



## Don't you want me, baby? Cardiac and electrocortical concomitants of romantic interest and rejection

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### ABSTRACT

Online dating has become a very popular way to find a romantic partner. In the present study, we examined whether romantic interest and rejection in such a setting would evoke differential electrocortical and cardiac responses. For this purpose a database was created, similar to a dating website, where the participants' personal information and photos were placed. Heterosexual, single participants (N = 61) evaluated the profiles of opposite-sex potential romantic partners and decided whether they would like to date this person or not. Subsequently, participants passively viewed (34 analyzable volunteers participated in the EEG session; 10 male; mean age = 20) the pictures of the potential partners together with their own judgment about the "dateability" of the potential partner, and the potential partner's judgment of the "dateability" of the participant. After viewing the pictures participants received the email addresses to contact their matches. Electrocortical and cardiac responses to these "match" or "non-match" judgments were measured. A significantly larger P3 response was found when participants received a positive evaluation as compared to negative evaluations. This is in line with an explanation in terms of reward. A significantly larger cardiac deceleration was found when participants received a negative evaluation as compared to positive evaluations, which is in line with an explanation in terms of social pain. Findings are discussed in terms of activation of different parts of the anterior cingulate cortex.

### 1. Introduction

Love is considered one of the basic human needs (Maslow, 1943). It is an essential part of human life across the globe, as traces of it have been found in 147 societies out of 166 (88.5%)<sup>1</sup>, making love an almost universal phenomenon (Baumeister, Wotman, & Stillwell, 1993; Fisher, 2004; Jankowiak & Fischer, 1992). Romantic love has been playing a major role in the evolution of humans. The urge to find a trustworthy partner and to maintain a lasting romantic relationship can be seen as an evolutionary adaptive mechanism essential for survival and reproduction (Baumeister & Leary, 1995; Leary, 2001). In recent years a shift in the methods to find a romantic partner has occurred with the rise of online dating services which have become extremely popular. Already in 2003, 2 out of 5 American singles visited online dating services (Gershberg, 2004). One of the most popular online dating applications, i.e. Tinder, has at least 10 million users a day, with every user logging in approximately 11 times every 24 h (Ayers, 2014). Despite all these new opportunities to find a romantic partner, cases of

romantic rejection are common. Rejection of romantic feelings are known to be implicated in the etiology of wide range of serious psychological consequences, including depression, anxiety, mood swings, apathy, and suicide (Monroe, Rohde, Seeley, & Lewinsohn, 1999; O'Donnell, Farmer, & Catal, 1996) and therefore it deserves further study. Moreover, it has also been found that the sensitivity to rejection cues is related to a number of personality traits, such as neuroticism and schizotypal personality, both of which seem to be related to altered attention to rejection cues (Premkumar et al., 2012, 2015). In order to address the gap in knowledge regarding the neurobiological basis of romantic rejection and acceptance, we studied event-related potentials (ERPs) and cardiac responses to these types of events. However, existing theory and research that has focused on the neural concomitants of romantic rejection as well as on romantic rejection in the context of online dating is very limited.

Relatively few studies have been performed on the topic of particularly romantic rejection as compared to, for example, social rejection and exclusion. This can probably be attributed to the difficulty of

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<sup>1</sup> In all other 19 societies love was not found either due to difficulties with gathering data or due to the issues with ethnographic knowledge about particular regions (Fisher et al., 2010).

creating a research design for this complicated phenomenon, especially in a laboratory setting (Baumeister et al., 1993). In one fMRI study (Fisher, Brown, Aron, Strong, & Mashek, 2010), researchers have investigated the neural correlates of romantic rejection in healthy participants who were recently rejected by their partners. The rejecter stimulus was a photograph of the ex-partner, and the neutral stimulus was a photograph of a familiar person of the same sex as the rejecter (Fisher et al., 2010). Viewing the rejecter photograph elicited more activation than viewing the neutral photograph in a wide range of areas including areas involved in the dopaminergic reward system (e.g., ventral striatum) (Fisher et al., 2010). Furthermore, thinking about the ex-partner elicited activation in the dorsal anterior cingulate cortex (dACC) and the anterior insular cortex (AI), which are known to be associated with the affective side of pain, both social and physical (Eisenberger, 2012), and to be involved in the processing of the negative social feedback, unpleasant stimuli, and prediction errors (Shackman et al., 2011; Somerville, Heatherton, & Kelley, 2006). Eisenberger and Lieberman (2004) conceptualized the dACC as a neural alarm system in which the dACC is both involved in detecting discrepancies (what is different?) and acts as a ‘sounding mechanism’ which signals that there is a problem that needs to be addressed (what is wrong?; e.g. pain). In a recent fMRI study (Cooper, Kreps, Wiebe, Pirkl, & Knutson, 2010), a speed-dating paradigm was developed to investigate romantic rejection. Participants met other potential partners during a number of speed-date events, each lasting five minutes. They had an face-to-face conversation without specific instructions, after which participants stated whether they wanted to meet that person again. During fMRI scanning, subjects viewed photographs of the people they interacted with along with their own answer and the potential partner’s answer. Romantic rejection led to heightened activity in a cluster in the dACC (Cooper et al., 2010), which is in line with the findings of Fisher et al. (2010) and supports the idea that romantic rejection activates the pain network.

An important disadvantage of studies using fMRI is the low temporal resolution of the measurements and the somewhat aversive laboratory environment. Therefore, it would be interesting to examine romantic rejection with an event-related brain potential (ERP) approach, which has a better temporal resolution and can be used to disentangle the time-course of the different involved brain processes. Although no studies on romantic rejection using this approach have been performed until now, this approach has been used in the study of social rejection (Van der Molen, Dekkers, Westenberg, van der Veen, & Van der Molen, 2017; Van der Molen, Harrewijn, & Westenberg, 2018; Van der Veen, van der Molen, van der Molen, & Franken, 2016; Van der Veen, van der Molen, Sahibdin, & Franken, 2014). These studies used a social rejection task based on task developed by Somerville et al. (2006), in which participants were asked to send a picture of themselves to the researchers, and they were told that a group of people would evaluate their picture on the basis of a first impression in terms of “like” or “do not like”. In the actual task, participants saw the picture of these virtual judges and were asked whether they thought this person liked them or not. In these studies it was found that the amplitude of the P3 component was largest for expected “like” judgments. The P3 is a positive going ERP component which is maximal between 300 and 800 ms, and most often an early, fronto-central P3a and a later parietal P3b component are distinguished. The P3a is suggested to be reflection of the frontal attention processes, and the P3b is considered to reflect attention and subsequent memory processing (Polich, 2007). Due to the relatively early onset, the P3 in the social rejection task has been interpreted as a P3a component. Van der Veen et al. (2014) suggested that the enhanced P3 to expected “like” judgments might be related to the interpretation of this condition as more socially rewarding in comparison to the other conditions (Van der Veen et al., 2014). They interpreted the enhanced P3-like response in this condition in terms of an electro-cortical manifestation of a social bias, which can be interpreted as the confirmation of the participants’ expectation to be liked is

socially rewarding. An interpretation in terms of social reward fits nicely with earlier work on the effects of reward on the P3 amplitude, which showed, by using monetary rewards, that the P3 is larger in response to positive, rewarding outcomes (Bellebaum, Polezzi, & Daum, 2010; Hajcak, Moser, Holroyd, & Simons, 2007; Van den Berg, Shaul, Van der Veen, & Franken, 2012). In this way the P3 amplitude can be linked to the motivational relevance of the stimulus as proposed by Nieuwenhuis, Aston-Jones, and Cohen, (2005). More recent studies have also stressed the specific relevance of motivational aspects influencing the P3 amplitude (e.g., San Martín, 2012; Threadgill & Gable, 2018).

Due to the fact that the effect of an enhanced P3 to expected acceptance stimuli was not replicated in two other ERP studies that used the same paradigm (Dekkers, van der Molen, Gunther Moor, van der Veen, & van der Molen, 2015; Van der Molen et al., 2013), it has been suggested that gender might be a possible important factor (Van der Veen et al., 2016). Although these two studies also reported the largest P3 amplitudes for expected “like” judgments, the differences were not statistically significant. As suggested by Van der Veen et al. (2016), this lack of differences is possibly related to the fact that these studies only included female participants, whereas in both studies of van der Veen et al. both males and females were included. Van der Veen et al. (2016) have shown that gender can influence the P3 amplitude in this paradigm and that males show the large P3 amplitude differences between expected “like” judgments and the other stimulus categories. Van der Veen et al. (2016) has, furthermore, argued that as social exclusion is related to negative outcomes, it might be perceived as being more painful by females rather than by males. This argument is supported by the research of Benenson et al. (2013), where it has been found that females react faster to social exclusion information, as well as become more aroused by an exclusion stimulus. Benenson et al. have argued that this higher use of and sensitivity to social exclusion is due to the stronger dependence of isolated one-on-one relationships in which social exclusion is a more useful strategy. In this way, it can be argued that negative information has a stronger influence on females, and so they could be faster in recognizing stimuli as social exclusion. Therefore, females might have paid almost the same amount of attention to negative social feedback and positive feedback stimuli, leading to smaller differences between the P3 amplitudes in different conditions (Dekkers et al., 2015; Van der Molen et al., 2013). Recent findings showed, however, that a significant P3 to expected acceptance feedback can be found in females with and without social anxiety (van der Molen et al., 2018). This suggests that gender might not be contributing to this effect as strongly as was argued by Van der Veen et al. (2016). Perhaps differences in the methodology (i.e., voltage analyses vs current source density analyses) that were used to analyze and display the P3 might be the reason why Dekkers et al. (2015) and Van der Molen et al. (2013) were not able to find the P3 effect.

Next to gender differences, ERP responses to social rejection have also been related to personality characteristics such as neuroticism and schizotypy (Premkumar et al., 2014, 2015). In these studies rejection, acceptance and neutral scenes were shown and the general finding was that P3 and following positive slow waves were enhanced during rejection scenes as compared to neutral and acceptance scenes. Moreover, it was found that an early attention related component (N100) was related to both positive schizotypy and rejection sensitivity (Premkumar et al., 2014) and that a later attention related component (P200) was differentially related to positive and negative schizotypy (Premkumar et al., 2015).

Besides examining effects on ERP components, it could also be of a particular interest to investigate cardiac responses to romantic rejection, as a consistent pattern of a transient cardiac deceleration in response to unexpected rejection has been found in the earlier described social rejection task (Dekkers et al., 2015; Gunther Moor, Crone et al., 2010; Gunther Moor, Crone, & van der Molen, 2010; Van der Veen et al., 2014, 2016). It has been suggested that this cardiac slowing

reflects activation of the parasympathetic nervous system in response to violations of expectations. This cardiac response has been related to activation of the dACC (Gunther Moor, Crone et al., 2010; Gunther Moor, Crone, & van der Molen, 2010), which is supposed to play a role in the earlier mentioned neural alarm system activated by cues that signal social pain (Eisenberger & Lieberman, 2004). It should be noted that recent work of Van der Molen et al. (2017, 2018) in which source-analysis of the EEG signal was used, showed that unexpected rejection was also associated with activation in brain areas overlapping with the pain network. Moreover, an effect quite similar to the cardiac findings was found, namely unexpected rejection led to a profound increase in theta oscillatory power. The findings further substantiate the link with social pain and provide a clear rationale for focusing on both electrocortical and cardiac measures in this study, since similar neurovisceral mechanisms might be at play in romantic rejection.

Taken together, it seems important to fill the obvious gaps left by previous research by examining the ERP and cardiac responses to both positive and negative romantic judgments. In this way, we can examine the brain and cardiac mechanisms involved in romantic evaluations and evaluate whether romantic evaluation is associated with similar brain mechanisms as social evaluation. Furthermore, we can evaluate whether online dating as opposed to speed dating can be successfully used as a research tool to study romantic evaluation. The main goal of the present investigation therefore was to examine whether the earlier described rewarding effect of social acceptance on P3 amplitude (e.g. Van der Veen et al., 2014) and the socially painful effect of social rejection on cardiac deceleration (e.g. Gunther Moor, Crone et al., 2010; Gunther Moor, Crone, & van der Molen, 2010) could be transferred to the romantic domain. To answer these questions, we used an online dating paradigm similar to the speed-dating paradigm of Cooper et al., 2010. The participants had to determine whether they would like to date another participant or not, while their own profiles were judged in the same way. Therefore, there were four possible outcomes: *match* outcome implies that both individuals said “yes”, rejection outcome indicates “yes” from the participant opposed to “no” from the potential partner; *unrequited* - “no” from the participant opposed to “yes” from the potential partner; *disinterest* implies that both participants had no desire to see each other again. In this study, we tested the following predictions. First of all, in line with our previous findings (Van der Veen et al., 2014, 2016) we expected to find an enhanced P3 amplitude at fronto-central locations as a response to a match stimulus, which can be seen as the most rewarding condition. Furthermore, we expected to see similar cardiac patterns in reaction to romantic rejection as to those of social rejection (Gunther Moor, Crone et al., 2010; Gunther Moor, Crone, & van der Molen, 2010), namely, the largest cardiac deceleration if the romantic feelings were unrequited (“yes” – “no” outcome). In line with the previous research on social feedback (Van der Veen et al., 2016), we expected that male participants would show the largest differences between the four different conditions in the task. Finally, contrary to the previous social rejection studies there is no real expectation in the romantic rejection paradigm, and therefore no modulation of conflict-sensitive ERP components were investigated. Subjects passively watched their own judgments and other people judgments about themselves. In the social rejection paradigm participants have to predict the evaluation of the judge and therefore the evaluation is either expected or unexpected.

## 2. Methods

### 2.1. Participants

Participants were 61 healthy, heterosexual, single undergraduate students who had normal or corrected-to-normal vision. Participants were recruited by means of flyers, posters and online advertisements. The study was approved by the local medical ethics committee. Participants gave written informed consent. Participants were unaware

of the fact that part of the profiles they judged were fake, but they knew that actual dates could be arranged due to the possibility of exchanging e-mail addresses with the actual participants of the experiment. The presence of fake profiles was debriefed at the end of the experiment.

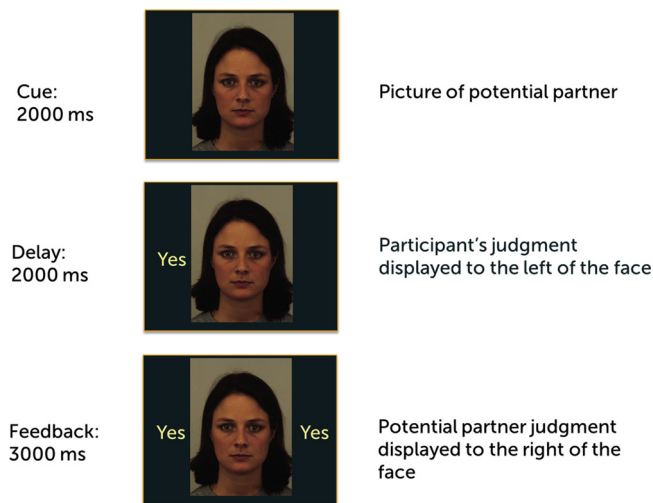
Upon registration, participants decided whether they wanted to participate in the online dating part of the experiment only or participate in an EEG session as well. The exclusion criteria for the EEG session were serious general health problems, neurological or psychiatric disorders in past or present, and left-handedness. Participants were screened by means of a short interview by phone before they were asked to participate in the experiment. In this interview a couple of health related questions were asked to check whether the participants had a history of neurological or psychiatric illness, used any medication interfering with brain function or had any disease interfering with normal brain function. During this interview, additional questions were asked to check whether participants were single and heterosexual. Due to too many artifacts the data of 12 EEG participants had to be excluded, leaving a total number of 34 analyzable participants (10 male; mean age = 20.1, SD = 1.6).

Participants who were in the EEG group were provided with a monetary reward of 20 Euros. Others received 5 Euros after completing the behavioral task. Prior to the actual EEG experiment, the participants had to complete a number of questionnaires related to mood and personality. The relatively low number of participants, however, prevented a proper analysis of these measures and therefore the results of these measures in relation to the physiological outcome measures are not reported in this paper. Participants in our sample scored on average  $7.4 \pm 5.7$  (mean  $\pm$  standard deviation) on the Dutch version of the Beck Depression Inventory (Beck, Steer, & Garbin, 1988; Bosscher, Koning, & Van Meurs, 1986) and  $38.3 \pm 9.6$  on state anxiety as measured with the State-Trait anxiety inventory (Spielberger, 1983).

### 2.2. Stimuli and procedure

The design of the experiment was based on that used by Cooper et al. (2010). Each of the participants had to submit his or her photograph with a short description of him- or herself including hobbies, interests, study program, and place of residence. From these data we made a database similar to that of a dating website. In order to obtain 80 male profiles and 80 female profiles, a number of fake profiles were added. The fake profiles were also used to keep the judgments of the potential partners as close to 50% positive as possible. We used a total 79 (42 male, 27 female) fake profiles. We did not use standardized pictures for the fake profiles, but pictures from different non-Dutch online dating services to complete the data base. Pictures had similar physical characteristics as the pictures from the real profiles. Participants thought that all the profiles were real. The participants were told that following the last EEG session, they would receive the names and email addresses of the participants with whom they had a “match”, so that they could contact each other if they wanted to. It should be noted that participants could be presented with photographs (during the online selection process, as well as the EEG experiment) from fellow students. That is, students they could see on campus or during university classes. This is an important difference with other studies on social feedback. In these earlier studies feedback was computer generated (and thus fake), but in this study participants received “real” feedback.

Participants had to consider the profiles of the other sex, deciding whether the person was “dateable” or not. Participants were asked to consider 50% of people as dateable, which they could check using the number of their chosen percentage shown on the screen. This was done in order to get approximately equal numbers of trials per condition. There were four possible outcomes: *match* outcome implies that both individuals said “yes”, *rejection* outcome indicates “yes” opposed to “no”; *unrequited* - “no” opposed to “yes”; *disinterest* implies that both participants judged each other as not dateable. Fifteen participants did



**Fig. 1.** Example of a trial sequence (match condition) for the romantic evaluation task. The example picture was taken from the KDEF stimulus set (The Karolinska Directed Emotional Faces; Lundqvist, Flykt, & Öhman, 1998) and was not used in the actual experiment.

not want to participate in the EEG session and only rated the profiles.

If the participants were also part of EEG group, they came to the laboratory as soon as possible for the EEG session, approximately one week after the behavioral part. Participants were told that they would see all the photographs once more with their own judgment about dateability of the person on the left, and the potential partner judgment of the dateability of themselves on the right side of the screen. Participants were seated in a comfortable chair in a dimly lit and sound attenuated room at approximately 1 m of the screen. A total of 80 photographs were shown on a CRT screen using the E-prime software (Psychology Software Tools, Pittsburgh, PA) in a single block, lasting approximately 10 min. The task was a passive viewing task in which first the face of the person that was judged by the participant was presented for 2 s. After this the same face was presented again for 2 s and with the judgment of the participant (Yes/No) printed left of the picture of the judged person. Finally, the same face was presented one more time, but now for 3 s and with the judgment of the participant on the left side and the potential partner judgment (Yes/No) printed on the right side of the screen. An example trial is shown in Fig. 1. There was no inter-trial interval and faces were shown continuously during a trial. After finishing the task, participants were debriefed about the evaluations, the presence of fake profiles and the goal of the experiment.

### 2.3. Data acquisition

The EEG was recorded with BioSemi Active-Two using 32 channels (10–20 system) with Ag/AgCl active electrodes mounted in an elastic cap. ECG was recorded from a single lead placed below the left ribcage. Signals were recorded with a low-pass filter of 134 Hz and were digitized with a sample rate of 512 Hz and 24-bit A/D conversion. Vertical EOG was derived from electrodes placed above and below the left eye. Horizontal EOG was derived from electrodes next to each eye. BioSemi uses the Common Mode Sense (CMS) and Driven Right Leg (DRL) electrodes to create a feedback-loop, which replaces the conventional ground electrode. The CMS was used as online reference. Also, the active electrodes provide suppression of interference by impedance transformation directly at the electrode. Therefore, it is unnecessary to check the impedance of each electrode, as is common with passive electrodes, but the signals were checked for good skin contact before start of the measurement. EEG and ECG data was analyzed offline using Brain Vision Analyzer 2 (Brain-Products GmbH, Munich, Germany). Signals were offline referenced to mathematically linked mastoids. EEG

signals were filtered using a band-pass filter between 0.1 and 30 Hz (phase shift-free Butterworth filters; 24-dB/octave slope). The EEG signal was locked to the onset of the face with both judgments visible, and epochs were extracted between 200 ms preceding and 800 ms following the onset of this stimulus. The epochs were corrected for vertical EOG artifacts by using an often used correction method (Gratton et al., 1983). Trials with out of range artifacts were excluded ( $\pm 75 \mu\text{V}$ ) from further processing. EOG correction was performed before the min/max voltage artifact procedure. On average, the grand average ERPs consisted of 17 (SD = 3.6) trials for the Match category ("yes" from participant and "yes" from potential partner), 17 (SD = 3.5) trials for the rejection category ("yes" from participant and "no" from potential partner), 20 (SD = 4.6) trials for the unrequited category ("no" from participant and "yes" from potential partner) and 19 (SD = 4.2) trials for the disinterest category ("no" from participant and "no" from potential partner).

For the analysis of cardiac responses, R-peaks were detected in the ECG signal using the peak detection algorithm implemented in Brain Vision Analyzer and inter-beat intervals were computed between consecutive R-peaks. R-peak time series were visually inspected to check for artifacts. Missing R-peaks were interpolated and extra R-peaks due to noise were removed. Number of interpolations was low (0 for most participants) and all trial were used to compute the average response to the different trial types. We selected six inter-beat intervals (IBIs) surrounding the judgment stimulus for further analysis; i.e. two preceding IBIs (IBIs -2 and -1), the concurrent IBI (i.e. IBI 0) and three subsequent IBIs (i.e. IBIs 1, 2, and 3). As in previous studies using a similar paradigm (Van der Veen et al., 2014, 2016), IBI 0 to IBI 3 were referenced to the second IBI preceding stimulus onset (IBI -2).

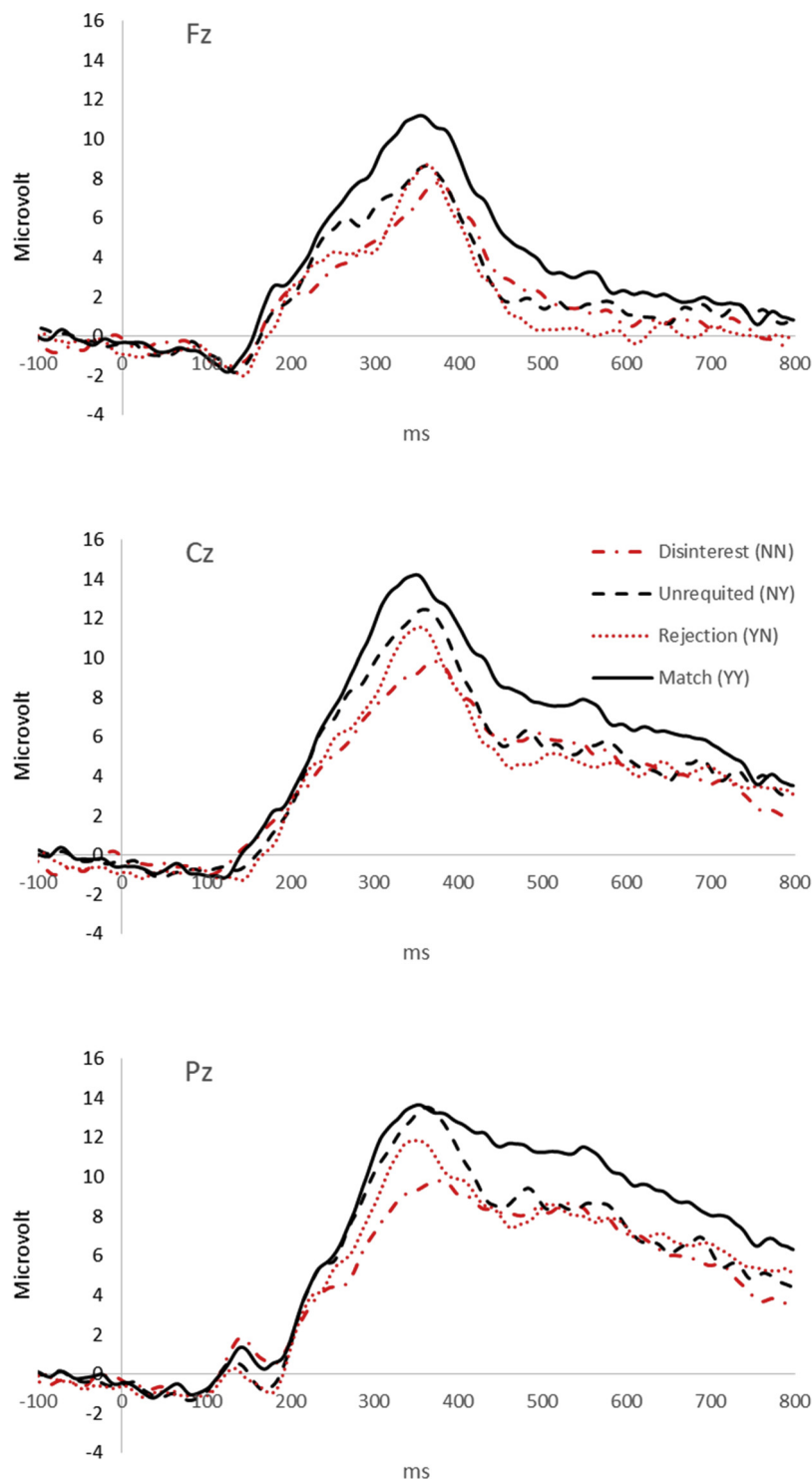
### 2.4. Statistical analysis

P3 and cardiac measures were statistically evaluated using IBM SPSS Statistics for Windows (Version 23.0. Armonk, NY: IBM Corp.). Analysis of variance was performed using a general linear model (GLM) analysis for repeated-measures. Visual inspection of the grand average ERP showed that as in a previous study using a similar experimental paradigm (Van der Veen et al., 2016) P3 amplitude was maximal between 300 and 400 ms after onset of the potential partner judgment (see Fig. 1). Therefore, we decided to quantify the P3 amplitude as the average voltage in the area between 300 and 400 ms after this stimulus onset. We chose to analyze the P3 amplitude on the midline electrodes Fz, Cz and Pz because the P3 is usually largest on these electrodes, we did not have hypotheses about possible lateralization and to be consistent with previous studies using comparable paradigms (e.g. Van der Veen et al., 2014, 2016). P3 amplitude was tested in a design with electrode position (three levels; Fz, Cz and Pz), own judgment (two levels; Yes vs No), and potential partner judgment (two levels; Yes vs No) as within-subjects factors. Inter-beat intervals were tested in a design with own judgment, potential partner judgment and sequential IBI (four levels; IBI 0, IBI 1, IBI 2 and IBI 3) as within-subjects factors. Huynh-Feldt corrections of degrees of freedom were applied whenever appropriate, but uncorrected degrees of freedom are reported. Effects size is reported as partial eta squared ( $\eta_p^2$ ). Follow-up statistics were corrected for multiple comparisons (Bonferroni).

## 3. Results

### 3.1. P3 amplitude

Grand average ERP responses locked to the potential partner judgment are shown in Fig. 2, mean P3 amplitudes are shown in Fig. 3. Statistical analyses showed main effects of electrode,  $F(1,33) = 41.2$ ,  $p < .001$ ,  $\eta_p^2 = .555$ , potential partner judgment,  $F(1,33) = 13.6$ ,  $p = .001$ ,  $\eta_p^2 = .291$ , and own judgment,  $F(1,33) = 5.1$ ,  $p = .031$ ,  $\eta_p^2 = .134$ . P3 amplitude was higher on Cz (mean averaged over



**Fig. 2.** Grand average ERPs for disinterest (No-No), romantic rejection (Yes-No), match (Yes-Yes), and unrequited (No-Yes) stimuli at mid-line electrodes. The zero point of time refers to onset of picture and the potential partner's judgment.

potential partner judgment and own judgment:  $10.9 \mu\text{V}$ ) as compared to Fz ( $7.9 \mu\text{V}$ ),  $p < .001$ , Cohen's  $d = 1.726$ , and on Pz ( $11.3 \mu\text{V}$ ) as compared to Fz,  $p < .001$ , Cohen's  $d = 1.072$ , but did not differ between Pz and Cz,  $p = .969$ , Cohen's  $d = .173$ . The P3 was larger for positive than negative potential partner judgments (means averaged over electrode position and own judgment:  $11.4$  vs.  $8.7 \mu\text{V}$ , Cohen's  $d = .641$ ) and higher for own positive than negative judgments (means averaged over electrode position and potential partner judgment:  $10.7$  vs.  $9.4 \mu\text{V}$ , Cohen's  $d = .390$ ). Finally, a three-way interaction between

electrode, own judgment and potential partner judgment was found,  $F(2,66) = 9.3$ ,  $p = .001$ ,  $\eta_p^2 = .220$ . Three follow-up GLM analyses, separate for the three electrodes, were performed to further analyze this interaction. For Fz we found main effects of own judgment,  $F(1,33) = 5.6$ ,  $p = .024$ ,  $\eta_p^2 = .145$ , and potential partner judgment,  $F(1,33) = 10.9$ ,  $p = .002$ ,  $\eta_p^2 = .248$ , and a two-way interaction between both factors,  $F(1,33) = 5.1$ ,  $p = .031$ ,  $\eta_p^2 = .133$ . Follow-up analyses showed that P3 amplitude was higher for match ("yes" from the participant and "yes" from the potential partner) stimuli as compared to

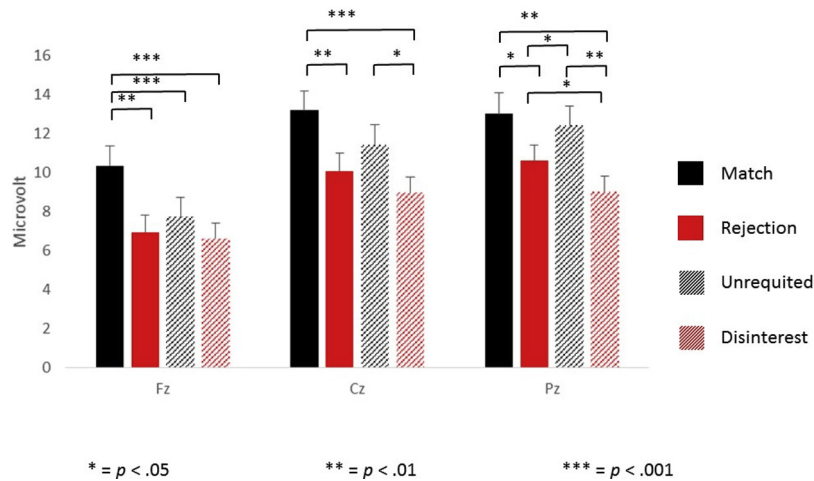


Fig. 3. P3 Amplitudes for disinterest (No-No), romantic rejection (Yes-No), match (Yes-Yes), and unrequited (No-Yes) stimuli at mid-line electrodes. Error bars indicate standard error of the mean.

unrequited stimuli (“no” from the participant opposed to “yes” from the potential partner),  $p = .004$ , but not for disinterest (“no” from the participant and “no” from the potential partner) as compared to romantic rejection stimuli (“yes” from the participant opposed to “no” from the potential partner),  $p = .699$ . For Cz we only found main effects of own judgment,  $F(1,33) = 5.4, p = .027, \eta_p^2 = .140$ , and potential partner judgment,  $F(1,33) = 13.1, p = .001, \eta_p^2 = .284$ . For Pz we only found a main effects of potential partner judgment,  $F(1,33) = 13.9, p = .001, \eta_p^2 = .296$ . To summarize, P3 was largest for own positive judgment on Fz and Cz, P3 was largest for potential partner judgment on all electrodes and only on Fz we found that P3 was largest for match stimuli (potential partner positive judgment was associated with larger P3 amplitudes and match stimuli were associated with larger P3 amplitudes as compared to unrequited stimuli). In a final separate GLM analysis we explored whether P3 amplitudes were affected by gender of the participants and found that gender did not affect P3 amplitude.

### 3.2. Inter-beat interval

Cardiac response to the potential partner judgment is shown in Fig. 4. For the IBIs associated with the onset of the potential partner judgment, we found a main effect of potential partner judgment,  $F$

(1,33) = 8.7,  $p = .006, \eta_p^2 = .209$ . Heart rate deceleration was larger for negative than positive potential partner judgments, regardless of the participant’s own judgment of dateability of that person (11.1 ms vs. 1.1 ms). In a separate GLM analysis we explored whether cardiac deceleration was affected by gender of the participants and found that gender did not affect cardiac deceleration. Fig. 3 seems to show a larger cardiac deceleration following romantic rejection (own judgment = yes, potential partner judgment = no) as compared to disinterest stimuli (own judgment = no, potential partner judgment = no), and an anonymous reviewer suggested that this effect might be better highlighted by focusing on the latter two IBI’s. This suggestion was based on previous research on social rejection that has shown that all effects in this task are late effects that only were present on IBI2 and IBI3 (e.g. Gunther Moor, Crone et al., 2010; Gunther Moor, Crone, & van der Molen, 2010; Van der Veen et al., 2014, 2016). Therefore we performed an additional GLM for repeated measures analysis, but now with only IBI2 and IBI3 as sequential IBI’s. This analysis showed a main effect of potential partner judgment,  $F(1,33) = 13.3, p = .001, \eta_p^2 = .287$ . As in the first analysis, heart rate deceleration was larger for negative than positive potential partner judgments. Furthermore, an interaction was found between own judgment and potential partner judgment,  $F(1,33) = 5.4, p = .026, \eta_p^2 = .141$ . Follow-up analyses confirmed our visual impression and showed that cardiac deceleration

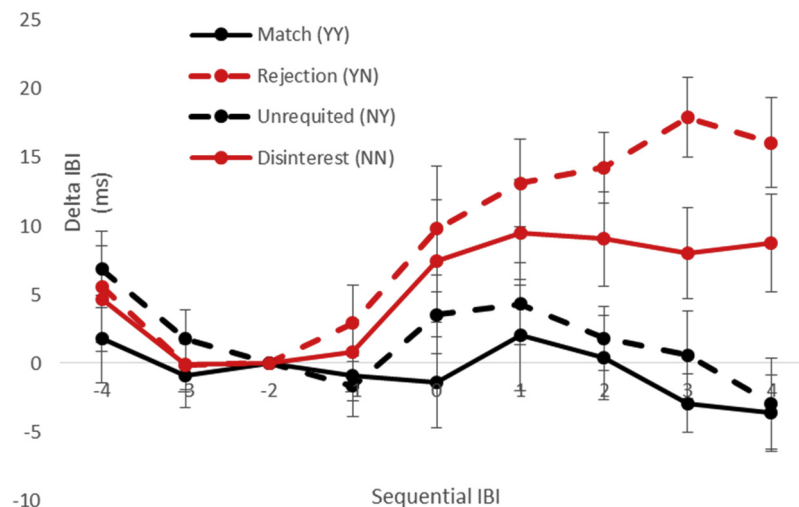


Fig. 4. Cardiac deceleration for disinterest (No-No), romantic rejection (Yes-No), match (Yes-Yes) and unrequited (No-Yes) stimuli. Deceleration is expressed as the IBI length as compared to  $IBI-2 \pm SEM$ .

was stronger for romantic rejection stimuli (16.1 ms) as compared to disinterest stimuli (8.5 ms),  $p = .022$ .

#### 4. Discussion

This study examined whether the previously found rewarding effect of social acceptance on P3 amplitude (e.g. Van der Veen et al., 2014) and the socially painful effect of social rejection on cardiac deceleration (e.g. Gunther Moor, Crone et al., 2010; Gunther Moor, Crone, & van der Molen, 2010) could be transferred to the romantic domain. Participants considered the profiles of people of the opposite sex, and decided whether that person was “dateable” or not. Participants were informed that they would receive the email addresses of the people with whom they had a match, to make sure that the participants were truly invested in the task. During the actual experiment, they viewed the pictures of the potential partners once again, and saw their own judgment and the judgment of the potential partner, which led to a situation of (un)matched romantic interest or rejection. As expected, romantic interest, especially when there was a match between both the judge and the potential partner, led to the largest P3 response. Also as expected, rejection led to the largest cardiac deceleration. In contrast to earlier studies that used a similar experimental paradigm in a non-romantic setting, the P3 had a more posterior distribution and the P3 was smallest in the disinterest condition. Also in contrast to these previous studies was the stronger cardiac deceleration following disinterest stimuli.

P3 amplitude was of greatest interest in the present study. In previous studies with a non-social version of the same paradigm P3 amplitude was associated with the rewarding properties of the stimulus and associated with activation of the vACC (Van der Veen et al., 2014, 2016). The hypothesis that reciprocal participant-potential partner feedback would lead to the strongest P3 response was confirmed. The finding that the P3 was largest in the match condition suggests that it is most rewarding when people that you find dateable also find you dateable. This makes sense because even though being romantically interested in someone may be a rewarding experience by itself, it will be even more rewarding if the romantic interest is reciprocated. Although the main finding was in line with previous studies that also reported the largest P3 amplitude in the most rewarding condition (Van der Veen et al., 2014, 2016), there were differences. Despite the fact that the largest difference in P3 amplitude between match and the other stimuli was found on Fz like in previous studies, the P3 amplitude itself was strongest on centro-parietal electrode positions. In previous studies (Van der Veen et al., 2014, 2016; Dekkers et al., 2015), the P3 amplitude was largest on fronto-central positions and due to this distribution and the early latency that P3 was interpreted as a P3a (Van der Veen et al., 2014). A possible explanation for the more posterior distribution in the current study might be the involvement of processes linked to the P3b, which is known to have a more posterior distribution. Although we still like to stress that rewarding properties of the stimulus probably play the most important role, the P3 in this study might be a mix between a P3a and a P3b. The P3b is thought to be related to amount of attention paid to the stimulus and to subsequent memory processing (Polich, 2007). Contrary to the previous studies, subsequent memory processing might have played a stronger role in the present study due to the possible consequences of the stimulus (i.e. dating opportunity) and the fact that participants made their decisions about whether they would like to go on a date with the person shown on the screen in an earlier phase of the experiment.

Expectancy and congruency might have played some role in the present study. However, contrary to the social rejection paradigm used in previous studies (2018, Dekkers et al., 2015, 2016; Van der Molen et al., 2017; Van der Veen et al., 2014), no real expectancy was created and congruency only plays a relatively small role in this paradigm due to the passive viewing instructions. Moreover, both expectancy (hope) and congruency might have a different influence on different types of

people, due to the specific paradigm. People with higher self-esteem, for instance, might respond differently to positive judgments of potential partners in combination with a sometimes regretted positive judgment of themselves, as opposed to people with lower self-esteem. Additional, more elaborate task paradigms and studies with more statistical power to focus on individual differences seem necessary to focus more strongly on these processes.

In the present study both male and female participants were included. In contrast to a recent study using a similar social rejection paradigm (Van der Veen et al., 2016), no gender differences were found for P3 amplitude. Although clear differences between the romantic and social rejection task were present, these differences do not offer clear explanations for the lack of gender differences in the present study. The most likely explanation might be the substantially lower power to detect gender differences in the present study due to a lower number of included participants.

Previous studies have associated the larger P3 amplitude for social acceptance stimuli to the rewarding properties of these stimuli and activation of the vACC (Van der Veen et al., 2014, 2016). In the introduction we related this P3 effect in response to the social acceptance stimulus to the broader literature on reward processing and stressed the importance of the motivational aspects of this stimulus (e.g., San Martín, 2012; Threadgill & Gable, 2018). In line with this, we would like to suggest that the larger P3 amplitude for the match stimulus, as compared to all other stimuli on the Fz electrode, reflects the rewarding and in this way the strong motivational properties of this stimulus. In a previous paper (Van der Veen et al., 2014) we discussed some indirect evidence (e.g. localization studies of the P3a) supporting the link between vACC activation and the P3a amplitude, but more direct evidence for a role of the vACC in acceptance has been presented recently by Cooper, Dunne, Furey, and O’Doherty (2014). Cooper et al. examined romantic interest and rejection in a similar paradigm in an fMRI study. They found activation of the ventromedial prefrontal cortex partly overlapping with the vACC for match stimuli, as compared to unrequited stimuli. Although Cooper et al. used a speed dating session as opposed to the online judgment of profiles in the present experiment, the actual experimental paradigm in the scanner was very similar to the paradigm used in our experiment, leading to similar stimulus categories which should evoke the same emotional and cognitive processes. Therefore, it might be that the VMPFC and vACC areas were activated in the match condition in the present study, although we have no direct evidence for this. It would be interesting to conduct an fMRI-ERP study to measure both the BOLD response in the VMPFC and vACC and the P3 amplitude in the same individuals in this romantic interest and rejection paradigm, to obtain direct evidence that the two are associated.

The cardiac results were generally in line with our expectations. The large deceleration for especially rejection stimuli suggests that this type of stimulus is seen as the most painful stimulus triggering the cardiac response related to activation of the dACC (Gunther Moor, Crone et al., 2010; Gunther Moor, Crone, & van der Molen, 2010), which is supposed to play a role in the neural alarm system activated by cues that signal social pain (Eisenberger & Lieberman, 2004). In the present study cardiac deceleration was also enhanced for disinterest stimuli. This suggests that this stimulus was seen as more painful than the two acceptance stimuli. This last finding is not in line with previous studies that studied social rejection which consistently found an enhanced cardiac deceleration for unexpected social rejection only (Van der Veen et al., 2014, 2016; Gunther Moor, Crone et al., 2010; Gunther Moor, Crone, & van der Molen, 2010; Dekkers et al., 2015), and found no differences between the other three stimulus categories. One important difference with the current paradigm, however, is that the participants did not have to predict the outcome of a judgment and only passively viewed their own previously given judgment and the judgment of the person displayed on the screen. Therefore, in the current experiment the larger cardiac deceleration cannot be attributed to expectancy violation. The found pattern of results, however, might still fit the

earlier suggested explanation by Gunther Moor, Crone et al. (2010) and Gunther Moor, van Leijenhorst, Rombouts, Crone, and Van der Molen (2010) who suggested that unexpected rejection can be painful and therefore might activate the dACC in the role of a neural alarm system that was proposed by Eisenberger and Lieberman (2004). This makes sense because a negative judgment of the person displayed on the screen may be hurtful even when the participant was not interested in a date with this potential partner. In the previous studies with the social rejection paradigm, the stimulus category that was most similar to the disinterest category was the expected rejection category. Expected rejection means that the participant predicted correctly that the person displayed on the screen did not like the participant, and in this way the outcome can also be seen as somewhat rewarding, which might have somewhat overshadowed the possible pain of being rejected. In the present study this rewarding aspect is not present, because no predictions had to be made. Therefore, in the present study being judged as “undateable” might be interpreted as painful even when the participant was actually not interested in a date with the person displayed on the screen. Of course it is more painful if you would like to go on a date with potential partner, which is reflected in the stronger cardiac deceleration for the rejection stimuli. The effects on cardiac deceleration were relatively late effects, which is in line with previous studies on social rejection (Dekkers et al., 2015; Van der Veen et al., 2014, 2016; Gunther Moor, Crone et al. (2010) and Gunther Moor, van Leijenhorst et al. (2010), and therefore we chose to add an analysis focusing on the latter two IBI's. This analysis confirmed that on these two IBI's deceleration is indeed stronger for romantic rejection as compared to disinterest stimuli.

This study has some limitations. First, the number of stimuli used and the number of participants included is relatively low. Although this might have played some kind of role in the lack of gender differences, we think the presented data are strong enough to draw general conclusions about the romantic rejection and acceptance in general independent of possible gender differences. Second, the use of online profiles, instead of using speed dating sessions in which the participants actually meet each other in real life might have weakened the impact of the both the positive and negative judgments. The data, however, appear to show that the impact of both positive and negative outcomes was strong enough to generate strongly differential effects on both ERPs and cardiac responses. Third, some selection bias might be present in the participants that were included in the final EEG sample. We think the choice to participate in the EEG session mostly depended on availability, need for money and need for course credit. Because the own and potential partner judgment were within-subject factors, any selection bias did not confound the effects of own and potential partner judgment on the P3 amplitude or heart rate. Fourth, the grand-averaged ERPs were based on a relatively low number of trials (as compared with prior studies, such as Van der Veen et al., 2016). This might have significantly impacted on the signal-to-noise ratio, and thus the ERP effects. Fifth, we asked participants to consider 50% of the candidates as dateable, which is somewhat forced. Like in all other social and non-social judgments, participants could have regretted their choices and this might have influenced their brain and cardiac responses. For more secure people with high self-esteem possibly more ‘yes’ judgments were regretted, whereas for less secure people with low self-esteem possibly more ‘no’ judgments were regretted. Future research possibly should focus on the influence of regret and the relationship with personality characteristics. Sixth, the way the EEG was measured (32 channels) and analyzed (focus on P3 while other components such as the N100 and P200 (Premkumar et al., 2014) were not quantified), use of visual inspection for determining the P3 area measure rather than PCA (Premkumar et al., 2015) might have led to a limited view on the underlying brain mechanisms. A final limitation of the used paradigm is that the participants were somewhat forced in their choices as to which potential partner they would like to date. Regret and hope may have played a role in the build-up of expectancies about the outcome, and

thus conflict as well. This is reflected in the cardiac response to romantic rejection that nicely mimics the results from earlier studies, showing similar effects when people receive unexpected rejection feedback. Regardless of this paradigm being passive, participants may still have built up an expectancy to be liked or disliked, and possibly when they hope to be liked. Getting “like” feedback is rewarding, and getting rejection feedback in such conditions is painful.

The present study showed that romantic acceptance and rejection have a strong impact on both ERPs and cardiac responses. Acceptance when you are romantically interested in the potential partner leads to a larger P3 amplitude, possibly related to the rewarding properties of this condition and activation of the vACC. Romantic rejection, irrespective of romantic interest in the other, leads to stronger cardiac slowing, possibly reflecting social pain and activation of the dACC. This study has shown that the online dating paradigm is useful to measure the physiological impact of romantic interest and rejection and can be used in future studies to examine how it relates to personality traits and psychopathology. The emergence of online dating may have increased the opportunities for finding rewarding matches, although that might come at the cost of increased opportunities for painful rejections.

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