OXFORD

Social Cognitive and Affective Neuroscience, 2022, **17**, 493–502
DOI: https://doi.org/10.1093/scan/nsab121
Advance Access Publication Date: 11 November 2021
Original Manuscript

Relationship Match: the neural underpinnings of social feedback in romantic couples

Thao Ha and Ryan S. Hampton

Department of Psychology, Arizona State University, Tempe, AZ 85287, USA
Correspondence should be addressed to Thao Ha, Department of Psychology, Arizona State University, 950 S. McAllister, Tempe, AZ 85287, USA.
E-mail: thaoha@asu.edu.
Thao Ha and Ryan S. Hampton contributed equally to this study.

Abstract

Romantic love involves an evaluative process in which couples weigh similarities and differences that facilitates pair bonding. We investigated neural attentive processes (P3) during evaluative relationship feedback within existing romantic couples using the Relationship Match Game. This paradigm included participant-driven expectations about relationship matching and relationship feedback from an expert panel of fictive peers and their romantic partner. In total, 49 couples participated who had dated less than one year. Participants showed significantly larger P3s in anticipation of feedback when they expected a mismatch, especially when supported by panel feedback. P3 amplitudes were also greater when participants received feedback from their partner congruent with their own assessment of compatibility. This was moderated by relational ambiguity, or one's preference to keep the relationship's status vague. We discuss how insecurity about the relationship is costly in terms of attentional resources contributing to over-alertness to cues of relationship evaluation.

Key words: social feedback; romantic evaluation; ERP; P3; relational ambiguity

Romantic love is a profound human experience facilitating long-term pair bonding (Fletcher *et al.*, 2015). Within romantic love, people evaluate relationship compatibility by deliberately weighing similarities and differences between partners to judge whether romantic love is viable (Vennum and Fincham, 2011). Recent studies show that romantic relationship evaluation also occurs at an automatic level outside of conscious awareness (Kuo *et al.*, 2017; McNulty *et al.*, 2013; Van der Veen *et al.*, 2019). Motivated by a desire to maintain relationships, people naturally attune to their romantic partner's thoughts, feelings and behaviors (Simpson and Campbell, 2013). Social feedback about compatibility from romantic partners may therefore signal important information about romantic relationship compatibility. A growing body of research investigates the neural mechanisms of social feedback processing as it facilitates social interactions and underlies bonding (Somerville *et al.*, 2006; Van der Molen *et al.*, 2018). However, most of the existing studies used social feedback from unfamiliar and fictive peers, which limits ecological validity and provides little information about existing relationships. Thus, we investigated the neural attentive processes during social feedback about romantic relationship compatibility from romantic partners and compared it to feedback from fictive peers. Because romantic partners have developed expectations about relationship compatibility that may be difficult to manipulate, social feedback processing was investigated in the context of one's own relationship expectations.

Social feedback processing is typically investigated using the original or an adapted form of the Social Judgment Paradigm (Somerville *et al.*, 2006). Using a picture of the participant, fictive peers are supposedly asked to indicate whether they would like (acceptance) or dislike (rejection) the participant based on their first impressions. Neuroimaging studies have shown that acceptance from fictive peers increased activity in the ventral portions of the medial prefrontal cortex (mPFC) and in particular areas associated with reward-based learning such as the ventral anterior cingulate cortex and subgenual region (subACC; Somerville *et al.*, 2006, 2010; Gunther Moor *et al.*, 2010; Guyer *et al.*, 2012; Masten *et al.*, 2012). Similarly, EEG studies investigating social feedback from fictive peers revealed significantly larger P3's in response to acceptance relative to rejection (Kujawa *et al.*, 2017; Funkhouser *et al.*, 2020) indicating motivated attention to positive social feedback.

The P3 component of the ERP (typically the third positive wave) is a particularly sensitive measure of selective attention and memory processes related to the cognitive processing of motivationally significant information and reward (Gray *et al.*, 2004;

Received: 5 May 2021; **Revised:** 21 August 2021; **Accepted:** 10 November 2021

Polich, 2007; Volpe et al., 2007). The P3 is especially enhanced when acceptance is expected, indicating a general tendency toward social rewarding experiences that underlie feelings of affiliation (Van der Veen et al., 2014, 2016; Van der Molen et al., 2018). However, some studies found enhanced P3 to unexpected social feedback (Dekkers et al., 2015) or no changes in the P3 (Van der Molen et al., 2014).

One study investigated social feedback processing in potential dating partners and adapted the Social Judgment Paradigm into a Tinder-like paradigm in which participants were told that they could potentially follow up with matched romantic partners (Van der Veen et al., 2019). An important advancement in ecological validity was that participants rated profiles of real potential partners who were college students at the same university. Fictive potential partners were also used to increase trail counts. Participants rated these real and fictive potential partners on whether or not they would date this person and received social feedback resulting in matched and unmatched romantic interest or rejection (i.e. match (Yes–Yes), disinterest (No–No), rejection (Yes–No) and unrequited (No–Yes)). Matched romantic interest was related to the largest P3 response followed by the unrequited condition in which a potential partner indicated romantic interest, but the participant was not interested in dating the other person.

Generally, these studies support the idea that selective attention is largest in social rewarding feedback to facilitate affiliation. However, once romantic relationships are formed, social feedback may serve different purposes as relationship goals change from affiliation to maintaining and deepening relationships. Social feedback may therefore provide evaluative information about whether romantic partners are compatible, which helps individuals judge whether romantic love is viable. In addition, social evaluation in real life is rarely only received by strangers, and people may show increased motivational and affective states to receiving relationship feedback from romantic partners. Therefore, it remains important to investigate whether social feedback from fictive peers can be generalized to feedback from romantic partners. One study investigated acceptance and rejection from adolescent romantic partners and fictive peers (Kuo et al., 2017). Distinguishing between earlier P3a and later P3b components, it was found that the P3a was enhanced for acceptance from romantic partners, but not for responses of fictive peers. This study showed that adolescents are initially attentive to socially rewarding feedback from their romantic partner. However, adolescents' own expectations about social feedback were not measured (Somerville et al., 2006). People develop inherent expectations about relationship feedback based on past, current and future interactions with romantic partners (Berscheid, 1999), and these expectations should be taken into account.

Investigating social-evaluative feedback processing within romantic relationships provides unique opportunities to test whether individual differences in relationship orientation moderates motivated attention to feedback from romantic partners. Relational ambiguity is a desire to keep the relationship status unclear and is increasingly normative in young adult relationships (Vennum and Fincham, 2011). Relational ambiguity is linked to sexual encounters outside a relationship (Owen et al., 2010; Howard et al., 2015) and to less commitment (Draucker et al., 2012). Relationship feedback might be more important for those high in relational ambiguity. They may be more sensitive to relationship feedback as an important indicator of how much resources and energy should spend on the relationship (Howard et al., 2015). Alternatively, high relational ambiguous individuals may have less desire to be in the relationship and hence may show less motivated attention to relationship feedback overall.

We developed the Relationship Match Game as an ecologically valid task of romantic relationship feedback in the context of one's own relationship expectations. Participants indicated whether they match with their romantic partner on various relationship characteristics, such as intimacy and chemistry. In addition, participants received randomized feedback on relationship compatibility from both an expert panel of fictive peers and their romantic partner. Furthermore, some studies identified that social and monetary reward cues during the anticipatory phase, which occurs before participants receive feedback, can elicit larger P3 amplitudes (Broyd et al., 2012; Doñamayor et al., 2012; Flores et al., 2015). During the anticipation phase of the Relationship Match Game, participants were cued for upcoming social feedback from fictive peers and romantic partners. Thus, we measured both motivated attention to cues of upcoming social feedback and attention to the feedback itself while incorporating participants' own expectations about relationship compatibility.

Using the Relationship Match Game among romantic couples, we investigated neural responses (P3) to (1) receiving social feedback and (2) anticipation of upcoming social feedback from unfamiliar peers and romantic partners. Importantly, we investigated these research questions in the context of the participants' own relationship match judgements. First, we hypothesized that when receiving social feedback, participants would show increased neural attention to positive social feedback and feedback that was in line with their own expectations. Further, we expected that this effect would be cumulative, increasing in size as more congruent feedback was received from both the panel and their partner. Critically, we expect that the P3 will be more sensitive for receiving feedback from romantic partners as compared to feedback from fictive peers overall. Second, we exploratively investigated whether neural responses (P3) during anticipation of feedback depend on the participants' own judgements of a relationship match and whether it cumulatively is dependent on congruent social feedback from fictive peers. Finally, we explored whether neural responses to feedback from romantic partners and fictive peers would be moderated by individual differences in relational ambiguity, enhancing the importance of social feedback on relationship compatibility. Gender differences were also explored as previous social judgement studies showed mixed results. One study found that males showed larger P3 differences between positive and negative social feedback among unfamiliar and fictive peers (Van der Veen et al., 2016), but another study did not find gender differences (Van der Veen et al., 2019) among unfamiliar potential romantic partners.

Methods

Participants

In total, 50 romantic couples ($N = 100$) were recruited from the university population who participated for study credits. This sample size was based on a power analysis of our pilot data suggesting that an *a priori* sample size of $N = 96$ would be required to have 90% power in detecting an interaction effect of $\eta^2 = 0.10$ in a $2 \times 2 \times 2$ repeated measures design (see Supplement). Couples were eligible when they were dating for less than a year to increase believability of the manipulation. Eight participants were omitted either for not finishing the study because of illness, not being in a romantic relationship or technical difficulties, and two participants were removed after artifact rejection. Thus, the final sample consisted of 90 participants (42 female) from

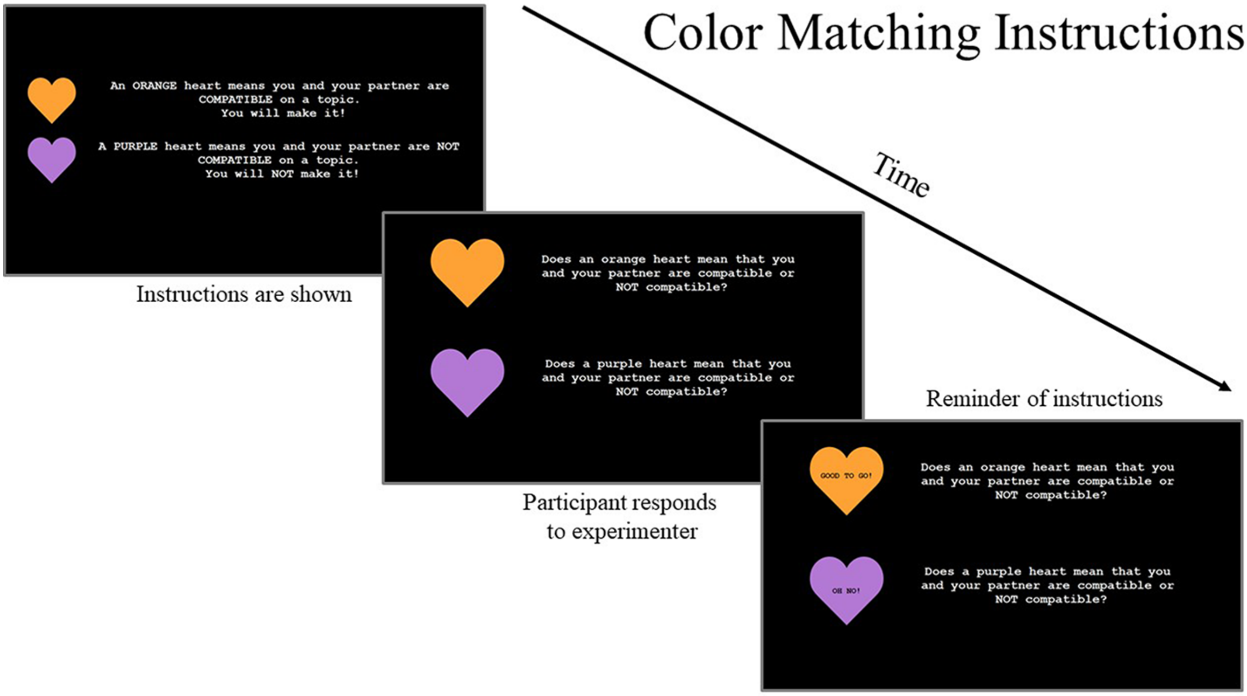

Fig. 1. Progression of instructions explaining how positive and negative feedback were tied to the colors of the hearts. Following these slides, participants underwent several practice trials that are outlined in Figure 2.

49 couples with a mean age of 20.21 ($SD = 2.71$), who primarily identified as White/Caucasian (56.7%), Hispanic/Latino (18.9%) or Asian (16.7%); African Americans, Native Americans, Pacific Islanders and those identifying as 'other' constituted the remaining 7.7% of participants, closely matching the overall racial distribution of the university (47.9% White, 18.5% Hispanic or Latino, 7.02% Asian, 3.73% Two or More Races, 3.48% Black or African American, 1.06% American Indian or Alaska Native and 0.184% Native Hawaiian or other Pacific Islanders). These couples were dating for an average of 5 months ($M = 5.16$ months, $SD = 3.48$) and included four same-sex couples.[1]

Procedure

Participants were informed about the goals of the study and signed consent forms. As part of the cover story, couples were told that they would find out whether they were compatible by the end of the two-hour laboratory session. First, couples underwent a battery of observational tasks and questionnaires designed to assess their compatibility as a couple. EEG data were collected at the end of the laboratory session which allowed for believability that the 'expert panel' had sufficient time to view their materials from earlier in the study. Participants were told that the panel consisted of peer experts from the University of California, Los Angeles (UCLA), who had been with the project for a long time and who were able to judge couples' relationship compatibility and relationship success with 95% accuracy.

Couples were then separated to two EEG systems across the hall from one another. During EEG preparation, experimenters attempted to keep electrode impedences under 5 kΩ. Participants were instructed on the task procedure and several checks were performed to make sure each participant understood these instructions including 10 practice trials (Figure 1). Participants were presented orange and purple hearts, which were counterbalanced to represent either positive or negative relationship feedback (i.e. compatible or not compatible). These hearts were generated using Photoshop to be identical on low-level perceptual factors (i.e. luminance and saturation).

The Relationship Match Game was pilot tested for design, believability, selection of relationship topics and for conducting a power analysis (see Supplement). This task was separated into four blocks of 25 trials during which participants' relationship compatibility judgements were measured about 100 relationship characteristics (e.g. intimacy and love; order randomized), followed by randomized feedback on relationship compatibility from an expert panel of fictive peers and then from their romantic partner. The full trial progression, including timings, is presented in Figure 2. The expert panel, which consisted of three fictive peers, typically expressed unanimous feedback. To enhance believability, five 'attention' trials were included in which the panel presented mixed feedback. Each of the four blocks was divided into five sub-blocks of four experimental trials, which was followed by one attention trial. In addition, memory tasks were randomly presented within each sub-block immediately after an experimental trial. Thus, there were four blocks that each consisted of 20 experimental trials and five attention trails, resulting in 100 total trials. At the beginning of each block, participants were shown three pictures of college students from UCLA with names and ages, which were balanced for gender and ethnicity across each panel with their faces blurred ostensibly to protect the identity of the expert panel members.

All participants were presented the same set of panel members in the same order. Trials were structured so that participants first saw one of 100 relationship topics (see Supplementary Table S1) and were asked if they were compatible with their partner on that topic, responding by using a Logitech F310 Gamepad controller's

[1] The pattern of data was similar when excluding the same-sex couples.

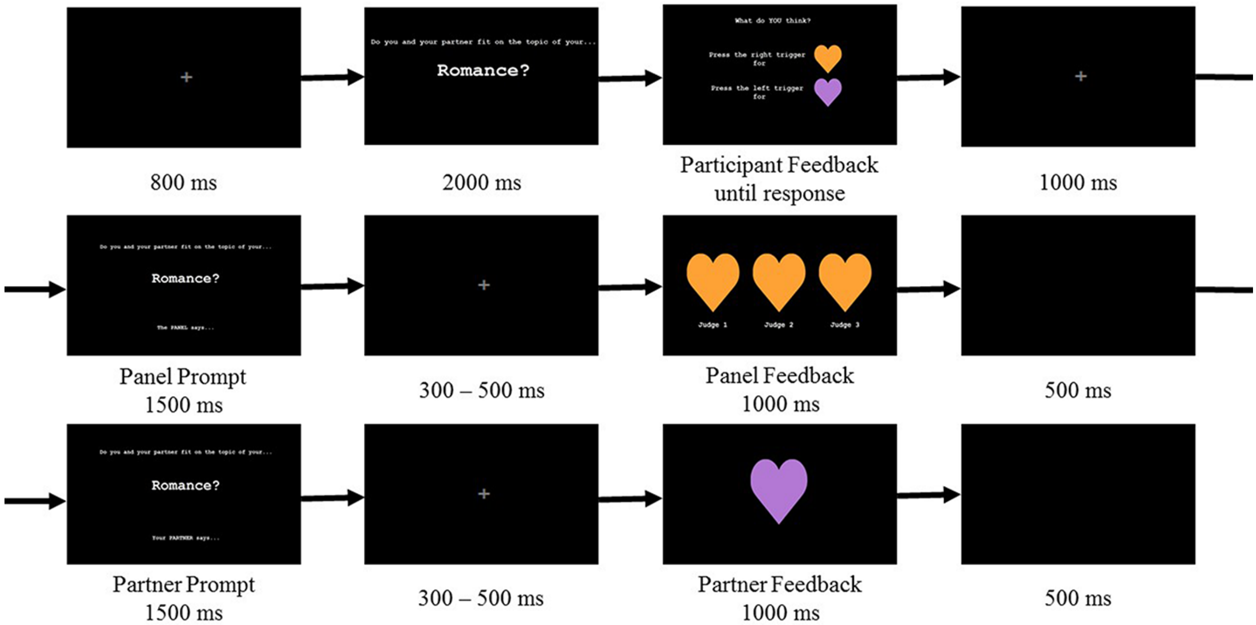

Fig. 2. Single trial methods including timings of the Relationship Match Game. The top row shows the process for participants' judgements about relationship compatibility, the middle row shows the process for receiving feedback from the peer expert panel and the final row shows the process for receiving feedback from their romantic partner. In this example, orange hearts represented positive feedback indicating the couple matched on a relationship characteristic and purple hearts represented negative feedback indicating the couple did not match on a relationship characteristic. Thus, the participant received positive feedback from the expert panel but negative feedback from their romantic partner.

'bumpers' (counterbalanced left/right) to indicate compatibility using the purple or orange hearts (Participant Feedback). Next, the participant was reminded of the topic and cued that they were about to see the feedback from the panel (Panel Prompt) and subsequently was presented with each panel member's feedback, which was always unanimous for experimental trials and presented all at once (Panel Feedback). Next, participants were reminded of the current topic and cued that they were about to receive feedback from their romantic partner (Partner Prompt) and subsequently were presented with their partner's feedback on the topic (Partner Feedback). Memory tasks were randomly presented within each sub-block. At the end of one random trial within each sub-block of four trials participants underwent a brief memory task in which they indicated their own, panels', and romantic partner's responses to ensure active participation. All feedback from both the panel and participant's partner were randomly selected from eight possible outcomes (Panel (Positive *vs* Negative) × Partner (Positive *vs* Negative) × 2 for repetition) resulting in an equal number of combined feedback conditions, varying only by the participant's response. The task took about 40 min to complete, and afterward, participants were debriefed that all feedback from both the expert panel and romantic partner was fabricated and did not reflect their relationship compatibility.

These procedures were approved by the Arizona State University Institutional Review Board. All data are publicly available at https://osf.io/c2xsb/. Study details, including sample size, visual stimuli, relationship topics, panel members and EEG parameters were pilot tested and altered in response to participant feedback and initial results to ensure rigorous standards of maximizing power and minimizing error/flaws in the design. A detailed discussion of this can be found in the supplementary materials.

EEG acquisition and processing

EEG was recorded at 1000 Hz with a NeuroScan Synamps RT system using an EasyCap 32-channel cap with an online bandpass filter of 0.1–100 Hz. The data were referenced offline to the average of the left and right mastoids and were bandpass filtered from 0.1 to 30 Hz and merged into continuous EEG files. Blinks were identified by correlating ICA component activations using CudaICA (Raimondo *et al.*, 2012) with data from EOC for vertical and horizontal eye movements and subsequently removed from the data (Jung *et al.*, 2000). After this step, exceptionally noisy channels were identified as those showing variance more than 4.5 standard deviations from the mean of the participant and interpolated using a spherical approximation of the surrounding electrodes.

For this study, a 'trial' consisted of all events occurring from the time that participants gave their response indicating their belief about compatibility on a topic until and including their partner's feedback on the same topic. Trials were thus epoched into separate events from −200 ms to 1000 ms around feedback presentation for ERP reactions to both panel and partner feedback, serving as the primarily analysis. After examining the ERPs for entire trials, we discovered large differences in how participants reacted to prompts of incoming feedback. *Post hoc* analyses were performed to investigate how preceding expectations would influence responses to relationship feedback cues. Because we did not originally design triggers for these events, epochs were created from −200 to 3000 ms around the participant's response for the Panel Prompt and the presentation of the Panel's feedback for the Partner Prompt. These epochs were not baseline corrected because we were interested in the effects of earlier information processing on later processing. In line with previous studies, high-pass filters were used to eliminate low-frequency noise (Widmann *et al.*, 2015; Maess *et al.*, 2016; Alday, 2019). Pre-stimulus potentials remained comparable across conditions (see Figure 3). We then

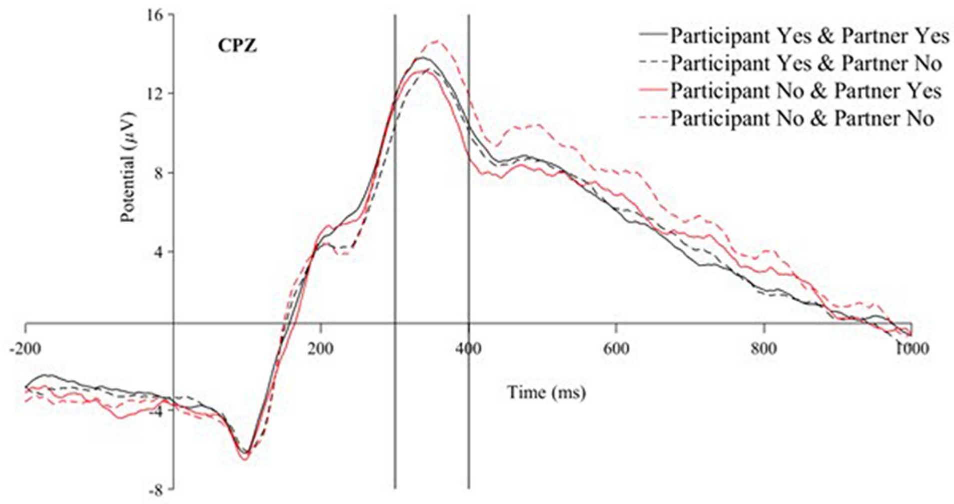

Fig. 3. ERP difference in receiving feedback reflecting the interaction between participant's response and partner's feedback at electrode CPz. A negative perception of the characteristic reinforced by negative feedback from their partner resulted in larger P3s. The measurement window used in analyses is indicated by vertical lines.

performed artifact rejection across midline electrodes (Pz, CPz, Cz, FCz and Fz) using an absolute voltage threshold of $\pm 100\,\mu V$ and averaged remaining trials by bins to form ERPs. Participants who retained fewer than 70% of trials after artifact rejection ($N = 2$) were omitted from data analysis (Hampton and Varnum, 2018).

For this study we focused on components indicating early allocation of attentional resources (fronto-central P2; Luck and Hillyard, 1994) and later, selective or motivated attention (posterior P3; Gray *et al.*, 2004).[2] For each component, we formed a grand average ERP that averaged across all experimental conditions and used this waveform to identify both the peak latency for the component and the peak electrode; measurement windows were generated as symmetrical windows of up to 100 ms total around the peak latency of the component. Thus, the P3 for the prompts was quantified as the mean amplitude from 1362 to 1462 ms (i.e. 362–462 ms after prompt onset) for the Panel Prompt and from 1829 to 1929 ms (i.e. 329–429 ms after prompt onset) for the Partner Prompt, both measured at Cpz. The P2 was not measured for the prompts. The P2 for feedback was quantified as the mean amplitude from 146 to 246 ms for both Panel and Partner Feedback, both measured at Cz. The P3 for feedback was quantified as the mean amplitude from 300 to 400 ms at CPz for both Panel and Partner Feedback conditions.

Statistical modeling and analytic strategy

Data were clustered at three levels; level three represented dyads, level two represented individual participants and level one represented the experimental conditions. To account for this clustering within dyads (in all models, level three variance contributed significant variance, $ps < 0.05$), we used the mixed-fixed model for repeated measures (Maas and Snijders, 2003) to account for clustering at level three and to model random effects for participants at level two. We applied the Satterthwaite correction for degrees of freedom (Satterthwaite, 1946), and results are reported with the adjusted degrees of freedom. Model assumptions for the mixed-fixed models were tested and adequately met (Maas and Hox, 2004).

Exploratory moderation analyses were performed using model building with five of the survey measures that participants completed. These five measures were depressive symptoms (CESD; Radloff, 1977) because of its known relationship with the P3 (Gangadhar *et al.*, 1993; Vandoolaeghe *et al.*, 1998), dyadic relationship satisfaction (Spanier, 1976), rejection sensitivity (Downey and Feldman, 1996), relational ambiguity (Vennum and Fincham, 2011) and relationship length in months as *a priori* selected measures expected to predict reactions to relationship feedback. We selected the appropriate model for interpretation using backward elimination. Each of these survey scores were separately entered as level two (Participant) variables within the mixed-fixed model to test for interactions with the conditions of the study at level one, resulting in four models. After removing non-significant main and interaction effects within each of these models involving the level two predictors, the remaining effects were simultaneously entered as predictors along with the main mixed-fixed model in a final model used for interpretation. Similarly, gender was tested as an exploratory level two (Participant) predictor and moderator for all models to test for gender differences. However, no significant main or interaction effects for gender were found in any of the primary or exploratory models.

All follow-up *t*-tests are Scheffe tests. Cohen's *D* effect sizes and 95% confidence intervals were calculated for *t*-tests using the correction for paired-samples (Dunlap *et al.*, 1996) on the Least Square Mean difference and standard error of Cohen's *D*. Partial eta-squared and 90% confidence intervals were calculated for fixed effects from *F* and uncorrected df values ($df_{dyad} = 48$; Lakens, 2013). All reported effects retain the same level of significance when controlling for gender and when removing same-sex couples.

Results

Behavioral responses

Of the 100 relationship topics each participant viewed, participants more frequently responded positively, indicating relationship compatibility ($M = 57.30$, $SD = 11.51$), than negatively,

[2] We considered testing for the feedback-related negativity (FRN) but neither the pilot data nor the current data showed strong evidence of an FRN response; a finding in line with previous work (Van der Molen *et al.*, 2014; Ding *et al.*, 2017).

Table 1. Average number of trials per condition for Panel Feedback (Top) and Partner Feedback (Middle and Bottom)

Trial counts per condition			
Panel feedback			
		Participant response	
		Compatible	Incompatible
Panel response	Compatible	29.01	10.38
	Incompatible	28.29	11.21
Partner feedback			
Participant indicates 'Compatible'			
		Partner response	
		Compatible	Incompatible
Panel response	Compatible	14.60	14.24
	Incompatible	14.24	14.01
Participant indicates 'Incompatible'			
		Partner response	
		Compatible	Incompatible
Panel response	Compatible	5.19	5.22
	Incompatible	5.40	5.66

indicating a lack of compatibility ($M = 21.59$, $SD = 11.05$), $F(1,89) = 230.48$, $P < 0.001$, $\eta^2 = 0.72$. This shows that the list of relationship topics successfully elicited participants' report of incompatibility at a rate that was roughly 1/4 of all responses.[3] These positive/negative responses were evenly distributed across the randomized conditions, $Fs < 3.2$, $ps > 0.05$ (Table 1).

Social feedback processing

Participants viewed a relationship characteristic and then responded positively or negatively to indicate whether they were a match on the particular relationship characteristic. Participants subsequently received feedback from the peer expert panel (Panel Feedback), resulting in a 2 (Participant: Positive/Negative) by 2 (Panel: Positive/Negative) model. Testing effects for both the P2 and P3 components revealed no significant effects in response to Panel Feedback, $Fs < 1.26$, $ps > 0.26$. Next, when participants viewed their partner's feedback on the relationship characteristic (Partner Feedback) after having viewed the Panel Feedback, this resulted in a 2 (Participant: Positive/Negative) by 2 (Panel: Positive/Negative) by 2 (Partner: Positive/Negative) model. When analyzing the P2 component, no significant effects were found, $Fs < 2.32$, $ps > 0.12$. However, when analyzing the P3 component, the interaction between Participant Feedback and Partner Feedback was significant, $F(1450) = 5.94$, $P = 0.015$, $\eta^2 = 0.110$, 90% CI = [0.010, 0.253]. This interaction was such that both positive and negative partner responses that were consistent with the participants' response elicited larger P3s (Figure 3), although follow-up tests revealed that only the comparison of positive feedback from both participants and partner ($M = 12.26$, $SE = 0.60$) versus positive feedback from the participant followed by negative feedback from the partner ($M = 11.39$, $SE = 0.60$) was significant, $t(263) = 2.55$, $P = 0.011$, $d = 0.21$, 95% CI = [–.19, 0.61].[4]

Next, separate exploratory analysis were conducted examining the relationship between each of the four self-report measures and the observed P3 effect in response to Partner Feedback. We performed several model-building steps to identify relevant moderators of this Participant Feedback by Partner Feedback interaction (see *Statistical Modeling and Analytic Strategy*). Of these models, only Relational Ambiguity (RA) interacted significantly with the Participant Feedback by Partner Feedback effect, $F(1447) = 7.16$, $p = 0.008$, $\eta^2 = 0.130$, 90% CI = [0.018, 0.276], indicating a strong moderation of the effect (Figure 4).[5] This moderation was such that the Participant Feedback by Partner Feedback interaction was exaggerated for those high in RA (Figure 4C; 'High RA effect') and absent for those low in RA (Figure 4B; 'Low RA effect').

Anticipation of social feedback processing

After viewing a relationship characteristic and responding positively or negatively, participants were cued to incoming feedback on the same topic from an expert panel (Panel Prompt). This two-level (Participant Feedback: Positive/Negative) model revealed significantly greater P3 responses to cues of feedback in participants who had previously responded negatively on the trial, $F(2,89) = 32.59$, $P < 0.0001$, $\eta^2 = 0.404$, 90% CI = [0.222, 0.535], indicating greater motivated attention to Panel Prompts in the context of expected negative feedback (Figure 5A).

Next, participants received feedback from the panel followed by another reminder that preceded feedback from their partner (Partner Prompt). This resulted in a 2 (Participant Feedback: Positive/Negative) × 2 (Panel Feedback: Positive/Negative) model predicting P3 responses. Similar to cues of the panel's feedback (Panel Prompt), participants showed significantly greater P3 activation when the participant had responded negatively to indicate a relationship mismatch, $F(1154) = 10.93$, $P = 0.001$, $\eta^2 = 0.185$, 90% CI = [0.046, 0.336]. Conversely, the main effect of Panel Feedback did not significantly predict attention to the Partner Prompt $F(1183) = 2.70$, $P = 0.102$, $\eta^2 = 0.053$, 90% CI = [0.000, 0.180]. Finally, the interaction between Participant Feedback and Panel Feedback was significant (see Figure 5B), $F(1154) = 5.18$, $P = 0.024$, $\eta^2 = 0.097$, 90% CI = [0.006, 0.238]. Follow-up pair-wise comparisons indicated that this was due to the condition in which both the participant and panel provided negative judgements of relationship match on the characteristic ($M = 3.90$, $SE = 0.50$) eliciting larger P3's than when the participant responded positively and the panel responded positively ($M = 2.42$, $SE = 0.38$), $t(96.1) = 3.40$, $P = 0.001$, $d = 0.48$, 95 CI = [0.07, 0.88], or when the participant responded positively and the panel responded negatively ($M = 2.20$, $SE = 0.48$), $t(103) = 3.07$, $P = 0.003$, $d = 0.49$, 95 CI = [0.09, 0.90], and when the participant responded negatively and the panel responded positively ($M = 2.74$, $SE = 0.38$), $t(95.8) = 2.73$, $P = 0.008$, $d = 0.37$, 95% CI = [–.02, 0.77].

Discussion

We developed the Relationship Match Game to investigate the neural mechanisms underlying social feedback processing within existing romantic couples. Neural responses were measured during anticipation and receiving of social feedback from an expert panel of fictive peers and their romantic partner in the context of participant's indication of whether they are a match on a relationship characteristic. Previous research among fictive peers or dating partners found larger selective attention to positive feedback, underscoring the importance of socially rewarding information that facilitates affiliation (Kujawa *et al.*, 2017; Funkhouser

[3] Five participants exclusively responded positively to all relationship topics; however, re-running all analyses without these participants did not change significance levels of reported effects and in fact, almost slightly increased the size of reported effects.

[4] 95% confidence intervals for paired-samples t-tests do not necessarily avoid crossing the 0 point because the t-test corrects for correlations between the means and Cohen's D does not (Dunlap *et al.*, 1996).

[5] This effect held when controlling for all other significant level two predictors, $F(4156) = 3.08$, $P = 0.018$.

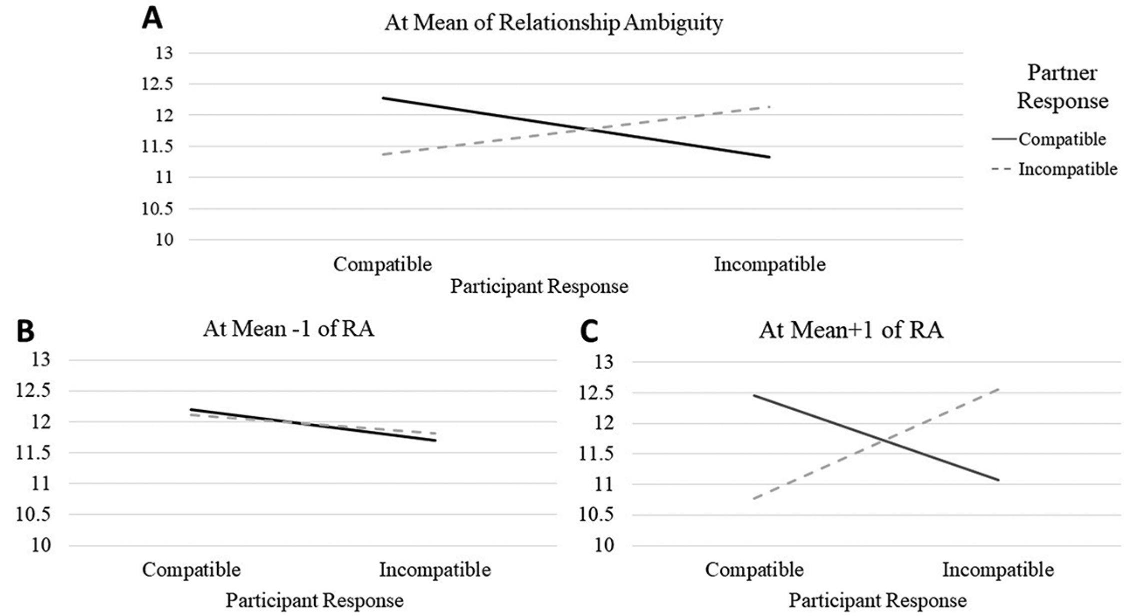

Fig. 4. Moderation of the Participant response by Partner feedback interaction (A) by Relational Ambiguity. At one standard error below the mean of RA (B), the overall interaction is not present, whereas at one standard error above the mean of RA (C), the interaction is strengthened.

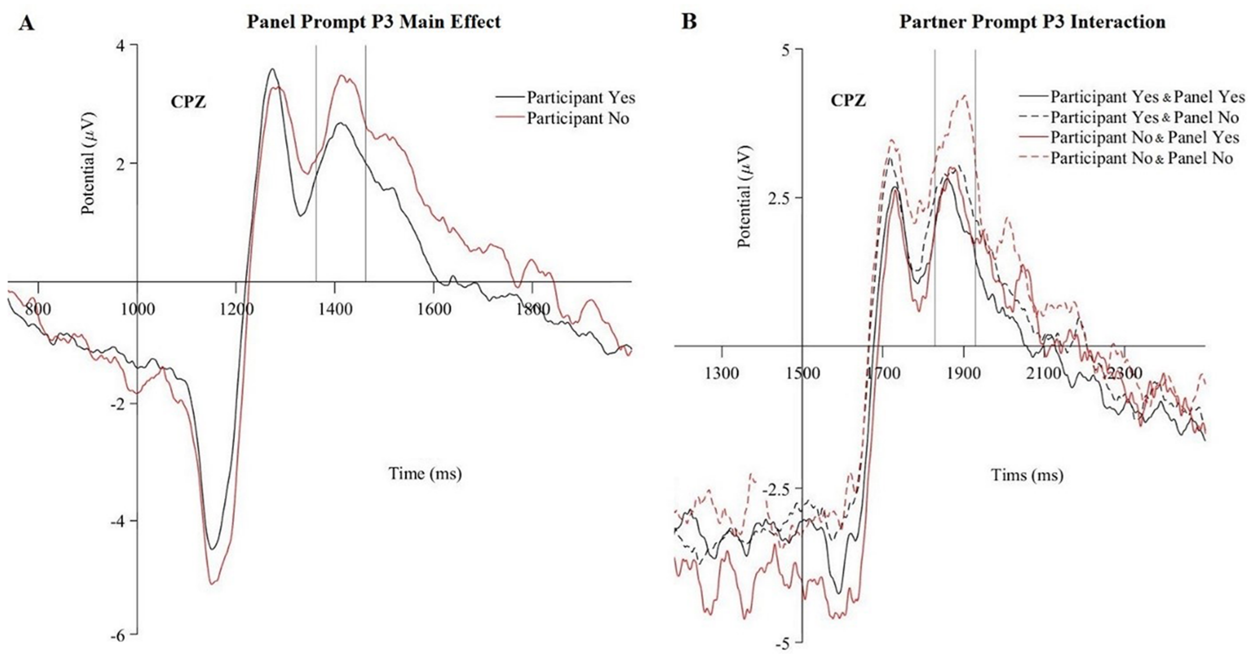

Fig. 5. ERP effects in response to prompts of incoming feedback from (A) peer expert panel and (B) romantic partner. Measurement windows used in the analyses are shown with vertical lines. These components cross the y-axis at the time following the previous trigger since we did not originally program triggers for these events.

et al., 2020; Van der Veen *et al.*, 2019). However, our results indicate that romantic partners show more selective attention to both confirmatory negative and positive social feedback.

This effect was strongly moderated by individual differences in relational ambiguity, such that participants high in relational ambiguity were attentive to both confirmatory negative and positive feedback of romantic partners. Congruent positive relationship feedback may be an important cue to spend more resources and energy in the relationship, whereas congruent negative relationship feedback may serve as a signal that the relationships may not be worth investing in. In contrast, partners who were low on relational ambiguity did not show this interaction pattern but instead showed equivalent P3 responses to both positive and negative partner feedback. Those low in relational ambiguity might be able to more efficiently use attention as they are less vigilant to social feedback from romantic partners or are at least equally attentive to both positive and negative feedback.

The P3 component in social feedback processing is interpreted as an indication that responses to partner feedback are both influenced by expectations (based on the participant's assessments about compatibility) and personal relevance of social feedback about one's romantic relationship. This is in line with general interpretations of the posterior P3 (P3b) based on classic work (Johnson, 1986; Donchin and Coles, 1988) and more modern theories (Gray *et al.*, 2004; Polich, 2007), suggesting that the P3 amplitude reflects both perceived probability and motivational relevance, especially self-relevance. Polich (2007) also pointed to the effects of task demand and stimulus duration of the P3 as evidence that the P3 amplitude strongly reflects the allocation of attentional resources. Thus, increased P3 amplitudes are interpreted as increased attentional allocation based on probabilistic expectations grounded in previous relationship experiences that are also highly self-relevant. Previous social feedback studies have interpreted the P3 as social reward (Van der Veen *et al.*, 2014, 2016). However, these studies were conducted with unfamiliar peers or romantic partners before these relationships were established. Within existing romantic couples, the interpretation of the P3's amplitude as indicative of 'reward' does not explain the current findings. This is especially true for cumulative negative social feedback of both the expert panel of fictive peers and romantic partner, which should be universally unrewarding. Processing social feedback in the context of established romantic couples may therefore serve the purpose of updating one's cognitive schemas regarding their romantic relationship.

A major extension to previous research is that no differential effects were found in response to evaluative feedback from fictive peers, corroborating an earlier report among couples (Kuo *et al.*, 2017), potentially indicating that when compared to partner feedback, the panel's feedback was less motivationally relevant for updating expectations about the relationship. The current results suggest that feedback from the panel of fictive peers was more relevant during the anticipation of feedback. During the anticipation phase, participants differentially attended to both panel and partner feedback cues based on their own expectations. When participants indicated a mismatch on a relationship characteristic, they showed larger P3's to cues signaling incoming feedback from the panel of fictive peers. If the panel of fictive peers corroborated the participants' evaluation of a relationship mismatch, then participants showed even larger P3's when cued that feedback from their partner was about to appear. Fictive peers were thus an important source of feedback by accumulating negative feedback about the relationship, which directed the participants' attention to upcoming partner feedback.

The anticipation phase is not often studied in social feedback studies, because researchers are typically interested in how social feedback is processed afterward (Van der Molen *et al.*, 2014, 2018). However, within the context of existing relationships this phase is crucial as there is an abundant supply of relationship feedback in real life. Keeping track of all relationship feedback cues may not be an efficient deployment of resources and previous studies have shown that social reward cues can draw differential attention as measured by P3 amplitudes (Flores *et al.*, 2015). Our results suggest that motivated attention during the anticipation of feedback may be especially strong when we doubt relationship compatibility. This may mean that insecurity about the relationship is costly in terms of attentional and emotional resources, which may contribute to over-alertness to otherwise innocuous cues.

The current study found no moderation of gender on the P3. The lack of gender differences is in line with a previous study among potential romantic partners that used a Tinder- like paradigm (Van der Veen *et al.*, 2019). In contrast, previous work among unfamiliar and fictive peers showed larger P3 differences between positive and negative social feedback for males (Van der Veen *et al.*, 2016). It is possible that the absence of gender differences to partner feedback is due to the fact that social feedback in the context of an existing romantic relationship is equally motivating and impactful to both males and females. Alternatively, we acknowledge that gender differences were possibly not found due to a lack of power to detect relatively smaller effects.

Limitations and future directions

Despite the novel test of social feedback within existing romantic couples in which we were able to successfully manipulate romantic relationship feedback in the context of one's own relationship expectations, there are limitations that should be noted. First, it will remain important to replicate current findings in larger samples of couples, especially for the anticipation phase as these were performed *post hoc*. Second, the fictive peer condition was included to be able to compare the social feedback results to previous literature. In young adulthood, social feedback from friends and other network members about one's romantic relationship is an important factor that may hold more importance than fictive peers (Sprecher, 2011). Acknowledging that it may be complicated to manipulate both real friend and romantic feedback in one study, it will be important to test the importance of social feedback from real friends. Third, as expected participants are more inclined to rate relationships characteristics as compatible and it will be important for future research to include more frequent incompatible ratings of participants. Fourth, the P3 in the current study was interpreted as a measure of motivationally relevant selective attention but alternative explanations of the P3 are possible. For example, it could reflect an effect of differential probability, as suggested by the significant interaction between the participant's expectations and their partner's social feedback on the relationship characteristics. In addition, the P3 could reflect increased relevance of the information presented. Since the P3 is a relatively large ERP component, it is likely that the P3 constitutes a combination of all of these explanations (Luck, 2014). Finally, we raise the possibility that congruent and incongruent social feedback may be important cues to either spend more or less time and energy in the relationship. Future studies should study how these neural responses predict the longevity of these romantic relationships by following the couples over time.

Figuring out whether a romantic partner is a match might be one of the most important decisions facing young adults, affecting future wellbeing, health and even mortality (Holt-Lunstad *et al.*, 2010). The current study shed more light on the neural dynamics underpinning this evaluative process. Using an ecologically valid Relationship Match Game in an ethnically diverse sample, this study showed that people are wired to anticipate and receive social feedback from real romantic partners about romantic relationship compatibility, especially when they are uncertain or have relationship doubts.

Acknowledgements

The authors are grateful to Jasmine Sutton and Ciera Arnett for their assistance in data acquisition. The authors thank Gene Brewer, Chris Blais, Michael Varnum and Kevin Grimm for their feedback on previous drafts of the paper.

Funding

This work was supported by start-up funds (to T.H.).

Conflict of interest

None declared.

Supplementary data

Supplementary data are available at SCAN online.

References

Alday, P.M. (2019). How much baseline correction do we need in ERP research? Extended GLM model can replace baseline correction while lifting its limits. *Psychophysiology*, **56**(12), 1–22.

Berscheid, E. (1999). The greening of relationship science. *American Psychologist*, **54**, 260–6.

Broyd, S.J., Richards, H.J., Helps, S.K., Chronaki, G., Bamford, S., Sonuga-Barke, E.J.S. (2012). An electrophysiological monetary incentive delay (e-MID) task: a way to decompose the different components of neural response to positive and negative monetary reinforcement. *Journal of Neuroscience Methods*, **209**(1), 40–9.

Dekkers, L.M.S., Van der Molen, M.J.W., Gunther Moor, B., Van der Veen, F.M., Van der Molen, M.W. (2015). Cardiac and electro-cortical concomitants of social feedback processing in women. *Social Cognitive and Affective Neuroscience*, **10**, 1506–14.

Ding, Y., Wang, E., Zou, Y., *et al.* (2017). Gender differences in reward and punishment for monetary and social feedback in children: an ERP study. *PLoS One*, **12**(3), e0174100.

Doñamayor, N., Schoenfeld, M.A., Münte, T.F. (2012). Magneto- and electroencephalographic manifestations of reward anticipation and delivery. *NeuroImage*, **62**, 17–29.

Donchin, E., Coles, M.G.H. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences*, **11**, 357–74.

Downey, G., Feldman, S.I. (1996). Implications of rejection sensitivity for intimate relationships. *Journal of Personality and Social Psychology*, **70**(6), 1327–43.

Draucker, C.B., Martsolf, D., Stephenson, P.S. (2012). Ambiguity and violence in adolescent dating relationships. *Journal of Child and Adolescent Psychiatric Nursing*, **25**, 149–57.

Dunlap, W.P., Jose, J.M., Vaslow, J.B., Burke, M.J. (1996). Meta-analysis of experiments with matched groups or repeated measures designs. *Psychological Methods*, **1**, 170–7.

Fletcher, G.J.O., Simpson, J.A., Campbell, L., Overall, N.C. (2015). Pair-bonding, romantic love, and evolution: the curious case of homo sapiens. *Perspectives on Psychological Science*, **10**, 20–36.

Flores, A., Münte, T.F., Donamayor, N. (2015). Event-related EEG responses to anticipation and delivery of monetary and social reward. *Biological Psychology*, **109**, 10–9.

Funkhouser, C.J., Auerbach, R.P., Kujawa, A., Morelli, S.A., Phan, K.L., Shankman, S.A. (2020). Social feedback valence differentially modulates the reward positivity, P300, and late positive potential. *Journal of Psychophysiology*, **34**, 255–67.

Gangadhar, B.N., Ancy, J., Janakiranaiah, N., Umapathy, C. (1993). P300 amplitude in non-bipolar, melancholic depression. *Journal of Affective Disorders*, **28**, 57–60.

Gray, H.M., Ambady, N., Lowenthal, W.T., Deldin, P. (2004). P300 as an index of attention to self-relevant stimuli. *Journal of Experimental Social Psychology*, **40**, 216–24.

Gunther Moor, B., van Leijenhorst, L., Rombouts, S.A.R.B., Crone, E.A., Van der Molen, M.W. (2010). Do you like me? Neural correlates of social evaluation and developmental trajectories. *Social Neuroscience*, **5**, 461–82.

Guyer, A.E., Choate, V.R., Pine, D.S., Nelson, E.E. (2012). Neural circuitry underlying affective response to peer feedback in adolescence. *Social Cognitive and Affective Neuroscience*, **7**, 81–92.

Hampton, R.S., Varnum, M.E.W. (2018). Do cultures vary in self-enhancement? ERP, behavioral, and self-report evidence. *Social Neuroscience*, **13**, 566–78.

Holt-Lunstad, J., Smith, T.B., Layton, J.B. (2010). Social relationships and mortality risk: a meta-analytic review. *PLoS Medicine*, **7**, e1000316.

Howard, D.E., Debnam, K.J., Cham, H.J., *et al.* (2015). The (mal) adaptive value of mid-adolescent dating relationship labels. *The Journal of Primary Prevention*, **36**, 187–203.

Johnson, R. (1986). A triarchic model of P300 amplitude. *Psychophysiology*, **23**(4), 367–84.

Jung, T.-P.-P., Makeig, S., Humphries, C., *et al.* (2000). Removing electroencephalographic artifacts by blind source separation. *Psychophysiology*, **37**, 163–78.

Kujawa, A., Kessel, E.M., Carroll, A., Arfer, K.B., Klein, D.N. (2017). Social processing in early adolescence: associations between neurophysiological, self-report, and behavioral measures. *Biological Psychology*, **128**, 55–62.

Kuo, C., Ha, T., Ebbert, A.M., Tucker, D.M., Dishion, T.J. (2017). Dynamic responses in brain networks to social feedback: a dual EEG acquisition study in adolescent couples. *Frontiers in Computational Neuroscience*, **11**, 1–13.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, **4**, 1–12.

Luck, S.J. (2014). *An Introduction to the Event-related Potential Technique*, 2nd edn, Cambridge, MA: The MIT Press.

Luck, S.J., Hillyard, S.A. (1994). Electrophysiological correlates of feature analysis during visual search. *Pyshchophysiology*, **31**, 291–308.

Maas, C.J.M., Hox, J.J. (2004). The influence of violations of assumptions on multilevel parameter estimates and their standard errors. *Computational Statistics and Data Analysis*, **46**(3), 427–40.

Maas, C.J.M., Snijders, T.A.B. (2003). The multilevel approach to repeated measures for complete and incomplete data. *Quality and Quantity*, **37**, 71–89.

Maess, B., Schröger, E., Widmann, A. (2016). High-pass filters and baseline correction in M/EEG analysis. Commentary on: “How inappropriate high-pass filters can produce artefacts and incorrect conclusions in ERP studies of language and cognition”. *Journal of Neuroscience Methods*, **266**(8), 164–5.

Masten, C.L., Telzer, E.H., Fuligni, A.J., Lieberman, M.D., Eisenberger, N.I. (2012). Time spent with friends in adolescence relates to less neural sensitivity to later peer rejection. *Social Cognitive and Affective Neuroscience*, **7**, 106–14.

McNulty, J.K., Olson, M.A., Meltzer, A.L., Shaffer, M.J. (2013). Though they may be unaware, newlyweds implicitly know whether their marriage will be satisfying. *Science*, **342**, 1119–20.

Owen, J.J., Rhoades, G.K., Stanley, S.M., Fincham, F.D. (2010). “Hooking up” among college students: demographic and psychosocial correlates. *Archives of Sexual Behavior*, **39**, 653–63.

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology*, **118**, 2128–48.

Radloff, L.S. (1977). The CES-D scale: a self-report depression scale for research in the general population. *Applied Psychological Measurement*, **1**, 385–401.

Raimondo, F., Kamienkowski, J.E., Sigman, M., Slezak, D.F. (2012). CUDAICA: GPU optimization of infomax-ICA EEG analysis. *Computational Intelligence and Neuroscience*, **2012**, 8.

Satterthwaite, F.E. (1946). An approximate distribution of estimates of variance components. *Biometrics Bulletin*, **2**, 110–4.

Simpson, J.A., Campbell, L. (2013). *The Oxford Handbook of Close Relationships*. New York: Oxford University Press.

Somerville, L.H., Heatherton, T.F., Kelley, W.M. (2006). Anterior cingulate cortex responds differentially to expectancy violation and social rejection. *Nature Neuroscience*, **9**, 1007–8.

Somerville, L.H., Jones, R.M., Casey, B.J. (2010). A time of change: behavioral and neural correlates of adolescent sensitivity to appetitive and aversive environmental cues. *Brain and Cognition*, **72**, 124–33.

Spanier, G.R. (1976). Measuring dyadic adjustment: new scales for assessing the quality of marriage and similar dyads. *Journal of Marriage and Family*, **38**, 15–28.

Sprecher, S. (2011). The influence of social networks on romantic relationships: through the lens of the social network. *Personal Relationships*, **18**, 630–44.

Van der Molen, M.J., Poppelaars, E.S., Van Hartingsveldt, C.T., Harrewijn, A., Gunther Moor, B., Westenberg, P.M. (2014). Fear of negative evaluation modulates electrocortical and behavioral responses when anticipating social evaluative feedback. *Frontiers in Human Neuroscience*, **7**, 936.

Van der Molen, M.J., Harrewijn, A., Westenberg, P.M. (2018). Will they like me? Neural and behavioral responses to social-evaluative peer feedback in socially and non-socially anxious females. *Biological Psychology*, **135**, 18–28.

Van der Veen, F.M., Van der Molen, M.W., Sahibdin, P.P., Franken, I.H.A. (2014). The heart-break of social rejection versus the brain wave of social acceptance. *Social Cognitive and Affective Neuroscience*, **9**, 1346–51.

Van der Veen, F.M., Van der Molen, M.J.W., Van der Molen, M.W., Franken, I.H.A. (2016). Thumbs up or thumbs down? Effects of neuroticism and depressive symptoms on psychophysiological responses to social evaluation in healthy students. *Cognitive, Affective, Behavioral Neuroscience*, **16**, 836–47.

Van der Veen, F.M., Burdzina, A., Langeslag, S.J.E. (2019). Don't you want me, baby? Cardiac and electrocortical concomitants of romantic interest and rejection. *Biological Psychology*, **146**, 107707.

Vandoolaeghe, E., van Hunsel, F., Nuyten, D., Maes, M. (1998). Auditory event related potentials in major depression: prolonged P300 latency and increased P200 amplitude. *Journal of Affective Disorders*, **48**, 105–13.

Vennum, A., Fincham, F.D. (2011). Assessing decision making in young adult romantic relationships. *Psychological Assessment*, **23**(739), 739–51.

Volpe, U., Mucci, A., Bucci, P., Merlotti, E., Galderisi, S., Maj, M. (2007). The cortical generators of P3a and P3b: a LORETA study. *Brain Research Bulletin*, **73**(4–6), 220–30.

Widmann, A., Schröger, E., Maess, B. (2015). Digital filter design for electrophysiological data – a practical approach. *Journal of Neuroscience Methods*, **250**, 34–46.