Event-related potentials of social comparisons in depression and social anxiety

Running title: Social comparisons in psychopathology

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Abstract

Social comparison is central in human life and can be especially challenging in depression and social anxiety. We assessed event-related potentials and emotions using a social comparison task in which participants received feedback on both their own and a co-player's performance, in participants with depression and/or social anxiety (n=63) and healthy controls (n=72). Participants reported more negative emotions for downward (being better than the co-player (participant correct, co-player wrong)) and upward (being worse than the co-player (participant wrong, co-player correct)) comparisons vs. even outcomes, with these effects being stronger in depression and social anxiety. At the Medial Frontal Negativity, both controls and depressed participants showed a more negative amplitude for upward comparison vs. both the participant and co-player performing wrong. Socially anxious subjects showed the opposite effect, possibly due to greater expectations about being worse than others. The P300 decreased for downward and upward comparisons compared to even outcomes, which may relate to the higher levels of conflict of social inequality. Depressed and socially anxious subjects showed a blunted P300 increase over time in response to the task outcomes, suggesting deficits in allocating resources for the attention of incoming social information. The LPP showed increased amplitude for downward and upward comparison vs. the even outcomes and no group effect. Emotional findings suggest that social comparisons are more difficult for depressed and socially anxious individuals. ERPs findings may shed light on the neural substrates of these difficulties.

Keywords: social comparison; depression; social anxiety; event-related potentials.

Introduction

Social comparison is central to human life. People naturally tend to compare their attitudes and abilities to those of others (Festinger, 1954). Whether we consider ourselves tall/short, clever/silly, successful/loser, handsome/ugly, earning good money or not is a judgment that we tend to make in comparative terms (Kedia et al., 2014). Comparisons can be made with someone considered to be better (upward), equal (lateral), or worse (downward) than oneself (A. P. Buunk & Gibbons, 2007). Upward comparisons are useful for learning and improving abilities but are often associated with negative affect and can be threatening to self-esteem. Downward comparisons can be positive for self-enhancement, but depending on the context they can also imply negative feelings such as guilt and concerns about eliciting negative emotions (e.g. envy) in others (A. P. Buunk & Gibbons, 2007; Swallow & Kuiper, 1988).

Social comparisons can be especially difficult for people with social anxiety due to fear of negative social evaluation, but is also difficult for people with depression (B. P. Buunk & Brenninkmeyer, 2000; McCarthy & Morina, 2020). Evidence suggests that engaging in social comparison predicts the recurrence of depression and reductions in the frequency of this engagement precedes improvement in the symptoms (Kelly et al., 2007). Moreover, a recent meta-analysis indicated that social comparison plays a role in the maintenance of symptoms for both disorders, as well as related cognitions, emotions, and behaviors(McCarthy & Morina, 2020). According to cognitive theories, social comparisons can play an important role in these disorders triggering negative evaluations about the self, low mood and social avoidance(Antony et al., 2005a; Swallow & Kuiper, 1988). Consistent with these theories, significant evidence shows that individuals with symptoms of depression and social anxiety interpret social comparisons in a less self-serving way, tend to believe that others are better than they are and demonstrate strong negative emotions and social avoidance when facing social comparison situations (B. P. Buunk & Brenninkmeyer, 2000; Fernández-Theoduloz et al., 2019; McCarthy & Morina, 2020; Uriarte-Gaspari et al., 2022). However, despite the crucial role of social comparisons in the maintenance of symptoms(McCarthy & Morina, 2020) in these disorders, studies investigating the neural basis of social comparisons in depression and social anxiety are very rare. To our knowledge, there is only one recent functional Magnetic Resonance Imaging (fMRI) study in this area, which reported reduced striatal activation in social anxiety related to social comparison (Lin et al., 2023).

In the last decade, there has been a growing interest in studying the neural substrates of social comparisons in healthy subjects (Kedia et al., 2014). Studies using electroencephalography (EEG) have shown at least three event-related potentials (ERP) components associated with social comparisons: the Medial Frontal Negativity (MFN), the P300, and the Late Positive Potential (LPP) (Boksem et al., 2011; Luo et al., 2015; Qiu et al., 2010; Wu et al., 2012; X. Zhang et al., 2021).

The MFN (also known as Feedback Related Negativity (FRN), feedback Error-Related Negativity (fERN) and Feedback-Negativity (FN)) typically presents in frontocentral regions 200-350 ms after feedback, and has been localized to the anterior cingulate cortex (ACC) (Gehring & Willoughby, 2002; Glazer et al., 2018; Nieuwenhuis et al., 2004). In reward tasks, the MFN typically shows a more negative amplitude following negative vs. positive feedback, such as when receiving monetary losses vs. monetary gains (Foti & Hajcak, 2009a; Gehring & Willoughby, 2002). The MFN is thought to reflect reward prediction errors

(Sambrook & Goslin, 2015) and motivation/affective processes associated with outcome evaluation (Brush et al., 2018; Gehring & Willoughby, 2002; Hajcak et al., 2006). During social comparisons, the MFN has been observed to be more negative both for downward and upward comparisons vs. even outcomes (Boksem et al., 2011; Luo et al., 2015; Qi et al., 2018; H. Zhang et al., 2021). This modulation has been interpreted as a prediction error and as a motivation/affective response in the face of inequality (Boksem et al., 2011; Luo et al., 2015).

The P300 is a positive centro-parietal peak at 300-600 ms following feedback (Glazer et al., 2018). This component is elicited by a wide variety of tasks, likely being involved in several cognitive processes such as attention, memory and motivation (Glazer et al., 2018; Polich, 2007; San Martín, 2012). One of the theories linked to the P300 is the context updating hypothesis, which suggests that the P300 signals brain activity related to a stimulus induced revision of the mental model of the task (San Martín, 2012). The P300 is thought to increase in amplitude for motivational/salient stimuli. The neuroanatomical correlates of the P300 are widespread and largely uncertain, likely including the temporo-parietal junction and adjacent areas, as well as the hippocampus, amygdala and thalamus as potential sources (Glazer et al., 2018). Interestingly, the P300 is also sensitive to the cognitive load, decreasing in amplitude with increasing task difficulty and when other tasks compete for cognitive resources (Kok, 2001; Polich, 2007). In particular, the P300 decreases in response to conflict situations that require cognitive effort (Hu et al., 2015). For example, the P300 has been observed to decrease when participants make deceptive vs. truthful responses (Hu et al., 2015; Johnson et al., 2003, 2008) and in response to proposals from others with a medium degree of unfairness vs. more extreme fair/unfair propositions (Fabre et al., 2015). In line with this, a social comparison study observed a decreased P300 for downward and upward comparisons compared to even outcomes (Qi et al., 2018), which may relate to the higher levels of social conflict that unequal comparisons entail (Luo et al., 2015), demanding cognitive resources that compete with processes that underlie the P300.

The LPP is a positive centro-parietal deflection starting approximately 300 ms post-stimulus änd it can last several seconds after stimuli onset (Hajcak et al., 2009). This component has usually been studied using passive emotional-picture viewing, and it is usually larger for negative than positive feedback (Glazer et al., 2018). It is considered to reflect sustained attention and extended processing of emotional stimuli. Social comparison studies have reported an increased LPP for large differences in earnings between the participant and other players (Luo et al., 2015; Wu et al., 2012), suggesting that upward and downward comparisons have a stronger motivational relevance and elicit higher levels of autonomic arousal compared to even outcomes (Luo et al., 2015).

ERPs have also become a fundamental tool in the search for the neural substrates of psychopathology (McLoughlin et al., 2014). Most studies looking into the MFN in depression and social anxiety have used reward tasks. Some of these studies have reported a greater differentiation between negative and positive outcomes in depression and social anxiety, linked to an increased sensitivity to negative feedback (Judah et al., 2016; Mueller et al., 2015; Tucker et al., 2003). However, other studies have reported a reduced MFN differentiation between positive and negative outcomes in depression and anxiety, associated with negative biases in outcome expectations (i.e. larger expectation for negative outcomes) (Foti & Hajcak, 2009b; Gu, Huang, et al., 2010). A decreased MFN to positive stimuli in depression has also been reported, related to blunted reward processing (Brush et al., 2018; Liu et al., 2014).

The P300 has been reported to be decreased in depression and social anxiety during oddball tasks (Gangadhar et al., 1993; Nan et al., 2018; Sachs et al., 2004; Zhou et al., 2019), and in depression during flanker (Klawohn et al., 2020; Santopetro, Brush, Bruchnak, et al., 2021) and reward tasks (Foti & Hajcak, 2009b; Santopetro, Brush, Burani, et al., 2021). These findings have been related to reduced motivation and allocation of resources for the processing of incoming stimuli in these disorders. It is thought that negative cognitive biases, rumination, and worries may underlie impairments in attention in these populations competing for cognitive resources (Hirsch & Mathews, 2012; Keller et al., 2019; van Vugt et al., 2018).

The LPP has been reported to be reduced in depression in response to pleasant pictures (Klawohn et al., 2021; Weinberg et al., 2016), which has been related to a reduced response to rewarding stimuli. In addition, a reduced LPP has also been observed in depression in response to negative stimuli (Bauer & MacNamara, 2021; Foti et al., 2010; Granros et al., 2022) , suggesting that the blunting in emotional reactivity may not be restricted to positive stimuli. However, an increased LPP has also been reported in depression in response to negative self-referential stimuli (Benau et al., 2019), which highlights the importance of self-relevance on emotional reactivity. In social anxiety, an increased LPP has been observed in the context of emotional faces and image presentation tasks, possibly related to enhanced emotional processing (Hagemann et al., 2016; Kinney et al., 2019; Wieser & Moscovitch, 2015). In addition, a blunted LPP has also been reported in social anxiety in a self-imagery study, linked to attentional avoidance (Kraft et al., 2022).

Here we aimed to investigate emotional and neural responses to social comparisons in participants with symptoms of depression and/or social anxiety and healthy controls using ERPs. It was hypothesized that upward comparisons would be associated with higher levels of negative emotions compared to even outcomes. We expected social comparisons to modulate the MFN, P300, and LPP. Based on the above findings, it was expected that the MFN would show increased negativity for downward and upward comparisons compared to even outcomes; that the P300 would attenuate for downward and upward comparisons compared to even outcomes due to the higher levels of conflict that unequal comparisons entail; and that the LPP would show an increased positivity for upward and downward comparisons vs. even outcomes.

Regarding the effect of psychopathology, it was expected that depression and social anxiety would be associated with stronger negative emotions for unequal comparisons. With respect to ERPs, an enhanced MFN negativity for downward and upward comparisons could be hypothesized in these disorders, due to negative cognitive biases leading to a deeper processing of conflictive/negative events. However, for upward comparison a diminished MFN negativity could also be expected due to negative biases in outcome expectation (i.e., greater expectation of not being as good as others). For the P300, we hypothesized decreased amplitudes in depression and social anxiety especially for downward and upward comparisons, due to negative cognitive biases, rumination, and worries competing for resources with the processes that underlie the P300. For the LPP, both an enhanced and a diminished positivity could be expected in response to downward and upward comparisons since both enhanced emotional processing or emotional disconnection/avoidance could be possible in these disorders.

Methods

Participants

This study was conducted following the Declaration of Helsinki and was approved by the Research Ethics Committee of the Faculty of Psychology, Universidad de la República. Written informed consent was obtained from all participants. Participants between 18-35 years old were invited to participate in the study. Exclusion criteria were: history of severe neurological disorders, having visual, hearing or motor difficulties that make it difficult to perform the task and being pregnant (this last criteria was added to avoid someone being pregnant going through the demands of the study). Subjects completed the Beck Depression Inventory-II (BDI-II) (Beck, 1961; Sanz et al., 2003) and the Liebowitz Social Anxiety Scale (LSAS) (Bobes et al., 1999; Liebowitz, 1987) on a website advertised through the university's social networks. Applicants were invited to a recruitment session, where they were screened for psychiatric symptoms using the MINI International Neuropsychiatric Interview (MINI-Plus, version 5.0.0) (L. Ferrando et al., comunicación personal, 2000; Sheehan, 1998). Two groups of participants were formed: a group with symptoms of major depression and/or social anxiety (MD-SA, n=63) and a group of healthy controls (n=72). Inclusion criteria for the MD-SA group were: satisfying MINI-Plus criteria for an episode of major depression and scoring ≥14 on the BDI-II and/or satisfying MINI-Plus criteria for social anxiety and scoring ≥55 on the LSAS, and at least three weeks of not taking psychiatric medication. The requirement of not being on medication was added to avoid a potential medication confound. Controls had no current or past history of psychiatric disorders. The two groups did not significantly differ in sex, age, years of education, etc. (Table 1). The MD-SA group was composed of 23 volunteers meeting criteria only for MD, 30 only for SA, and 10 for both disorders (see Supplementary Material for psychological rating scales).

Since depression and social anxiety are highly comorbid and share a similar affective and cognitive profile (Arditte Hall et al., 2019; Kashdan, 2004), statistical analyses were performed comparing controls vs. the whole MD-SA group to increase statistical power for identification of common neural substrates. However, analyses were also performed splitting the MD-SA group into participants presenting only MD and only SA (participants with both MD and SA were not included as they were only 10) to test for specific effects of these disorders.

Behavioral task

The social comparison task was similar to tasks previously used in social comparison studies (Boksem et al., 2011) (Figure 1). In each trial, a blue circle was presented, which changed color to green after 2–2.5 seconds. Participants were told to press the spacebar one second after the color change and that they would earn one/zero points (along with a smiley/sad face) depending on whether they had done a correct/wrong time estimation. After the participants pressed the spacebar, the circle turned gray for 0.5 seconds to notify them that their responses had been recorded. Participants were told that they would play simultaneously with another player in a nearby room and that on every trial, both would receive feedback on their own and the co-player's performance (the actual name of the participant and a fictitious name for the co-player were displayed along with the feedback). During the task, four feedback combinations were possible: "You correct-Other correct", "You correct-Other wrong", "You wrong-Other correct", "You wrong-Other wrong". It was stressed that the earnings of both subjects were independent. In reality, there was no real co-player, and the feedback was preprogrammed to be positive in 50% of trials for both players. When participants failed to respond, they received negative feedback, resulting in a final distribution of outcomes for the participants as follows: positive feedback (49.21%), and negative feedback (50.79%).

Before the task, participants were presented with the supposed co-player and told that later after the experiment they would be reunited to discuss the task and that each would receive a monetary reward based on their respective points. It was controlled that the participant did not know the co-player, that the interaction was brief, and that both were about the same age and of the same sex.

The task was programmed in PsychoPy2 and was composed of 168 trials, 42 in each condition. Trials were divided into three blocks (conditions were balanced between the blocks). Participants also performed the Ultimatum Game task. Data from this task has already been reported (Nicolaisen-Sobesky et al., 2023). The order of tasks was counterbalanced across participants.

After the experiment, participants rated on nine-point Likert scales: their emotions (happiness, relief, anger, envy, sadness, nervousness, disappointment, shame, and guilt) in response to the task’s conditions, their emotions regarding meeting again with the co-player, and their perception of their own and the co-players performance. After the experiment, participants were also debriefed regarding the cover story and rewarded for their collaboration (participants received a cinema ticket or pen drive).

EEG recording and preprocessing

EEG was recorded using 64 Ag/AgCl active channels (Biosemi, Amsterdam, Netherlands) mounted in an elastic cap following the 10/20 international system (Jasper, 1958). Data were sampled at 256 Hz and online filtered using a fifth-order low-pass sinc filter with a 52 Hz cut-off (-3 dB). Following the BioSemi design, the voltage at each active electrode was recorded with respect to a common mode sense active electrode and a Driven Right Leg passive electrode, replacing the ground electrode. Data were preprocessed offline using the FieldTrip toolbox in MATLAB (Oostenveld et al., 2011). Data were re-referenced to an average mastoid reference, and offline filtered using a band-pass Butterworth filter at 0.1-30 Hz with a two-pass zero-phase forward and reverse direction (order: 4). Epochs were cut at 200 ms before and 800 ms after feedback. ERPs from each subject and condition were averaged separately, and a baseline voltage averaged over the 200 ms interval preceding feedback was subtracted from these averages (see Supplementary Material).

Relevant ERP components were identified by visual inspection of the time series (average over all subjects and all conditions) and topographical distributions. The MFN was computed as the mean amplitude averaged over frontocentral electrodes in the 200-300 ms time window. The P300 was computed as the mean amplitude averaged over middle-line and centro-parietal electrodes in the 300-450 ms time window. The LPP was computed as the mean amplitude averaged over centro-parietal electrodes in the 450-800 ms time window. Selected time windows and topographies align with those reported in similar studies (Boksem et al., 2011; Hu et al., 2017; Qi et al., 2018; Wu et al., 2012) (selected electrodes are listed in Figure 3).

Statistical analyses

Emotional reports were analyzed using three-way ANOVAs with participant and co-player outcomes as within-subjects factors and the group as the between-subjects factor. The Greenhouse-Geisser correction was applied in cases where the sphericity hypothesis was not met. Effect sizes were calculated using the partial Eta squared method (η^2_p). Pairwise comparisons were tested using paired and independent-sample t-tests. For independent-sample t-tests, Levene's correction was applied in cases where the hypothesis of equality of variances was not met, and effect sizes were calculated as Cohen's $d=(\bar{x}1-\bar{x}2)/\sqrt{(s1^2+s2^2)/2}$.

The classical approach to studying ERPs involves averaging epochs of the same condition in each subject. This approach obscures modulations of the ERPs along the task. Recent approaches have used Mixed Linear Models (MLM) to explore ERPs' modulations along the task (Brush et al., 2018; Volpert-Esmond et al., 2018). We implemented MLMs (R package "lmer"), selecting models with the best fitting for each ERP based on the Akaike Information Criterion (AIC). For all ERPs, the model included mean voltage as the response variable, subject as a random effect, and self-outcome, other-outcome, group (Control, MD-SA; or Control, MD, SA), trial, and all their interactions as fixed effects. The mean voltage corresponded to the mean amplitude averaged over the electrodes and time windows previously specified for the MFN, P300 and LPP. Post-hoc comparisons were performed using the Holm-Bonferroni correction (R package "emmeans"). Statistical analysis was done on Rstudio (version 1.0.153) and SPSS (version 22). As a request from one of our reviewers, we also performed these analyses adding age as a regressor. These analyses yielded essentially the same results as the ones presented.

Split-half reliability estimates were calculated for each ERP component as follows (see Pronk et al., 2022 for a systematic review and comparison between methods) (Pronk et al., 2022). For each subject and type of feedback, trials were splitted into halves using the odd-even split, and mean amplitude values for each type of feedback were computed for each split. Then, the correlation between values for each split were computed, and corrected using the Spearman-Brown formula.

Data and Code availability statement

Data of this study cannot be made available, because it would require participants to sign an additional consent form which is not possible to implement at the moment. The code implemented to analyze ERPs is openly available at https://github.com/valentinapazperez/MLM_ERPs

Results

Of the sample of 135 participants, 117 attended the experimental session. For emotional analyses, four participants were excluded for not believing the cover story, leading to a sample of n=113 (59 Controls, 54 MD-SA). In addition, for the EEG analysis 15 participants were excluded due to: technical problems during data acquisition (n=3), artifacts in the EEG signal (n=11), and unbalanced trials between conditions after excluding artifacts (n=1), leading to a sample of n=98 (49 Controls, 49 MD-SA).

Emotional results

The mixed ANOVA with factors self-outcome, other-outcome and group (Control, MD-SA) (see Supplementary Materials for means and standard deviations of emotional responses by group and the main effects of self-outcome, other-outcome, group and the self-outcome*group interaction) identified a significant self-outcome*other-outcome interaction for the emotions of happiness ($F_{1,111}$=4.08; p<0.046; η^2_p=0.04), relief ($F_{1,111}$=22.99; p<0.001; η^2_p=0.17), sadness ($F_{1,111}$=8.97; p<0.003; η^2_p=0.7), guilt ($F_{1,111}$=19.03; p<0.001; η^2_p=0.14), shame ($F_{1,111}$=40.11; p<0.001; η^2_p=0.26), envy ($F_{1,111}$=46.92; p<0.001; η^2_p=0.29), anger ($F_{1,111}$=8.77; p=0.004; η^2_p=0.07), nervousness ($F_{1,111}$=16.10; p<0.001; η^2_p=0.12) and disappointment ($F_{1,111}$=13.72; p<0.001; η^2_p=0.11) (Figure 2A). Post hoc pairwise comparisons identified that the even correct outcome ("You correct-Other correct"), elicited less sadness (t_{112}=3.94, p<0.001), guilt (t_{112}=4.15, p<0.001), and shame (t_{112}=2.46, p=0.015) and more envy (t_{112}=-2.23, p=0.027) than downward comparisons ("You correct-Other wrong"). Upward comparison ("You wrong-Other correct") elicited more anger (t_{112}=2.78, p=0.006), nervousness (t_{112}=4.66, p<0.001), shame (t_{112}=5.64, p<0.001), disappointment (t_{112}=4.74, p<0.001) and envy (t_{112}=6.63, p<0.001), and less relief (t_{112}=-7.28, p<0.001) than the even wrong outcome ("You wrong-Other wrong"). For the emotion of happiness, the post hoc comparisons were not significant (p>0.7). These findings show that emotions were modulated by social comparison.

A significant self-outcome*other-outcome*group (Control, MD-SA) interaction was observed for the emotions of nervousness ($F_{1,111}$=5.97; p=0.016; η^2_p=0.05), guilt ($F_{1,111}$=8.52; p=0.004; η^2_p=0.07), shame ($F_{1,111}$=9.10; p=0.003; η^2_p=0.08) and disappointment ($F_{1,111}$=4.70; p=0.032; η^2_p=0.04) (Figure 2A). Follow-up of these interactions showed that even correct comparisons ("You correct-Other correct") did not trigger different emotional responses between groups, while downward comparison ("You correct-Other wrong") led to MD-SA participants reporting more nervousness ($t_{86.98}$=-4.15, p<0.001), guilt ($t_{61.55}$=-3.58, p<0.001) and shame (t_{53}=-3.80, p<0.001) than controls. During upward comparison ("You wrong-Other correct"), MD-SA participants reported more nervousness ($t_{94.93}$=-4.54, p<0.001), guilt ($t_{75.61}$=-2.88, p<0.001), shame ($t_{80.20}$=-5.45, p<0.001) and disappointment (t_{111}=-3.48, p<0.001) than controls; while during even wrong comparisons ("You wrong-Other wrong") MD-SA participants reported more shame ($t_{54.96}$=-4.39, p<0.001) than controls (with this between-group difference not being as strong as for the "You wrong-Other correct" outcome ($t_{221.97}$=-3.21, p=0.002)).

MD-SA participants reported less happiness ($t_{105.56}$=2.92; p=0.004; d=0.550.54), more nervousness ($t_{90.80}$=-7.48; p<0.001; d=1.43), shame ($t_{79.92}$=-6.23; p<0.001; d=1.20), anger ($t_{56.78}$=-2.05; p=0.045; d=0.40) and sadness ($t_{60.16}$=-2.19; p=0.032; d=0.43) than controls about anticipating meeting again with the co-player.

All participants rated their performance as less accurate than the co-player ($F_{1,110}$=32.98; p<0.001). MD-SA participants evaluated their performance as less accurate than controls ($F_{1,110}$=4.58; p=0.035). A significant interaction between the group and the subject object of the evaluation was found ($F_{1,110}$=7.60; p=0.007), with groups not differing in their perception of the co-player's performance (p=0.092), but MD-SA participants rating their own performance as less accurate than controls (p=0.003) (Figure 2B).

Additional analyses splitting the group factor in three levels (Controls, MD, SA) (see Supplementary Materials) showed that both the MD and SA subgroups contributed to the between-group differences in emotions between the Control and MD-SA groups (Supplementary Figure 1 and Supplementary Analyses).

Event-Related Potential results

In this section the most relevant ERPs findings are reported. Please see the Supplementary Materials for additional significant findings.

MFN

The Spearman-Brown corrected reliability coefficients for the MFN was 0.89. Significant main effects of self-outcome ($F_{1,14105.98}$=5.37; p=0.02) and other-outcome ($F_{1,14105.15}$=12.52; p<0.001) were found, with larger negativity for negative vs. positive feedback. A significant self-outcome*other-outcome*group (Control, MD-SA) interaction ($F_{1,14105.58}$=5.19; p=0.023) was found. In both groups, downward comparisons ("You correct-Other wrong") elicited a larger negativity than the even correct comparison ("You correct-Other correct"). However, only for controls, upward comparison ("You wrong-Other correct") elicited larger negativity than the even wrong outcome ("You wrong-Other wrong") (p=0.05), while these two outcomes did not show significant differences in MD-SA participants (Figure 3 A1 & A2).

Interestingly, the MLM with the group factor divided into three levels (Control, MD, SA) showed a significant self-outcome*other-outcome*group interaction ($F_{2,13282.26}$=4.58; p=0.010). In all groups, the MFN was more negative for "You correct-Other wrong" compared to "You correct-Other correct" (p<0.002). However, while in both controls (p=0.05) and MD (p=0.02) participants, the MFN was more negative for "You wrong-Other correct" compared to "You wrong-Other wrong", in the SA group, the opposite effect was observed (i.e. the MFN was more positive for "You wrong-Other correct" compared to "You wrong-Other wrong") ($p=0.05$). This difference was significant between the SA and the other two groups (vs. MD: $p=0.002$, vs. Control: $p=0.006$) (Figure 3 A3, Table 2).

P300

The Spearman-Brown corrected reliability coefficients for the P300 was 0.93. A significant self-outcome*other-outcome interaction was found ($F_{1,14105.02}=60.45$; $p<0.001$) with even conditions eliciting larger amplitudes than unequal comparisons. This is, the even correct outcome (“You correct-Other correct”) elicited a larger P300 than the downward comparison (“You correct-Other wrong”) ($p<0.001$), and the even wrong outcome (“You wrong-Other wrong”) elicited a larger P300 than the upward comparison (“You wrong-Other correct”) ($p<0.001$) (Figure 3 B1).

A significant trial*self-outcome*other-outcome was found ($F_{1,14104.95}=14.845$; $p<0.001$). When the participant was correct, the mean amplitude of P300 increased over trials (“You correct-Other correct” and “You correct-Other wrong”) ($t_{14108.92}=2.48$; $p=0.013$; $\beta=0.001$; $t_{14108.86}=5.95$; $p<0.001$; $\beta=0.002$ respectively). However, when the participant was wrong, the mean amplitude of P300 increased only when the co-player was also wrong (“You wrong-Other wrong”) ($t_{14109.40}=-2.71$; $p<0.001$; $\beta=-0.001$) but not when the co-player was correct (“You wrong-Other correct”) ($t_{14109.33}=1.35$; $p=0.18$; $\beta=0.000$), with these slopes being significantly different ($t_{14108.94}=-2.80$; $p<0.001$; $\beta=-0.001$) (Figure 3 B2).

In addition, a significant trial*group (Control, MD-SA) interaction was found ($F_{1,14105.86}$=7.70; p=0.006), with P300 increasing over time for controls ($t_{14.111.87}$=4.49; p<0.001; β=0.001) but not for MD-SA participants ($t_{14111.71}$=0.58; p=0.56; β=0.000). Since trial 120, the mean amplitude was larger for controls than for MD-SA participants (p<0.05) (Figure 3 B3). Both MD and SA subgroups contributed to this effect (Supplementary Figure 2 and Supplementary Analysis) (Table 2).

LPP

The Spearman-Brown reliability corrected coefficients for the LPP was 0.87. Significant main effects of self-outcome ($F_{1,14106.13}$=35.84; p<0.001) and other-outcome ($F_{1,14105.20}$=9.87; p=0.002) were found, with larger amplitudes for negative vs. positive feedback. Additionally, these factors interacted ($F_{1,14105.69}$=11.065; p=0.001), with unequal comparisons showing larger amplitudes than even outcomes. Specifically, downward comparison ("You correct-Other wrong") elicited a larger amplitude than the even correct condition ("You correct-Other correct") (p<0.001), and upward comparison ("You wrong-Other correct") elicited a larger amplitude than the even wrong condition ("You wrong-Other wrong") (p<0.001) (Figure 3 C1). There were no significant group effects with the group factor opened into two (Control, MD-SA) or three levels (Control, MD, SA) (Table 2).

Discussion

This study examined emotional and neural responses to social comparison in participants with symptoms of depression and/or social anxiety and healthy controls. The task was successful in eliciting social comparison processes. When participants were correct, they reported more negative feelings for downward comparison than for the even outcome. When participants were wrong, in agreement with hypotheses they reported more negative emotions for upward comparison than for the even outcome. These results are in line with the notion that upward comparison can lead to negative affect being a threat to self-esteem, and with the proposal that (depending on the context) downward comparisons can also elicit negative feelings (A. P. Buunk & Gibbons, 2007; Luo et al., 2018).

Crucially, as hypothesized the MD-SA group reported more negative feelings for downward and upward comparisons than healthy controls. This is consistent with evidence showing that depressed and socially anxious individuals are more sensitive to social comparison (B. P. Buunk & Brenninkmeyer, 2000; McCarthy & Morina, 2020), and with the theory that social comparison can act as a trigger for negative cognitive biases, in particular negative self-evaluations, in these populations (Antony et al., 2005b; Swallow & Kuiper, 1988).

MFN

The MFN was more negative when participants were wrong than when they were correct, which is consistent with previous findings (Gehring & Willoughby, 2002; Glazer et al., 2018; Hajcak et al., 2006; Sambrook & Goslin, 2015). As expected, across participants, downward comparison elicited a more negative MFN than the even correct outcome. This MFN modulation for downward comparison is consistent with a previous study and may relate to the emotional processes involved in downward comparison (Qi et al., 2018). Interestingly, MFN modulations have been associated with empathy (Fukushima & Hiraki, 2009; Thoma & Bellebaum, 2012), which could be acting during downward comparisons. In addition, the MFN modulation for downward comparison could also reflect a warning signal linked to a potential social threat since outperforming others can trigger negative feelings and actions from those others (Boksem et al., 2012).

When the participant was wrong, it was observed that upward comparison elicited a more negative MFN than the even wrong outcome both in controls and depressed participants, while the opposite was found in the SA group. The MFN modulation observed in controls and depressed participants for upward comparison is consistent with previous social comparison studies (Boksem et al., 2011; Qi et al., 2018; X. Zhang et al., 2021), and it may reflect the negative emotional/motivational impact of upward comparison, as well as prediction error signals related to inequality. More broadly, this finding is consistent with the extensive reward literature reporting a more negative MFN for negative than neutral or positive outcomes (Glazer et al., 2018). Interestingly, socially anxious individuals showed the opposite MFN modulation for upward comparison. It could be thought that upward comparison did not generate a negative emotional response in this group. However, this is not consistent with the emotional reports. Alternatively, it is possible that in social anxiety the upward comparison does not elicit a prediction error signal, due to socially anxious subjects not being as surprised for being worse than others, given their typical pessimistic expectations about themselves. The MFN effect on social anxiety is in line with a previous study showing a reduced MFN in high vs. low trait anxiety individuals in a monetary gambling task (Gu, Ge, et al., 2010). Nevertheless, replication of this finding is important since MFN studies in social anxiety are very scarce and have reported both a trend for an enhanced MFN linked to an accentuated negative response (Judah et al., 2016), as well as an altered MFN related to abnormal expectations (Cao et al., 2015). In addition, including a measure of participants' expectations regarding their and the co-player performance on the task before the EEG experiment would be desirable, in order to more directly link altered expectations with abnormal neural responses.

P300

The P300 signal increased over time for positive but not for negative outcomes. During most of the task, the P300 was larger for self-correct than for self-wrong, consistent with previous social comparison studies (Qi et al., 2018; Wu et al., 2012; X. Zhang et al., 2021). This may relate to the higher motivational significance of positive vs. negative feedback.

In addition, the P300 was modulated by social comparison. As expected, inequitable outcomes (both downward and upward comparisons) led to decreases in P300 compared to even outcomes, consistent with a previous study (Qi et al., 2018). The decreased P300 for inequitable outcomes may relate to the conflict, difficulty, and affective/cognitive load that these situations entail. It has been observed that the P300 decreases in conflict situations that engage cognitive processes that compete for resources (Fabre et al., 2015; Hu et al., 2015). In our task, both downward and upward comparisons are likely to imply higher levels of social conflict compared to the even outcomes, as they face individuals with social inequality. Interestingly, P300 amplitudes increased over time for all outcomes except for upward comparison, suggesting that, especially in this situation, it may be difficult for subjects to learn how to deal with conflict and liberate cognitive resources for the P300.

Crucially, in line with hypotheses the mean amplitude of the P300 increased over time in controls but not in MD-SA participants. This result suggests that in controls, as time progresses, there is a decrease in the level of conflict and cognitive/affective load that social comparison information elicits, allowing for a decrease in competitive processes for the P300.

In contrast, this learning/facilitation effect would be blunted in the MD-SA group. Depression and social anxiety are characterized by a cognitive style marked by negative cognitive biases, self-referential processing, rumination, and worries (LeMoult & Gotlib, 2019; Wells et al., 1995). This cognitive style could be contributing to MD-SA participants lingering on the negative aspects of social comparison, precluding them from liberating resources for the processes behind the P300. In line with this, rumination and worries are thought to underlie impairments in attention, concentration, and memory in depression and anxiety, taking away resources that are needed for the performance of tasks (Hirsch & Mathews, 2012; Keller et al., 2019; van Vugt et al., 2018). At the neural level, depression and social anxiety are thought to relate to an abnormal interaction between neural networks biasing attention to the internal vs. the external world (Fossati, 2019; Yoon et al., 2019). Specifically, an altered interaction between the default mode network (DMN) and attentional networks would lead to an increased attention to the internal world at the expense of attention to external stimuli. In agreement with this, several studies have shown increased activations of DMN regions in depression (Harvey et al., 2005; Kaiser et al., 2015; Mitterschiffthaler et al., 2008) and social anxiety (Abraham et al., 2013; K. Blair et al., 2008; K. S. Blair et al., 2010, 2011; Boehme et al., 2015; Gentili et al., 2009; Heitmann et al., 2016, 2017; Yoon et al., 2016). Nevertheless, it should be noted that the group factor did not interact with the task outcomes on the P300, suggesting that the MD-SA cognitive style similarly affected the processing of all task conditions at the P300. It would be worth it to further explore in future work whether psychopathology has a more specific effect on the P300 processing of social comparison outcomes.

LPP

As expected and in agreement with previous studies, inequitable outcomes (downward and upward comparisons) elicited a larger LPP than even outcomes (Luo et al., 2015; Wu et al., 2012). Since the LPP is thought to reflect extended processing of the affective value of outcomes, these findings suggest higher emotional intensity and arousal of inequitable vs. even outcomes, which is in line with the emotional reports.

We did not observe group effects on the LPP. Both reduced and enhanced LPPs have been observed in depression (Bauer & MacNamara, 2021; Benau et al., 2019) and social anxiety (Kinney et al., 2019; Kraft et al., 2022), suggesting that the effects of these disorders on the LPP are complex and likely dependent on factors such as self-relevance of the stimuli. Further research on the effect of these disorders on the LPP during social comparison is relevant, given our findings of increased emotional responses in MD-SA participants and the observed modulation of the LPP with social comparison.

Limitations

The sample was composed of university students between 18 and 35 years, primarily women, limiting the generalizability of results. In particular, it would be interesting to extend this work to the study of more severe clinical populations derived from the health system. In addition, more advanced analysis methods (such as source localization and source-level functional connectivity) or techniques (such as fMRI) could be used to see the activation of different brain regions and their connections.

Conclusion

This study investigated the neural responses to social comparison in depression and social anxiety. Individuals with these disorders showed enhanced negative emotions towards downward and upward comparisons. Interestingly, controls and depressed volunteers differentiated from socially anxious participants at the MFN, possibly due to socially anxious individuals not being as surprised for being worse than others. At the P300, downward and upward comparisons led to decreases compared to even outcomes, which may relate to the higher levels of conflict that social inequality implies. The MD-SA group showed a blunted P300 increase over time in response to the task outcomes, which may relate to difficulties in this group in dealing with social comparison information, precluding individuals from liberating resources that could be allocated for attending incoming social information. While the LPP modulated with social comparison, we observed no group effects on this signal. Findings may contribute to the understanding of the neural substrates of social comparison in people with depression and social anxiety.

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Author contributions

VP: data curation, funding acquisition, formal analysis, investigation, methodology, project administration, software, visualization, writing original draft, writing review and editing; ENS: data curation, funding acquisition, investigation, methodology, project administration, writing review and editing; GFT: investigation, methodology, writing review and editing; AP: investigation, software, implementation, writing review and editing; FCC: methodology, writing review and editing; EMM: investigation, methodology, writing review and editing; DK: investigation, methodology, supervision, validation, writing review and editing; ÁC: investigation, methodology, supervision, writing review and editing; VBG: conceptualization, funding acquisition, investigation, methodology, project administration, resources, supervision, writing original draft, writing review and editing.

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Conflicts of Interest Disclosure

The authors declare no conflicts of interest.

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Figure Legends

Figure 1. The social comparison task. In each trial, a blue circle was presented, which changed color to green after 2–2.5 seconds. Participants had to press the spacebar one second after the color change. That would be presented with a smiley face accompanied by '+1' (earning one point) if they responded correctly and a sad face and '+0' (making zero points) if they responded incorrectly. After the participants pressed the spacebar, the circle turned gray for 0.5 seconds to notify them that their responses had been recorded. Subjects were given feedback on their performance and on their co-player's performance. The actual name of the participant (here María) and a fictitious name for the co-player (here Gabriela) were displayed along with the feedback.

Figure 2. A) Emotional responses to the task outcomes. B) Participants' evaluation of their performance and the co-player's performance on the task. Error bars denote 95% confidence intervals. C/C: "You correct-Other correct"; C/W: "You correct-Other wrong"; W/C: "You wrong-Other correct"; W/W: "You wrong-Other wrong".

Figure 3. Event-related potentials. A1) Grand-average waveform corresponding to the MFN (200-300 ms, frontocentral electrodes). A2) Mean amplitude of the MFN over the time window and electrodes of interest for the Control and the MD-SA groups. A3) Mean amplitude of the MFN over the time window and electrodes of interest for the Control, MD, and SA groups. B1) Grand-average waveform corresponding to the P300 (300-450 ms,

middle-line and centro-parietal electrodes). B2) Amplitude of P300 across trials for each task condition. B3) Amplitude of P300 across trials for all the conditions averaged for the Control and the MD-SA groups. C1) Grand-average waveform corresponding to the LPP (450-800 ms, centro-parietal electrodes). In A1, B1, and C1, the origin of the horizontal axis represents feedback presentation, and the shadowed region indicates the time window studied. Error bars denote 95% confidence intervals.

Table 1. Sample characteristics

	Control	MD-SA	p-value	Cohen's d/w
n	72	63		
Sex				
Female	67	57	0.58	0.05
Male	5	6		
Age	22.5 ± 3.8	23.5 ± 4.4	0.17	0.24
Years of education				
Undertaken	15.8 ± 2.8	15.9 ± 2.9	0.89	0.02
Complete	14.2 ± 2.6	13.5 ± 2.2	0.07	0.32
Nicotine consumption				
No	62	53	0.75	0.28
Yes	10	10		
Skilful hand				
Left-handed	12	7	0.35	0.08
Right-handed	60	56		
Discipline of study				

Health science	45	39		
Social science and arts	12	14	0.61	0.09
Technology and science	15	10		
BDI-II	1.4 ± 1.9	22.7 ± 10.9	<.001	2.79
SHAPS	0.1 ± 0.4	2.7 ± 3.0	<.001	1.23
SAD	2.4 ± 2.6	21.8 ± 5.7	<.001	4.46
FNE	7.1 ± 5.4	23.9 ± 5.7	<.001	3.02
LSAS				
Total	13.1 ± 9.8	74.9 ± 23.6	<.001	3.51
Fear/anxiety	7.1 ± 6.1	37.4 ± 12.7	<.001	3.11
Avoidance	6.0 ± 4.8	37.6 ± 12.4	<.001	3.46
STAI				
Trait	35.3 ± 5.3	59.3 ± 7.4	<.001	3.78
State	28.1 ± 4.5	46.0 ± 10.7	<.001	2.24
INCOM	30.1 ± 7.6	37.8 ± 9.2	<.001	0.91
PANAS				
Positive affect	34.7 ± 5.6	19.8 ± 4.4	<.001	2.93
Negative affect	16.3 ± 2.7	26.5 ± 6.1	<.001	2.22
RSES	25.6 ± 3.7	12.4 ± 5.6	<.001	2.83
ACIPS	90.2 ± 7.5	70.5 ± 14.3	<.001	1.76
IIP				
Total	51.1 ± 21.3	107.1 ± 24.8	<.001	2.43
Domineering/controlling	6.2 ± 3.8	8.4 ± 4.1	<.001	0.57
Vindictive/self-centered	4.4 ± 3.0	7.5 ± 3.9	<.001	0.90

Cold/distant	3.7 ± 3.0	12.0 ± 5.1	<.001	2.02
Intrusive/needy	5.9 ± 4.0	8.6 ± 5.3	<.001	0.58
Socially inhibited	4.6 ± 4.0	18.4 ± 7.2	<.001	2.40
Nonassertive	6.6 ± 4.9	19.1 ± 6.0	<.001	2.33
Overly accommodating	8.7 ± 5.1	16.2 ± 6.0	<.001	1.37
Self-sacrificing	11.0 ± 4.6	16.8 ± 4.9	<.001	1.21

Values are given as mean ± standard deviation. p values are based on the independent-samples t-test. Effect sizes were calculated as Cohen's d for differences in means between groups and Cohen's w for frequency differences. BDI-II: Beck Depression Inventory-II (scores from the experimental session); SHAPS: Snaith-Hamilton Pleasure Scale; SAD: Social Avoidance and Distress; FNE: Fear of Negative Evaluation; LSAS: Liebowitz Social Anxiety Scale (scores from the experimental session); STAI: State-Trait Anxiety Inventory; INCOM: Iowa-Netherlands Comparison Orientation Scale; PANAS: Positive And Negative Affect Schedule; RSES: Rosenberg Self-Esteem Scale; ACIPS: Anticipatory and Consummatory Interpersonal Pleasure Scale; IIP: Inventory of Interpersonal Problems.

Table 2. Results of ERPs

	Control	MD-SA
MFN		
"You correct-Other correct"	11.1 ± 13.0	10.2 ± 12.8
"You correct-Other wrong"	8.0 ± 12.5	8.1 ± 12.6
"You wrong-Other wrong"	7.2 ± 12.1	7.0 ± 12.9
"You wrong-Other correct"	6.4 ± 12.5	7.1 ± 12.5
P300		

"You correct-Other correct"	23.9 ± 13.2	21.4 ± 13.9
"You correct-Other wrong"	22.6 ± 13.7	19.9 ± 13.9
"You wrong-Other wrong"	21.7 ± 13.3	20.0 ± 15.1
"You wrong-Other correct"	19.3 ± 14.3	18.0 ± 14.7
LPP		
"You correct-Other correct"	13.8 ± 12.8	13.7 ± 14.1
"You correct-Other wrong"	16.7 ± 12.9	15.9 ± 14.1
"You wrong-Other wrong"	15.0 ± 13.2	14.4 ± 15.3
"You wrong-Other correct"	16.3 ± 14.6	16.2 ± 15.3

Values are given as mean ± standard deviation.