-go	Participants in the social group (between-subjects study) were observed by a friend from their school. The friend was told to simply watch and say nothing. The participant and observer would then swap roles. A separate group of participants completed an alone condition.	Physical	No authority figure	No deception	Trial-level
Masaki et al., 2017	Spatial stroop	A research assistant with a laptop was seated behind and to the right of the participant. Participants were told that their performance was being evaluated and compared to others that did the task.	Physical	Authority figure	No deception	None
Niu et al., 2023	Arrow flanker	A "peer" (confederate) was seated next to the participant during the task under the guise of "learning about the task". The observer read aloud the computer-generated feedback provided after each task block. The experimenter was present in the room for the social and alone conditions.	Physical	No authority figure	Deception	Block-level
Palmwood & Simons, 2021	Letter flanker	In the social observation condition, observers (romantic partners) were instructed to silently count the number of errors the participant made. Participants and observers were also instructed not to communicate with each other during the task. The observer with the highest error-counting accuracy received $50 at the end of the study.	Physical	No authority figure	No deception	None
Schillinger et al., 2016	Numerical stroop	In the social observation (termed "high-pressure" in the article) condition, participants were observed by the research assistant via webcam and told that their performance would be evaluated. The participant with the best score would get $30 at the end of the study. There was no monetary reward in the alone/ "low pressure" condition.	Virtual	Authority figure	No deception	Block-level
Voegler et al., 2018	Go No-go flanker	An "experienced psychologist" (confederate) observed participants directly and via webcam and made a note on a chart any time the participant made a mistake. The confederate was seated next to the participant, facing them. There was also an experimenter that was seated behind a curtain.	Physical	Authority figure	Deception	Trial-level

Table 3: Summary of results included in review

	Effect of social observation (social – alone)						
Journal article	**ERN**	**ΔERN**	**CRN**	**RT**	**Accuracy**	**PES**	**Anxiety x ERN**
Barker et al., 2015	ERN larger only for HSA	ΔERN larger only for HSA	CRN not significantly different	RT not significantly different	Accuracy not significantly different	NA	ERN larger only for HSA
Barker et al., 2018	ERN larger only for younger adolescents	NA	CRN not significantly different	RT faster	Accuracy not significantly different	PES not significantly different	NA
Buzzell, Troller-Renfree, et al., 2017	ERN larger	NA	CRN larger	RT faster	Accuracy not significantly different	PES not significantly different	Social-effect residualized ERN larger for higher BI
Clayson et al., 2025	ERN smaller	ΔERN larger	NA	RT faster; RT faster with experimenter than spouse observer	NA	NA	NA
Hajcak et al., 2005	ERN larger	NA	CRN not significantly different	RT not significantly different	Accuracy not significantly different	NA	NA
Kim et al., 2005	ERN larger	NA	NA	RT not significantly different	Accuracy not significantly different	NA	NA
Masaki et al., 2017	ERN larger only for HSPA	NA	CRN not significantly different	RT not significantly different	Accuracy not significantly different	NA	ERN larger only for HSPA

Niu et al., 2023	ERN larger	NA	CRN not significantly different	RT not significantly different	Accuracy not significantly different	NA	ERN larger for higher FNE
Palmwood & Simons, 2021	ERN not significantly different	NA	NA	RT slower	Accuracy greater	PES not significantly different	NA
Schillinger et al., 2016	ERN not significantly different	ΔERN larger	NA	RT slower	Accuracy greater	NA	ERN not significantly different based on test anxiety
Voegler et al., 2018	ERN larger	NA	CRN not significantly different	RT not significantly different overall	Accuracy not significantly different	PES not significantly different	ERN not significantly different based on SAD

Note: All results boxes refer to the social condition(s) vs. the alone condition. For example, "ERN larger" indicates that the ERN was larger (more negative) in the social condition than in the alone condition. ERN indicates error-related negativity, CRN indicates correct-related negativity, ΔERN indicates the subtraction of the CRN from the ERN, RT indicates response time, PES indicates post-error slowing, HSA indicates high socially anxious, HSPA indicates high sport anxiety, SAD indicates Social Anxiety Disorder, NA indicates that the measure was not reported.

Error monitoring is increased under social observation

An examination of all studies reviewed suggests that social observation leads to a relatively consistent increase in the ERN (and/or ΔERN; see Table 4). That is, the majority of studies reviewed (eight out of eleven total studies) reported either a main effect of social observation increasing the ERN (five studies; Buzzell, Troller-Renfree, et al., 2017; Hajcak et al., 2005; Kim et al., 2005; Niu et al., 2023; Voegler et al., 2018), or an increase in the ERN under social observation when individual differences were further considered (three studies; Barker et al., 2015, 2018; Masaki et al., 2017). In terms of individual differences, social observation was found to influence the ERN as a function of social anxiety (Barker et al., 2015), sports/performance anxiety (Masaki et al., 2017), and age (Barker et al., 2018). There are also some deviations from the overall pattern of results. Two studies found no effect of social observation on the ERN (Palmwood & Simons, 2021; Schillinger et al., 2016), and one study found the ERN was smaller under social observation (Clayson et al., 2025).

When results for ΔERN are also considered, the evidence in favor of a consistent, overall effect of social observation on error monitoring is further strengthened. For example, the only study that reported a significantly *smaller* ERN under social observation (Clayson et al., 2025) also found that ΔERN was significantly *larger* under social observation. Similarly, of the two studies[1] finding no effect of social observation on the ERN, one of these studies (Schillinger et al., 2016) nonetheless reported a main effect of social observation increasing ΔERN. All three studies that examined the ΔERN (see Table 4) reported either a main effect of social observation increasing the ΔERN (Clayson et al., 2025; Schillinger et al., 2016) or an increase

[1] As reported in the text, two studies reported no effect of social observation on the ERN. One of these studies (Schillinger et al., 2016) nonetheless reported a main effect of social observation increasing ΔERN. It is also worth noting that the other study that reported a null effect (Palmwood & Simons, 2021) also reported that a difference score between the ERN from the social and nonsocial conditions ("social-effect ERN") was related to levels of partner unsupportiveness. However, we do not include this result in the main text or tables, given the primary focus on the ERN and ΔERN.

in the ΔERN under social observation when individual differences were considered (Barker et al., 2018). These findings point to the possibility that the relative difference between error- and correct-related neural activity (i.e., the ΔERN) may be particularly sensitive to the influence of social observation on error monitoring. However, given that only three studies examined the ΔERN, further research studying these associations are needed. Accordingly, for the remainder of this review, we focus primarily on results for the ERN, given that less data is available for assessing how social observation influences the ΔERN.

Taken together, the literature presents a largely consistent body of evidence to demonstrate that social observation enhances the ERN (and/or ΔERN). This evidence is summarized in Table 4. For ease of interpretation, study results are color coded in terms of the direction of effect. Studies reporting that the ERN (or ΔERN) was significantly larger (more negative) in the social condition are displayed in green, null effects are displayed in blue, and significant effects in the opposite direction (smaller ERN under social observation) are displayed in red. We further distinguish between studies reporting significant main effects of social observation (dark green), from those that only reported significant interactions that consider individual differences variables (light green). This choice of color coding reflects the notion that both main effects and interactions provide positive evidence that social observation influences the ERN, but main effects provide stronger evidence at the broader population level. That is, a significant main effect indicates strong positive evidence that social observation influences the ERN, on average. Interaction effects also provide positive evidence for the influence of social observation on the ERN, albeit only for a subset of individuals. Throughout the remainder of this review, we employ a similar color-coding scheme and logic to report and interpret all results of interest.

Table 4: ERN and ΔERN results

Journal article	ERN under social observation	ΔERN under social observation
Buzzell, Troller-Renfree, et al., 2017	ERN larger	NA
Hajcak et al., 2005	ERN larger	NA
Kim et al., 2005	ERN larger	NA
Niu et al., 2023	ERN larger	NA
Voegler et al., 2018	ERN larger	NA
Barker et al., 2015	ERN larger with interaction	ΔERN larger with interaction
Barker et al., 2018	ERN larger with interaction	NA
Masaki et al., 2017	ERN larger with interaction	NA
Palmwood & Simons, 2021	ERN not significantly different	NA
Schillinger et al., 2016	ERN not significantly different	ΔERN larger
Clayson et al., 2025	ERN smaller	ΔERN larger

Note: Results correspond to the comparison of the social observation vs. alone conditions. For example, "ERN larger" indicates that the ERN was larger (more negative) under social observation vs alone. Results are color-coded to denote direction of effect. Studies finding that the ERN (or ΔERN) was significantly larger in the social condition are displayed in green (main effects are displayed in dark green, whereas effects dependent on an interaction with individual differences are displayed in light green). Studies finding no significant effect of social observation are displayed in blue. Studies finding that the ERN was instead significantly smaller in the social observation condition are displayed in red. ERN indicates error-related negativity; ΔERN indicates the subtraction of the correct-related negativity (CRN) from the ERN, NA indicates that the measure was not reported.

The role of paradigm-related factors

Physical and virtual observation

Social contexts can be constructed in various ways, and it is possible that specific kinds of social observation paradigms more strongly impact error monitoring. Thus, we assessed how various paradigm-related factors might lead to differences in the observed effects on the ERN, beginning with a comparison of studies that employed physical or virtual observation. For this review, we describe “physical” observation as occurring when someone was in the room with the participant and “virtual” observation as someone watching from a separate location via a mirrored display screen or webcam. Our consideration of observation type (physical or virtual) includes both studies with and without deception (see the “Deception” section below for further details).

For the eight studies involving physical observation (see Table 5), the majority of studies found either a main effect of physical observation increasing the ERN (Hajcak et al., 2005; Kim et al., 2005; Niu et al., 2023; Voegler et al., 2018) or an increase in the ERN under physical observation when individual differences were further considered (e.g., high social anxiety or sports anxiety; Barker et al., 2015; Masaki et al., 2017). However, results for the other two studies involving physical observation were mixed. Specifically, Clayson et al. (2025) found smaller ERNs under physical observation in comparison to the ERN while alone. Palmwood and Simons (2021) found no difference between the ERN under physical observation vs. the alone condition. Nonetheless, it appears that overall, physical social observation typically results in a larger ERN, either as a main effect or based on individual differences.

Studies investigating the effects of virtual observation on the ERN are less common, with only three reported studies to date (Barker et al., 2018; Buzzell, Troller-Renfree, et al., 2017; Schillinger et al., 2016). Among these studies, a consistent main effect of virtual

observation on the ERN was not observed, as only Buzzell, Troller-Renfree et al. (2017) found an overall enhancement of the ERN under virtual observation. Barker et al. (2018) reported a greater ERN under virtual observation only for younger adolescents and Schillinger et al. (2016) found no difference in the ERN for the virtual social context vs. alone comparison. However, with so few virtual observation studies, conclusions about the effects of physical and virtual observation on the ERN are tentative. Studies that directly compare the effects of physical and virtual observation are needed, especially given the rising prevalence of online social situations (Lieberman & Schroeder, 2020).

Table 5: The effects of physical and virtual observation

Journal article	Observation type	ERN under social observation
Hajcak et al., 2005	Physical	ERN larger
Kim et al., 2005	Physical	ERN larger
Niu et al., 2023	Physical	ERN larger
Voegler et al., 2018	Physical	ERN larger
Barker et al., 2015	Physical	ERN larger with interaction
Masaki et al., 2017	Physical	ERN larger with interaction
Palmwood & Simons, 2021	Physical	ERN not significantly different
Clayson et al., 2025	Physical	ERN smaller
Buzzell, Troller-Renfree, et al., 2017	Virtual	ERN larger
Barker et al., 2018	Virtual	ERN larger with interaction
Schillinger et al., 2016	Virtual	ERN not significantly different

Note: Results correspond to the comparison of the social observation vs. alone conditions. For example, “ERN larger” indicates that the ERN was larger (more negative) under social observation vs alone. Results are color-coded to denote direction of effect. Studies with physical observation are displayed in dark gray and those with virtual observation are displayed in light gray. Studies finding that the ERN was significantly larger in the social condition are displayed in green (main effects are displayed in dark green, whereas effects dependent on an interaction with individual differences are displayed in light green). Studies finding no significant effect of social observation are displayed in blue. Studies finding that the ERN was instead significantly smaller in the social observation condition are displayed in red. ERN indicates error-related negativity.

Finer methodological/paradigm differences among the studies that employed physical observation also require further consideration and investigation. For example, Voegler and colleagues (2018) note that the physical presence of an observer could imply observation of the physiological consequences of making a mistake (i.e., blushing, trembling, and blinking following error commission). In line with this idea, the assumed social consequences of making mistakes under observation might be more readily apparent under physical observation conditions, in turn increasing the motivational significance of making an error. Similarly, error significance may be affected by the location/orientation of the observer in relation to the participant. Indeed, closer interpersonal distance in a virtual reality setting has been rated as more arousing and less pleasant (Kroczek et al., 2020), and those with social anxiety disorder perceive strangers to be physically closer than they really are (Givon-Benjio et al., 2020). However, among the physical observation studies in this review, only Hajcak et al. (2005) reported the relative distance of the observer from the participant (0.5 meters). In contrast, the relative orientation of the observer was more frequently reported in the reviewed studies. Thus, we further categorized the physical observation studies in terms of whether the observer was: 1) seated next to the participant, or 2) seated behind the participant (Table 6). Based on the limited number of studies assessed, it appears that error monitoring is more consistently increased when the observer is seated to the side vs. behind the participant.

Among the four studies in which the observer was seated beside the participant, two of these studies reported main effects of social observation increasing the ERN (Niu et al., 2023; Voegler et al., 2018), one reported an increase in the effect of social context on the ERN for individuals high in social anxiety symptoms (Barker et al., 2015), and one reported no effect of social observation on the ERN (Palmwood and Simons, 2021). In contrast, for the two studies in which the observer was seated behind the participant, only one study (Masaki et al., 2017) reported an increase in the ERN under social observation–and only for individuals high in performance/sports anxiety. The second study in which the observer was seated behind the

participant reported smaller ERNs under social observation (Clayson et al., 2025). To summarize, although there are currently too few studies to draw strong conclusions regarding how the relative spatial orientation of the observer impacts the effect of social observation on the ERN, current studies suggest that the impact of social observation may be more prominent when the observer is seated beside the participant. Future studies should be careful to provide details regarding the position of the observer, relative to the participant, as well as consider direct manipulations of observer distance/spatial orientation.

Table 6: The effects of observer location

Journal article	Observation Type	Observer location	ERN under social observation
Niu et al., 2023	Physical	To side	ERN larger
Voegler et al., 2018	Physical	To side	ERN larger
Barker et al., 2015	Physical	To side	ERN larger with interaction
Palmwood & Simons, 2021	Physical	To side	ERN not significantly different
Masaki et al., 2017	Physical	Behind	ERN larger with interaction
Clayson et al., 2025	Physical	Behind	ERN smaller
Kim et al., 2005	Physical	Not specified	ERN larger
Hajcak et al., 2005	Physical	Not specified	ERN larger

Note: Results correspond to the comparison of the social observation vs. alone conditions. For example, "ERN larger" indicates that the ERN was larger (more negative) under social observation vs alone. Results are color-coded to denote direction of effect. Studies where the observer was located to the right or left of the participant are displayed in dark gray, studies where the observer was behind the participant are displayed in light gray, and those that did not report the location of the observer are displayed in white. Studies finding that the ERN was significantly larger in the social condition are displayed in green (main effects are displayed in dark green, whereas effects dependent on an interaction with individual differences are displayed in light green). Studies finding no significant effect of social observation are displayed in blue. Studies finding that the ERN was instead significantly smaller in the social observation condition are displayed in red. ERN indicates error-related negativity.

Deception

The use of deception is relatively common in social neuroscience/psychology studies and can take various forms (Hertwig & Ortmann, 2008; Olson & Raz, 2021). To assess the possible impacts of deception in this review, we considered any form of deception, including deception about who the observer was, why they were observing the participant, or whether there was even an observer at all. Interestingly, the effects of social observation on the ERN were more varied among the seven studies that did *not* utilize deception (Clayson et al., 2025; Hajcak et al., 2005; Kim et al., 2005; Masaki et al., 2017; Palmwood & Simons, 2021; Schillinger et al., 2016), compared to the five studies that *did* utilize deception (Barker et al., 2015, 2018; Buzzell, Troller-Renfree, et al., 2017; Niu et al., 2023; Voegler et al., 2018). General enhancements of the ERN under social observation were found among all studies that employed deception. However, among the seven studies without deception, only Hajcak et al. (2005) and Kim et al. (2005) reported main effects of social observation increasing the ERN, while Masaki et al. (2017) reported a larger ERN under social observation only for individuals high in performance/sports anxiety symptoms. Further, two of the studies without deception reported no significant effects of social observation on the ERN (Palmwood & Simons, 2021; Schillinger et al., 2016) and one study reported smaller ERNs under social observation (Clayson et al., 2025).

One possibility is that the wider variety of results for studies without deception arises from greater diversity in the social observation paradigms employed for these studies (See Table 7). For example, three of the studies without deception incorporated an observer that was familiar to the participant (romantic partner, Palmwood & Simons, 2021; marital spouse, Clayson et al., 2025; classmate, Kim et al., 2005), whereas none of the studies using deception employed a familiar observer. It is possible that the effects of social observation could differ for a familiar vs. unfamiliar observer (i.e., social buffering of stress; Kikusui et al., 2006). However,

it is also worth noting that Clayson et al. (2025) included two conditions with social observation– one involving a familiar observer (spouse) and one involving an unfamiliar observer (research assistant)–and the ERN was smaller under social observation (vs. the alone condition), regardless of familiarity of the observer. A second way in which the studies without deception exhibited greater diversity in methods was the use of an authority figure as an observer. Four out of the seven paradigms without deception employed an authority figure as the observer (Clayson et al., 2025; Hajcak et al., 2005; Masaki et al., 2017; Schillinger et al., 2016), whereas only one out of the five non-deception studies employed an authority figure (Voegler et al., 2018). Nonetheless, it remains unclear whether the presence of an authority figure impacts the effect of social observation on the ERN (see the section below, entitled “Authority”).

Another potential explanation for why the studies with deception exhibited a more consistent effect of social observation increasing the ERN could be that studies using deception typically also employ a higher level of experimental control over the social observation paradigm. That is, a confederate may have strict protocols/scripts to follow while interacting with participants in order to either to prevent the participant from discovering the deception and/or to keep methods similar across participants. For example, Niu and colleagues (2023) explicitly mention that they trained their confederates to greet and make eye contact with participants, but to limit conversation and refrain from making additional comments during the experiment. Likewise, when the presence of the observer is simulated, like in the shared paradigm of Buzzell, Troller-Renfree, et al. (2017) and Barker et al. (2018), the “observers” always provide the same feedback scripts based on performance. Although structured interactions between participants and observers are not unique to deception paradigms, these interactions are likely more uniform than in non-deception paradigms. Taken together, it is possible that the effects of deception vs. no deception on relations between social observation and the ERN arise from factors other than deception– such as differences in the level of experimental control among deception vs. non-deception studies.

Table 7: The effects of deception

Journal article	Deception	ERN under social observation	Familiar observer	Authority figure
Buzzell, Troller-Renfree, et al., 2017	Deception	ERN larger	-	-
Niu et al., 2023	Deception	ERN larger	-	-
Voegler et al., 2018	Deception	ERN larger	-	Present
Barker et al., 2015	Deception	ERN larger with interaction	-	-
Barker et al., 2018	Deception	ERN larger with interaction	-	-
Hajcak et al., 2005	No deception	ERN larger	-	Present
Kim et al., 2005	No deception	ERN larger	Present	-
Masaki et al., 2017	No deception	ERN larger with interaction	-	Present
Palmwood & Simons, 2021	No deception	ERN not significantly different	Present	-
Schillinger et al., 2016	No deception	ERN not significantly different	-	Present
Clayson et al., 2025 (Spouse observer)	No deception	ERN smaller	Present	-
Clayson et al., 2025 (Experimenter observer)	No deception	ERN smaller	-	Present

Note: Results correspond to the comparison of the social observation vs. alone conditions. For example, "ERN larger" indicates that the ERN was larger (more negative) under social observation vs alone. Results are color-coded to denote direction of effect. Studies in which deception was present are displayed in dark gray and studies in which no deception was present are displayed in light gray. Studies finding that the ERN was significantly larger in the social condition are displayed in green (main effects are displayed in dark green, whereas effects dependent on an interaction with individual differences are displayed in light green). Studies finding no significant effect of social observation are displayed in blue. Studies finding that the ERN was instead significantly smaller in the social observation condition are displayed in red. ERN indicates error-related negativity and Present indicates that the paradigm contained that factor (e.g., an observer that was familiar to the participant).

Authority

The presence of an authority figure or expert observer could motivate participants to respond in ways that they believe are more favorable to the authority/expert (Nichols & Maner, 2008). Indeed, prior work demonstrates that such a presence can improve behavioral performance on simple tasks (Bond & Titus, 1983; Claypoole & Szalma, 2017) or lead to higher levels of anxiety and negative affect (Claypoole & Szalma, 2017). Collectively, this work suggests that the presence of an authority figure may influence the importance of doing well on a task and therefore increase the significance of errors. In the current review, we assessed this possibility, defining observers as authority figures when they were introduced as being in charge of the experiment or having some level of expertise in the task or scenario.

Based on the studies reviewed, the presence of an authority figure does not seem to yield more consistent effects of social observation on the ERN (See Table 8). Among the five studies involving an authority figure, two reported a main effect of social observation increasing the ERN (Hajcak et al., 2005; Voegler et al., 2018), one identified larger ERNs under social observation only for individuals high in sports anxiety (Masaki et al., 2017), one reported no effect of social observation on the ERN (Schillinger et al., 2016), and one reported smaller ERNs under social observation (Clayson et al., 2025). Similarly, among the seven studies that did not involve an authority figure, three studies reported greater ERNs under social observation (Buzzell, Troller-Renfree, et al., 2017; Kim et al., 2005; Niu et al., 2023), two reported greater ERNs under social observation only for certain groups (high anxiety and younger adolescent girls, respectively; Barker et al., 2015, 2018), one reported no effect of social observation on the ERN (Palmwood & Simons, 2021), and one reported a smaller ERN under social observation (Clayson et al., 2025). Here, it is worth noting again that Clayson et al. (2025) reported on two social observation conditions, one with the participant's spouse observing and one with a member of the research team observing (authority figure). Taken together, and based on the

limited evidence to date, there does not appear to be a systematic modulation of the effect of social observation on the ERN based on whether an authority figure served as the observer or not.

Table 8: The effects of authority

Journal article	Authority	ERN under social observation
Hajcak et al., 2005	Yes	ERN larger
Voegler et al., 2018	Yes	ERN larger
Masaki et al., 2017	Yes	ERN larger with interaction
Schillinger et al., 2016	Yes	ERN not significantly different
Clayson et al., 2025 (Experimenter observer)	Yes	ERN smaller
Buzzell, Troller-Renfree, et al., 2017	No	ERN larger
Kim et al., 2005	No	ERN larger
Niu et al., 2023	No	ERN larger
Barker et al., 2015	No	ERN larger with interaction
Barker et al., 2018	No	ERN larger with interaction
Palmwood & Simons, 2021	No	ERN not significantly different
Clayson et al., 2025 (Spouse observer)	No	ERN smaller

Note: Results correspond to the comparison of the social observation vs. alone conditions. For example, “ERN larger” indicates that the ERN was larger (more negative) under social observation vs alone. Results are color-coded to denote direction of effect. Studies in which the observer was presented as an authority figure are displayed in dark gray and studies in which the observer was not an authority figure are displayed in light gray. Studies finding that the ERN was significantly larger in the social condition are displayed in green (main effects are displayed in dark green, whereas effects dependent on an interaction with individual differences are displayed in light green). Studies finding no significant effect of social observation are displayed in blue. Studies finding that the ERN was instead significantly smaller in the social observation condition are displayed in red. ERN indicates error-related negativity.

Feedback

Based on prior literature suggesting that task feedback can influence motivation (Gehring & Willoughby, 2002; Masaki et al., 2006), we might expect the presence of feedback to interact with social observation to further increase the motivational significance of errors. Moreover, prior work has demonstrated that a related ERP component, the feedback-related negativity (FRN), is enhanced under social observation (Huang & Yu, 2018; Tian et al., 2015). To this end, we assessed the presence of task feedback in the reviewed studies, as well as further consideration of whether feedback was presented at the trial- vs. block-level.

Tentatively, it appears that the presence of feedback may enhance the effect of social observation on the ERN (see Table 9). Among the seven studies that utilized feedback (trial- or block-level), six reported greater ERNs under social observation either as a main effect of social observation (Buzzell, Troller-Renfree, et al., 2017; Kim et al., 2005; Niu et al., 2023; Voegler et al., 2018) or when individual differences were further considered (e.g., high social anxiety and younger adolescent girls; Barker et al., 2015, 2018). Only one of the seven studies employing feedback reported no differences between ERNs under social observation vs. alone (Schillinger et al., 2016). Of note, both of the two studies that specifically employed trial-level feedback (Kim et al., 2005; Voegler et al., 2018) reported a significant main effect of social observation increasing the ERN. Conversely, among the four studies that did not include any form of feedback, only Hajcak et al. (2005) reported a main effect of social observation increasing the ERN, whereas Masaki et al. (2017) found a greater ERN under social observation only for those with high sports anxiety. The other two studies that did not employ feedback reported either no effect of social observation on the ERN (Palmwood & Simons, 2021) or smaller ERNs under social observation (Clayson et al., 2025).

To summarize, the effect of social observation on the ERN appears to be more consistent for studies that include feedback, compared to those that do not, and this is

especially the case for studies involving trial-level feedback. A meta-analysis by Buzzell et al. (2024) supports this idea, as they reported that associations between anxiety and the ERN (albeit not under social observation) were increased twofold by the presence of block-level feedback. Buzzell et al. (2024) discuss the possibility of feedback acting as a quasi-social context, where participants are reminded that their performance is being evaluated. Therefore, one possible interpretation for the findings of the current review is that the presence of feedback serves to increase the effect of social observation on the ERN by providing a reminder of the social context of observation. However, further work is needed to draw strong conclusions regarding how feedback influences the effect of social observation on the ERN. Feedback is traditionally contingent on performance and therefore poses a confound between feedback and performance. Thus, studies that directly manipulate the presence/absence and frequency/type of feedback, in a manner that is independent from behavioral performance, are needed to further clarify the impact of feedback on social observation and the ERN.

Table 9: The effects of feedback

Journal article	Feedback	ERN under social observation
Kim et al., 2005	Trial-level	ERN larger
Voegler et al., 2018	Trial-level	ERN larger
Buzzell, Troller-Renfree, et al., 2017	Block-level	ERN larger
Niu et al., 2023	Block-level	ERN larger
Barker et al., 2015	Block-level	ERN larger with interaction
Barker et al., 2018	Block-level	ERN larger with interaction
Schillinger et al., 2016	Block-level	ERN not significantly different
Hajcak et al., 2005	None	ERN larger
Masaki et al., 2017	None	ERN larger with interaction
Palmwood & Simons, 2021	None	ERN not significantly different
Clayson et al., 2025	None	ERN smaller

Note: Results correspond to the comparison of the social observation vs. alone conditions. For example, “ERN larger” indicates that the ERN was larger (more negative) under social observation vs alone. Results are color-coded to denote direction of effect. Studies in which feedback was given after each trial are displayed in dark gray, studies in which feedback was given after each block of trials are displayed in light gray, and studies without feedback are displayed in white. Studies finding that the ERN was significantly larger in the social condition are displayed in green (main effects are displayed in dark green, whereas effects dependent on an interaction with individual differences are displayed in light green). Studies finding no significant effect of social observation are displayed in blue. Studies finding that the ERN was instead significantly smaller in the social observation condition are displayed in red. ERN indicates error-related negativity.

The role of individual factors

Anxiety

We turn now to an exploration of how individual factors (i.e., individual differences) might influence the effects of social observation. We begin by first considering the potential role of individual differences in anxiety. To date, studies investigating how individual differences in anxiety might influence the effect of social observation on the ERN have focused on social/performance anxiety and related symptom domains or traits. Thus, we first review the influence of any form of social/performance anxiety, broadly defined, on the relationship between the ERN and social observation. Our review included: 1) studies that assessed global measures of social anxiety (dimensionally, Barker et al, 2015; clinically, Voegler et al., 2018), 2) studies that assessed fear of negative evaluation (FNE), a core symptom domain of social anxiety (Niu et al., 2023; this study additionally assessed global social anxiety symptoms); 3) studies that assessed behavioral inhibition (BI), a temperament trait that predicts social anxiety disorder (Buzzell, Troller-Renfree, et al., 2017; this study additionally assessed global social anxiety symptoms); and 4) studies that assessed specific forms of performance anxiety (sports anxiety, Masaki et al., 2017; test anxiety, Schillinger et al., 2016).

In the assessment of how social/performance anxiety influences relations between social observation and the ERN, four out of six studies reported at least partial evidence that increases in social/performance anxiety, broadly defined, were associated with stronger effects of social observation on the ERN (see Table 10). Specifically, two of the six studies reported interactions between social/performance anxiety and social observation, such that the ERN was enhanced under social observation for individuals high in social/performance anxiety (high social anxiety, Barker et al., 2015; high sports anxiety, Masaki et al., 2017). An additional two of the six studies identified no significant relations between global social anxiety symptoms and the ERN under social observation, but nonetheless found that FNE (Niu et al., 2023) and BI

(Buzzell, Troller-Renfree, et al., 2017) were each related to an enhanced ERN under social observation. Finally, the last two of six studies (Schillinger et al., 2016; Voegler et al., 2018) did not find any effects of social/performance anxiety on relations between social observation and the ERN.

Overall, we found that social/performance anxiety, broadly construed, was often associated with an enhanced ERN under social observation, albeit findings were mixed. However, relatively recent work has demonstrated that an enhanced ERN under social observation might be more closely associated with the specific symptom domain of FNE, as opposed to other social/performance anxiety symptoms more generally (Niu et al., 2023). Thus, future studies should further investigate the influence of FNE levels, in particular, on the relationship between the ERN and social observation.

Table 10: The effects of anxiety

Journal article	Anxiety x ERN under social observation
Barker et al., 2015	ERN larger only for high social anxiety symptoms
Masaki et al., 2017	ERN larger only for high sport anxiety symptoms
Buzzell, Troller-Renfree, et al., 2017	Increased BI related to larger social effect residualized ERN
Niu et al., 2023	Increased FNE related to larger ERN in social context
Schillinger et al., 2016	ERN not different based on text anxiety scores
Voegler et al., 2018	ERN not different based on SAD

Note: Results correspond to the comparison of the social observation vs. alone conditions. For example, "ERN larger" indicates that the ERN was larger (more negative) under social observation vs alone. Results are color-coded to denote direction of effect. Studies in which the ERN in social conditions was associated with anxiety or a related measure are displayed in gray and studies in which the ERN in social conditions was not associated with a measure of anxiety are displayed in white. ERN indicates error-related negativity, FNE indicates fear of negative evaluation, SAD indicates Social Anxiety Disorder, and BI indicates behavioral inhibition.

Age

Adolescent development is characterized by a greater awareness of the social world and an increase in social-evaluative concerns (Blakemore & Mills, 2014; Somerville, 2013), including increases in FNE (Nelemans et al., 2019; Westenberg et al., 2007). Consequently, adolescents (in comparison to adults) have been shown to exhibit increased neural activity associated with socio-affective processing activity when placed into social-evaluative contexts (Somerville, 2013; Somerville et al., 2013; Westenberg et al., 2007). At the same time, the ERN also exhibits protracted development throughout adolescence and into adulthood (Davies et al., 2004). For

these reasons, we also assessed whether the effects of social observation on the ERN differ across studies involving youth vs. adults (Table 11).

Only four studies have investigated the effects of social observation on the ERN in youth. Nonetheless, all four studies identified an effect of social observation increasing the ERN, either as a main effect of social observation (Buzzell, Troller-Renfree, et al., 2017; Kim et al., 2005; Niu et al., 2023) or for a specific age range of youth participants (Barker et al., 2018). Specifically, main effects of social observation enhancing the ERN were observed in the studies by Buzzell and colleagues (2017) among 13-year-olds, Kim and colleagues (2005) among youth 7-12 years old, and Niu and colleagues (2023) among youth aged 15-19 years old. For the study by Barker and colleagues (2018), within a sample of youth 8-17 years old, an interaction revealed that social observation increased the ERN, specifically among younger adolescents. The findings of Barker et al. (2018) are somewhat inconsistent with the findings of Niu et al. (2023), which reported a main effect of social observation increasing the ERN in older adolescents. However, this discrepancy might be explained by the fact that Barker et al. (2018) employed a female-only sample, whereas Niu et al. (2023) employed a sample of males and females. On average, females exhibit: 1) an earlier onset of puberty/adolescence (Negriff & Susman, 2011), 2) accelerated social development (Keenan & Shaw, 1997), and 3) greater adolescent increases in social-evaluative concerns and FNE relative to males (Nelemans et al., 2019; Rudolph & Conley, 2005). Such peri-adolescent differences among males and females may therefore explain why Barker and colleagues (2018) observed a selective effect of social observation on the ERN for younger adolescents in their all-female sample. Nonetheless, an expansion of studies that examine how sex and puberty may further moderate relations between age, social observation and the ERN are needed in order to draw firm conclusions.

Although the majority of studies conducted using either youth or adult samples observed an overall effect of social observation increasing the ERN, the effects of social observation on the ERN were far more consistent among youth vs. adult samples. As reviewed above, all four

studies in youth reported an effect of social observation increasing the ERN. In contrast, of the seven adult studies reviewed, only four of the seven adult studies reported an effect of social observation increasing the ERN (Barker et al., 2015; Hajcak et al., 2005; Masaki et al., 2017; Voegler et al., 2018). Importantly, two of these adult studies that observed an effect of social observation increasing the ERN only found such an effect for individuals high in social/performance anxiety. Moreover, the remaining three studies conducted in adults reported either no effect of social observation on the ERN (Palmwood & Simons, 2021; Schillinger et al., 2016).

Thus, while both youth and adult studies report an effect of social observation enhancing the ERN, such effects appear to be more consistent within youth samples. One potential explanation for this difference between youth and adults is that the increased consistency of social observation effects observed in youth is a result of the normative increase in social concerns that characterizes adolescence. As previously mentioned, social concerns and FNE peak during the peri-adolescent window before subsiding to adult levels (Nelemans et al., 2019). As a result, main effects of social observation on the ERN may be more commonly observed during adolescence (when there is a normative increase in social fears/worries), but that in adulthood, such effects are less prevalent in the general population and therefore more dependent on consideration of individual differences in social/performance anxiety as well (e.g., Barker et al., 2015; Masaki et al., 2017). Future longitudinal investigations could be particularly informative.

Table 11: The effects of age

Journal article	Age	Age range	ERN under social observation
Buzzell, Troller-Renfree, et al., 2017	Youth	*M* = 13.8	ERN larger
Kim et al., 2005	Youth	7 - 11	ERN larger
Niu et al., 2023	Youth	15.68 - 17.91	ERN larger
Barker et al., 2018	Youth	8.67 - 17.14	ERN larger only for younger adolescents
Hajcak et al., 2005	Adult	Undergraduates, age not reported	ERN larger
Voegler et al., 2018	Adult	SAD: *M* = 24.73, HC: *M* = 23.00	ERN larger
Barker et al., 2015	Adult	HSA: *M* = 19.77, LSA: *M* = 19.51	ERN larger with interaction
Masaki et al., 2017	Adult	HSPA: *M* = 20.5; LSPA: *M* = 21.4	ERN larger with interaction
Palmwood & Simons, 2021	Adult	*M* = 19.04	ERN not significantly different
Schillinger et al., 2016	Adult	18 - 32, *M* = 21.06	ERN not significantly different
Clayson et al., 2025	Adult	Female: *M* = 24, male: *M* = 25	ERN smaller

Note: Results correspond to the comparison of the social observation vs. alone conditions. For example, "ERN larger" indicates that the ERN was larger (more negative) under social observation vs alone. Results are color-coded to denote direction of effect. Studies with a youth sample are displayed in dark gray, and studies with an adult sample are displayed in light gray. Studies finding that the ERN was significantly larger in the social condition are displayed in green (main effects are displayed in dark green, whereas effects dependent on an interaction with individual differences are displayed in light green). Studies finding no significant effect of social observation are displayed in blue. Studies finding that the ERN was instead significantly smaller in the social observation condition are displayed in red. ERN indicates error-related negativity. HSA indicates high socially anxious, LSA indicates low socially anxious group, HSPA indicates high sport anxiety, LSPA indicates low sport anxiety, SAD indicates Social Anxiety Disorder, and HC indicates healthy controls.

Additional considerations

In this section, we provide a selective review of the effects of social observation on: 1) the correct-related negativity (CRN), 2) additional error-related neural measures (midfrontal theta oscillations and fMRI blood oxygenation level dependent activity), and 3) behavioral measures (response time and accuracy).

CRN

Often studied alongside the ERN, the CRN is an additional ERP component that emerges following correct responses, which may be indicative of more general performance monitoring processes that also occur on correct trials (Suchan et al., 2007; Vidal et al., 2003). Out of the seven reviewed studies that directly tested/reported possible effects of social observation on the CRN, we find that studies are relatively consistent in *not* finding an effect of social observation on the CRN. That is, five of the seven studies investigating the CRN reported no effect of social observation (Barker et al., 2015, 2018; Hajcak et al., 2005; Masaki et al., 2017; Niu et al., 2023), one study reported a trend towards the CRN being decreased in amplitude (smaller) under social observation (Voegler et al., 2018), and only one of the seven studies reported an enhanced CRN under social observation (Buzzell, Troller-Renfree, et al., 2017). However, it is also worth noting that because the ΔERN reflects a subtraction of the ERN from the CRN, studies that assess whether the ΔERN is impacted by social observation provide insight into whether relative differences between the ERN and CRN are impacted by social observation. Of note, two of the reviewed studies (Clayson et al., 2025; Schillinger et al., 2016) did not observe increases in the ERN under social observation, but nonetheless found that the ΔERN was enhanced by social observation. Taken together, the literature consistently does not find an effect of social observation on the CRN on its own, however, initial evidence indicates that social observation may nonetheless impact relative differences between the ERN and CRN,

in addition to the previously reviewed effects of social observation on the ERN. Further work is needed to clarify the effects of social observation on relative differences between the ERN and CRN.

Additional error-related neural measures

Here, we briefly discuss related findings from studies that have assessed the effects of social observation on other error-related neural measures associated with error monitoring. Prior work demonstrates that the commission of errors is associated not only with an ERN (Falkenstein et al., 1991; Gehring et al., 1993), but also an increase in the strength (power) and consistency (phase alignment) of theta (~4-8 Hz) oscillations recorded over the midfrontal scalp (Cavanagh et al., 2009). Studying error-related midfrontal theta dynamics in adolescents under social observation (vs. alone), Buzzell et al. (2019) reported that error-related midfrontal theta power is significantly increased under social observation. Employing fMRI, Smith et al. (2019) also investigated the effects of social observation on error-related neural activity. The authors found that social observation interacted with response accuracy and social anxiety predicted enhanced error-related activation within the pregenual anterior cingulate cortex (pgACC) while under social observation (Smith et al., 2019). Importantly, other work has implicated the ACC in error-processing (Swick & Turken, 2002; van Noordt & Segalowitz, 2012) and source modeling work demonstrates that the ACC is a source of the ERN signal (Buzzell, Richards, et al., 2017; Conte et al., 2023). Taken together, the literature indicates that social observation typically elicits an increase in error-related neural activity, whether such activity is indexed via the ERN (Table 4), midfrontal theta oscillations (Buzzell et al., 2019), or fMRI BOLD activity within the ACC (Smith et al., 2019).

Behavioral findings

To further contextualize the effects of social observation on the ERN, we additionally considered potential changes in task behavior for the eleven ERN studies reviewed (see Table 12). Given that all eleven studies reported response time (RT) and accuracy, we focused on these two behavioral metrics in our review. Overall, findings were mixed in terms of whether social observation impacts RT, whereas effects on accuracy were consistently not found (except in two cases, when corresponding RT slowing was observed). Specifically, three of the eleven studies reported faster RT under social observation (Barker et al., 2018; Buzzell, Troller-Renfree, et al., 2017; Clayson et al., 2025), two of the eleven studies reported slower RT under social observation (Palmwood & Simons, 2021; Schillinger et al., 2016), and six reported no effects of social observation on RT (Barker et al., 2015; Hajcak et al., 2005; Kim et al., 2005; Masaki et al., 2017; Niu et al., 2023; Voegler et al., 2018). Of note, the only two studies that reported slower RT under social observation were also the only two studies to report any changes in accuracy under social observation (increased accuracy; Palmwood & Simons, 2021; Schillinger et al., 2016).

Table 12: Response time and accuracy results

Journal article	RT results under social observation	Accuracy results under social observation
Barker et al., 2018	RT faster	Accuracy not significantly different
Buzzell, Troller-Renfree, et al., 2017	RT faster	Accuracy not significantly different
Clayson et al., 2025	RT faster	NA
Palmwood & Simons, 2021	RT slower	Accuracy greater
Schillinger et al., 2016	RT slower	Accuracy greater
Barker et al., 2015	RT not significantly different	Accuracy not significantly different
Hajcak et al., 2005	RT not significantly different	Accuracy not significantly different
Kim et al., 2005	RT not significantly different	Accuracy not significantly different
Masaki et al., 2017	RT not significantly different	Accuracy not significantly different
Niu et al., 2023	RT not significantly different	Accuracy not significantly different
Voegler et al., 2018	RT not significantly different	Accuracy not significantly different

Note: Results correspond to the comparison of the social observation vs. alone conditions. For example, "RT faster" indicates that response times were faster (shorter) in the social context than in the alone context. Results are color-coded to denote direction of effect. Studies finding that RT or accuracy were significantly faster/greater in the social condition are displayed in green. Studies finding no significant effect of social observation are displayed in blue. Studies finding that RT was instead significantly slower in the social observation condition are displayed in red. RT indicates response time and NA indicates that the measure was not reported.

Given the observed variability in terms of how social observation appears to impact RT across studies, we further assessed whether the effects of social observation on the ERN consistently differ based on the accompanying pattern of behavior observed for each study (see Table 13). Overall, this analysis revealed that social observation more consistently led to an

increase in the ERN for studies that did not observe corresponding changes in RT. Specifically, for the six studies that reported no social observation effects for RT, the ERN was consistently increased under social observation either as a main effect (Hajcak et al., 2005; Kim et al., 2005; Niu et al., 2023; Voegler et al., 2018) or at least for participants high in social/performance anxiety (Barker et al., 2015; Masaki et al., 2017). In contrast, only one of the three studies reporting faster RTs under social observation also reported a significant main effect of social observation increasing the ERN (Buzzell, Troller-Renfree, et al., 2017). For the other two of three studies reporting faster RTs, one reported a significant increase in the ERN under social observation only for the younger participants (Barker et. al., 2018), and the other reported smaller ERNs under social observation (Clayson et. al, 2025). Finally, for the two studies reporting *slower* RTs (and increased accuracy) under social observation, no significant effect of social observation on the ERN was observed (Palmwood & Simons, 2021; Schillinger et al., 2016), although one of these two studies reporting slower RTs under social observation did report an increase in the ΔERN under social observation (Shillinger et al., 2016). Collectively, these data suggest that the likelihood of observing an effect of social observation on the ERN may be dependent on accompanying behavioral findings (or vice versa), with social observation effects on the ERN being less consistent when observation-related changes in RT are also present. Future research should further investigate inter-relations between social observation, the ERN, and associated behavioral dynamics.

Table 13: Response time and ERN results

Journal article	RT results under social observation	ERN results under social observation
Buzzell, Troller-Renfree, et al., 2017	RT faster	ERN larger
Barker et al., 2018	RT faster	ERN larger with interaction
Clayson et al., 2025	RT faster	ERN smaller
Palmwood & Simons, 2021	RT slower	ERN not significantly different
Schillinger et al., 2016	RT slower	ERN not significantly different
Hajcak et al., 2005	RT not significantly different	ERN larger
Kim et al., 2005	RT not significantly different	ERN larger
Niu et al., 2023	RT not significantly different	ERN larger
Voegler et al., 2018	RT not significantly different	ERN larger
Barker et al., 2015	RT not significantly different	ERN larger with interaction
Masaki et al., 2017	RT not significantly different	ERN larger with interaction

Note: Results correspond to the comparison of the social observation vs. alone conditions. For example, "ERN larger" indicates that the ERN was larger (more negative) under social observation vs alone. Results are color-coded to denote direction of effect. Studies finding that the RT or accuracy were significantly faster in the social condition are displayed in dark gray. Studies finding that the RT was instead significantly slower in the social observation condition are displayed in light gray. Studies finding no significant effect of social observation are displayed in white. Studies finding that the ERN was significantly larger in the social condition are displayed in green (main effects are displayed in dark green, whereas effects dependent on an interaction with individual differences are displayed in light green). Studies finding no significant effect of social observation are displayed in blue. Studies finding that the ERN was instead significantly smaller in the social observation condition are displayed in red. RT indicates response time and ERN indicates error-related negativity.

Summary

In this review, we assessed the effect of social observation on the ERN. The ERN is, in general, enhanced under social observation versus while alone, so we investigated how paradigm-related factors and individual differences may influence this effect. Furthermore, we considered the impact of social observation on the CRN, other error-related neural measures, and behavior.

First, we examined the effects of four paradigm-related factors– physical and virtual observation, presence of deception, presence of an authority figure, and presence of feedback– on the relations between the ERN and social observation. The majority of studies with physical observation reported increases in ERN under social observation. A further breakdown of observer location suggests that observers sitting to the side of the participant (as opposed to behind) may be associated with more consistent increases of the ERN under physical observation. Under virtual observation, there are some increases in the ERN, but more studies are necessary. The comparison between studies with and without deception in their paradigms yielded a clearer pattern; all five studies with deception reported enhanced ERNs under social observation, while the seven without deception contained much more variability in results. We posit that this pattern could be due to the decreased diversity of methods in the studies with deception and/or the greater level of experimental control inherently present in paradigms that utilize deception (e.g., defined interactions between observers and participants). Studies that utilized trial-level or block-level feedback generally showed greater ERNs under social observation, while studies that did not have a form of feedback were less consistent in their results. Unlike the other paradigm-related factors, the presence of an authority figure does not appear to impact relations between the ERN and social observation.

Second, we investigated the effects of individual differences in anxiety and age on the relations between the ERN and social observation. When examining any form of

social/performance anxiety, including related symptom domains and traits, four of the six studies reported an anxiety-related enhancement in the ERN under social observation. In regards to age, all four youth studies reviewed showed an increase in the ERN under social observation, while the effects in adults were more mixed. This age-related pattern may be due to an increase in social concerns and FNE peaking in peri-adolescence.

Third, we considered the impact of social observation on the CRN, additional measures of error-related neural activity, and behavior. While the CRN by itself does not appear to be affected by social observation, the relative difference between the ERN and CRN (ΔERN) may be impacted by social observation. Additionally, findings that social observation also increases other error-related neural measures, namely error-related midfrontal theta power and fMRI BOLD activation within the pgACC, are broadly consistent with the reviewed effects of social observation on the ERN. Patterns among the reviewed behavioral measures were less clear. Nonetheless, we tentatively suggest that the likelihood of observing an effect of social observation on the ERN is inversely associated with the likelihood of observing a significant effect of social observation on behavior.

Recommendations for future studies

In this section we provide recommendations for future research in an effort to better understand the precise factors that impact relations between the ERN and social observation. As previously mentioned in the physical and virtual observation section, more studies employing virtual observation, as well as studies that directly compare physical and virtual observation, are necessary to determine whether these two forms of observation differ in their effects on the ERN. Voegler and colleagues (2018) discuss the possibility that task-focused social observation (i.e., specifically monitoring only the participant's speed and accuracy of responses) may differentially impact the ERN relative to general social observation in which both the participant

and their task performance are monitored. For example, paradigms that incorporate general social observation might elicit additional worries about physiological responses to errors (e.g., blushing or blinking) and drive stronger error-monitoring responses under general social observation, relative to task-focused social observation (Voegler et al., 2018). Crucially, in a virtual observation paradigm, the visual view of the participant and observer are restricted to the size, video quality, and location of the device, and auditory input may be further restricted. Thus, physiological responses to errors might be more readily apparent (or seem that way from the participant's standpoint) in a physical observation paradigm and paradigms without as many restrictions (i.e., physical observation) may therefore lead to more consistent increases in the ERN under social observation. However, further research that directly compares physical and virtual social observation paradigms are needed.

Current studies examining the effects of age are similarly limited. First, there is a need for more studies examining the effects of social observation on the ERN in youth. Second, there is a critical need for longitudinal studies within this domain. Longitudinal studies are necessary given documented age-related changes in both the error monitoring system (Buzzell, Richards, et al., 2017; Davies et al., 2004) and concerns over social evaluation (Westenberg et al., 2007), especially during adolescence. Furthermore, sex/gender should be considered, especially within the context of developmental samples, as there are known sex/gender-dependent differences in concerns for social evaluation (Rudolph & Conley, 2005) and in brain development more generally (Alarcón et al., 2018; Christakou et al., 2009; Li et al., 2009; Palejwala & Fine, 2015). The need for research that considers both sex/gender as well as age/development is highlighted by the seemingly contrasting results reported by Barker et al. (2018) and Niu et al. (2023). Within an all-female sample, Barker et al. (2018) reported that the ERN was only enhanced under social observation for younger adolescents/children but not older adolescents (the age of the full sample was 9-17). In contrast, Niu et al. (2023) reported that social observation enhanced the ERN among a mixed sample of male/female older adolescents (~15-

17 years old). As previously discussed, sex/gender differences across these two samples may explain the otherwise inconsistent findings across studies. Relatedly, future research should further consider the effects of puberty.

Our review led to the conclusion that the likelihood of detecting an effect of social observation on the ERN might be dependent on the presence/absence of commensurate behavioral effects (changes in response time or accuracy as a function of social observation). Thus, we suggest that future research should consider controlling for behavioral effects when testing whether the ERN differs based on social observation. Additionally, we recommend including assessments of post-error behavioral measures, such as post-error slowing (PES) and post-error accuracy (Danielmeier & Ullsperger, 2011), in future research. Post-error behavioral measures represent the functional consequences of error monitoring; thus, consideration of post-error measures may offer further insights into how social observation influences error monitoring.

Future research should also consider the believability of social observation paradigms that utilize deception. If participants do not actually believe that they are being observed, then this might lead to null effects of social observation on the ERN. Of the reviewed studies that employed deception, only Barker et al. (2018) conducted a manipulation check for believability– they excluded participants who reported not believing the social manipulation and confirmed that the results were similar with and without these participants. Such manipulation checks are an important foundation for assessing believability, although it is important to note that manipulation checks may not tell the whole story. Surveys employed to assess whether a participant was deceived are often not tested for validity or reliability, and these surveys may not capture the full extent of a participant's suspicions. Relatedly, participants may lie about whether or not they were deceived either to save face or in an attempt to conform to experimenter expectations (Barrett et al., 2023). Thus, in addition to employing manipulation

checks in studies that utilize deception, we also encourage careful consideration of the methods used to assess believability.

We also recommend that believability should be evaluated for *all* social observation paradigms, not just those that utilize deception. This reasoning is two-fold. First, a baseline measure of believability in paradigms without deception would allow for more informative testing of believability when deception is employed. Second, participants may still question whether they were actually under social observation, even in the absence of deception. Indeed, previous research suggests that participants may be suspicious of experimental paradigms due to previous participation in or knowledge of the use of deception in psychological paradigms (Barrett et al., 2023; Stricker et al., 1969). Our review of the literature found that studies without deception were actually more mixed in terms of whether they produced consistent effects of social observation on the ERN. As previously discussed, this may be due to higher levels of experimental control being enacted for paradigms that use deception. Relatedly, higher levels of experimental control (if executed properly) might improve the believability that social observation indeed was performed. That is, paradigms that employ deception attempt to counteract participant suspicions with specific scripts and training. Paradigms without deception, in contrast, may not employ such efforts, perhaps due to an assumption that a lack of deception obviates the need for such measures. As a result, paradigms without deception, counterintuitively, may actually vary more in how effectively they establish a credible sense of being placed under social observation, leading to greater variability in the likelihood of “social observation” influencing the ERN. These ideas could be directly tested in future research studies.

Relatedly, studies that manipulate social observation should consider the impacts of having an experimenter (the person running the data collection session) present. The presence of an experimenter in some capacity is necessary to ensure that high quality EEG data is continuously collected. However, the mere presence of an experimenter necessarily introduces

an additional form of social observation that is present even when the participant is “alone” (alone in terms of whether the official observer is present or not) and the participant may still feel like they are being “observed” in such situations, even if the experimenter is not within their line of sight. For example, it is not uncommon during the collection of EEG data for an experimenter to enter the participant data collection room mid-study, often between blocks, to remedy a problem associated with EEG signal quality. Yet, this may also lead to the participant feeling like they are also being “observed” by the experimenter, complicating an otherwise simple manipulation of social observation that involves only the participant and a third-party observer. Given that it is advisable to ensure high-quality EEG data is collected throughout an experiment, a compromise could involve having the EEG experimenter being explicit with participants about what they can and cannot see when they are monitoring EEG data quality. For example, this could involve the EEG experimenter stating that they can see the EEG data, but can’t tell what the participant is thinking and can’t tell if they are performing the task well or not.

Our final, and perhaps most important recommendation, is that future studies strive to carefully provide as much detail as possible about their task paradigms and social protocols when conducting studies to evaluate the impacts of social observation on the ERN. In terms of the protocols employed, it is important to provide clear details about the social observation procedure, whether deception was used or not. In deception studies, sufficient details regarding the cover story are crucial, as are further details in terms of exact scripts, stimuli, technology, etc., used to establish deception. In studies without deception, it is crucial to provide sufficient detail about any instructions provided to participants/observers, demographics, opportunities for social interaction, etc. For physical social observation, it is important to carefully describe the relative position in the room where the observer was located and any sounds/actions performed. To this end, it is worth noting that details such as the distance between and orientation of the participant and the observer may impact social interactions (Givon-Benjio et

al., 2020; Kroczek et al., 2020). For non-physical social observation, extensive details regarding the software and hardware employed, what could and could not be observed, and any further explanations provided. In terms of the task paradigms employed, it is crucial to provide details regarding stimulus timing, whether a fixation cross/image appeared on each trial, inter-trial interval lengths, whether trial or block feedback was provided, the number of trials per block, and whether responses were made with one or two hands. For the latter point, regarding how many hands were used to respond, preliminary work indeed suggests that whether participants used one hand or two to respond to the task can influence the relationship between anxiety and the ERN (Buzzell et al., 2024; Lin et al., 2015), which may further extend to associations between the ERN and social observation. Where appropriate, the participant should likewise be asked about their perceptions of these factors and the potential moderating role of these subjective reports should be further considered. We encourage authors to include details that do not fit within strict word counts in online supplements or through other open science resources.

Conclusions

In the current narrative review, we find that the literature broadly supports the notion that social observation leads to an increase in the ERN. At the same time, some discrepancies were present across studies, with variation in certain paradigm-related factors or individual differences influencing the likelihood that social observation enhances the ERN. Of note, studies that employed deception and/or task-related feedback more consistently reported an effect of social observation on the ERN. Similarly, younger participants, as well as those high in social/performance anxiety, may be more likely to exhibit an increased ERN under social observation. Further work examining the impact of these and other paradigm-related factors, as well as state and trait individual differences measures are needed. Moreover, future studies

should strive for greater methodological detail when reporting the tasks and social observation paradigms/protocols employed. Ultimately, these efforts will advance understanding of how, why, and when social observation impacts the brain's processing of mistakes.

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