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Peer Rejection Cues Induce Cardiac Slowing After Transition Into Adolescence

Bregtje Gunther Moor
University of Amsterdam and Leiden University

Marieke G. N. Bos
University of Amsterdam

Eveline A. Crone
University of Amsterdam and Leiden University

Maurits W. van der Molen
University of Amsterdam

The present study examined developmental and gender differences in sensitivity to peer rejection across the transition into adolescence by examining beat-by-beat heart rate responses. Children between the ages of 8 and 14 years were presented with unfamiliar faces of age-matched peers and were asked to predict whether they would be liked by the other person. Their prediction was followed by feedback indicating that the peer had accepted or rejected them. Results revealed cardiac slowing to unexpected peer rejection in 11- to 14-year-olds. The cardiac response to unexpected rejection was most pronounced in girls. This pattern of findings supports the hypothesis of an increase in sensitivity to peer rejection after transition into adolescence and indicates that social rejection may be particularly salient in adolescent girls.

Keywords: peer rejection, adolescence, heart rate, autonomic nervous system

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Integration into the peer group is essential for adolescent development. The transition from childhood to adolescence co-occurs with a shift in social orientation from parents to peers (Steinberg & Morris, 2001). As such, adolescents seek to gain independence from their parents, resulting in the need of peer acceptance. Adolescents report increased concerns about how other peers think of them, and these concerns typically increase during late childhood rising into adolescence (e.g., Kloep, 1999; O'Brien & Bierman, 1988). Further, social rejection has been shown to evoke strong negative feelings in adolescence (e.g., Deater-Deckard, 2001; Masten & Eisenberger, 2009; Sebastian, Viding, Williams, & Blakemore, 2010). Thus, adolescents are likely to experience more peer-related stress and, at the same time, show a heightened sensitivity to social rejection.

Despite the wealth of research suggesting that adolescence is associated with enhanced sensitivity to peer evaluation, little is known about its underlying mechanisms. Recently, changes in social behavior during adolescence have been increasingly linked to a remodeling of brain regions (e.g., Burnett, Sebastian, Cohen Kadosh, & Blakemore, 2011; Pfeifer & Blakemore, 2012). More specifically, major changes in limbic brain regions involved in social and affective processing are believed to characterize adolescent development (e.g., Crone & Dahl, 2012; Nelson, Leibenluft, McClure, & Pine, 2005). These changes may lead to an intensification of emotional and motivational experiences and have been argued to be the basis for the increased salience of peers. As such, the transition from childhood into adolescence is believed to be an important window for understanding changes in social-affective behavior (e.g., Steinberg, 2008).

To date, only few laboratory studies examined developmental change in social rejection sensitivity during transition into adolescence. Experimental tasks to study the impact of social rejection frequently involve excluding participants from a simulated social interaction (i.e., ball tossing game) or receiving feedback about acceptance or rejection. Developmental studies examining age-related changes in self-reported peer rejection sensitivity yielded equivocal findings. Some studies revealed that social rejection sensitivity is more pronounced in adolescents than in adults (e.g., Pharo, Gross, Richardson, & Hayne, 2011; Sebastian et al., 2010) and that ostracism affects children differently from adolescents and adults (Abrams, Weick, Thomas, Colbe, & Franklin, 2011). Other studies, however, reported developmental stability rather than change in self-reported distress (e.g., Bolling, Pitskel, Deen, Crowley, Mayes, & Pelphrey, 2011; Gunther Moor et al., 2012; Sebastian et al., 2010). Recently, the processing of social-

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Bregtje Gunther Moor, Department of Psychology, University of Amsterdam, Amsterdam, the Netherlands, and Institute of Psychology, Leiden University, Leiden, the Netherlands; Marieke G. N. Bos, Department of Psychology, University of Amsterdam; Eveline A. Crone, Department of Psychology, University of Amsterdam, and Institute of Psychology, Leiden University; Maurits W. van der Molen, Department of Psychology, University of Amsterdam.

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Correspondence concerning this article should be addressed to Bregtje Gunther Moor, Department of Psychology, University of Amsterdam, Weesperplein 4, 1018 XA, Amsterdam, the Netherlands. E-mail: bregtjegm@gmail.com

evaluative feedback was studied in 9- to 17-year-olds by evaluating an objective index of emotion and cognitive processing; i.e., the pupillary response. The results showed that social rejection (i.e., not being selected for an online chat session) was associated with an enhanced pupillary response, which was more pronounced with advancing age. These findings were interpreted to suggest that youth is sensitive to social rejection feedback and that this feedback is becoming more salient with advancing age (Silk et al., 2012).

A more explicit procedure for examining the impact of receiving feedback about being liked or disliked by another person is the social-judgment task developed by Somerville, Heatherton, and Kelley (2006). In this paradigm, participants view photographs of unfamiliar others and are asked to predict whether they think the other person would like them or not. They then receive rigged feedback indicating that they are liked (acceptance) or disliked (rejection) by the other person. This paradigm has been used in a later fMRI study testing for developmental differences in neural activity associated with social feedback processing from childhood into adulthood. Results of this study revealed age-related increases in activation in brain regions for predicted social rejection, including the left lateral prefrontal cortex. This finding was taken to suggest that adults may be better able to regulate the impact of negative thoughts or feelings (Gunther Moor, Van Leijenhorst, Rombouts, Crone, & van der Molen, 2010).

The processing of feedback received considerable attention in the adult literature on decision making (e.g., Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). Psychophysiological research demonstrated that negative feedback (i.e., feedback violating prior expectations) is associated with a transient heart-rate slowing that is more pronounced compared to positive feedback (Crone et al., 2003). Cardiac deceleration is believed to be a manifestation of a neural system including the anterior cingulate cortex; a brain structure that is implicated also in the processing of social exclusion and physical pain (for a review, see Eisenberger, 2012). In line with this literature, a recent study by Gunther Moor, Crone, and van der Molen (2010) obtained findings indicating that social rejection processing is associated with cardiac slowing. In this study, adult participants performed two tasks with the same overall design: the social-judgment task and an age-judgment task, which served as a control task. Results of this study revealed that unexpected social rejection induced a pattern of transient heart rate slowing that was considerably more pronounced compared to the cardiac response to (a) other conditions of the social-judgment task, i.e., expected rejection, unexpected acceptance, expected acceptance, and (b) comparable conditions in the nonsocial control task.

The current study aimed at examining age-related change in the processing of peer rejection feedback using the social-judgment task, while including a control task. The focus is on the transition from childhood into adolescence to assess the alleged increase in sensitivity to peer rejection during the transition into and during adolescence (e.g., Bolling, Pitskel, Deen, Crowley, Mayes, & Pelphrey, 2011; Masten & Eisenberger, 2009; Silk et al., 2012; Steinberg & Morris, 2001). Two groups of children participated in the study; a group of 8- to 10-year-olds (late childhood) and a group of 11- to 14-year-olds (early adolescents). During task performance, the participant's heart rate was recorded to evaluate the impact of social rejection. Heart rate is a cost-effective and nonobtrusive method that has been shown to provide reliable measures of children's feedback processing in cognitive tasks (e.g., Crone, Jennings, & van der Molen, 2004; Crone & van der Molen, 2007; Groen, Wijers, Mulder, Minderaa, & Althaus, 2007; Luman, Oosterlaan, & Sergeant, 2008). Moreover, it provides a window on the temporal dynamics of feedback processing. The transient slowing of heart rate to negative feedback is believed to be mediated by the parasympathetic nervous system (e.g., Berntson, Quigley, & Lozano, 2007), which is involved in self-regulatory processes facilitating adaptive and flexible behaviors (Porges, 2003; Thayer, Ahs, Fredrikson, Sollers, & Wager, 2012).

Two hypotheses were tested. First, it was predicted that the heightened sensitivity to peer rejection feedback after transition into adolescence would result in stronger cardiac slowing to unexpected peer rejection in 11- to 14-year-olds compared to 8- to 10-year-olds. Second, it was predicted that 11- to 14-year-old girls would show more pronounced heart rate slowing to social rejection compared to both 8- to 10-year-old girls and boys, and 11- to 14-year-old boys. The latter hypothesis was based on literature suggesting that social rejection is especially salient in adolescent females and that sex differences in social behavior become more accentuated during adolescence (e.g., Guyer, McClure-Tone, Shiffrin, Pine, & Nelson, 2009; Rudolph & Conley, 2005). Finally, using behavioral observations (i.e., the button presses indicating the participant's judgments), we explored developmental and gender differences in expectations of social evaluation. Assuming that adolescents would experience increased concerns about how other peers think of them, we expect 11- to 14-year-olds to report higher levels of negative expectations related to social evaluation.

Method

Participants

A total of 101 children between 8–14 years old were included in the study. Participants were assigned to two age groups that are thought to be associated with two distinct phases of development: late childhood ($N = 50$; 25 girls; ages 8–10, mean age $= 9.81$, $SD = 0.71$) and early adolescence ($N = 51$; 27 girls; ages 11–14, mean age $= 12.92$, $SD = 1.03$). A chi-square analysis revealed no significant differences in gender distribution between both age groups, $\chi^2(1, 101) = 0.09$, $p = .77$. In addition, one-way analyses of variance (ANOVAs) revealed that boys and girls did not differ in age in both groups: 8- to 10-year-olds $F(1, 48) = .44$, $p = .51$, 11- to 14-year-olds $F(1, 49) = .16$, $p = .69$.

Children were recruited from a primary and secondary school and their primary caregiver gave informed consent for the study. All participants were healthy with no history of neurological or psychiatric disorders and had normal or corrected-to-normal vision. Six additional participants were excluded from the study; two participants (two boys) were excluded because of a lack of sufficient number of observations in one of the task conditions and four participants (one boy, three girls) because of equipment malfunction. All procedures were approved by the ethical committee of the university.

Task Description

Approximately 2 weeks prior to the experiment, participants were told that they were enrolled in a study on first impressions.

For this reason, the experimenter took a portrait photograph of all participants. They were told that their photograph would be sent to another school participating in the study, where a panel of age-matched peers would rate the photograph on first impressions. During the experiment, participants observed neutral faces of age-matched peers while performing two tasks (a social-judgment task and an age-judgment task). Each face was presented in color against a black background in the center of a computer screen. Two different versions of both tasks were created containing faces of different age ranges (8–11 or 12–14 years). The version that was used was based on the age of the participant. For each age-matched version of the experiment a total of 120 different faces were used, with an equal distribution of male and female faces. Each facial stimulus was displayed once in each task, such that the same faces were viewed in both tasks. Facial stimuli were obtained by the help of primary schools and high schools in different cities in the Netherlands. Photographs were taken after caregivers provided written approval. Mean ages of the photographed individuals were 10.2 and 13.0 years. An independent sample of participants of comparable ages rated the valence of the pictures using the Self-Assessment Manikin (SAM) on a 9-point scale (Lang, Bradley, & Cuthbert, 2005). Averaged scores were 5.02 (SD = 0.33) for the faces for 12- to 14-year-olds and 5.48 (SD = 1.16) for 8- to 11-year-olds, which did not differ between age groups, $F(1, 49) = 2.09$, $p = .15$.

Both tasks required participants to make judgments about the faces. In the social-judgment task (adopted from Somerville et al., 2006), participants were instructed to predict whether the person in the picture would like or dislike them. On each trial, the participant was required to answer the question "Do you think this person liked you?" The age-judgment task involved making judgments about the age of the other person. In this task, participants were instructed to answer the question "Do you think this person is 10 years of age or older (for 8- to 11-year-olds) or 13 years of age or older (for 12- to 14-year-olds)?" Judgments in both tasks were followed by feedback indicating acceptance or rejection by the person, or correctness in estimating the age of the person. The age-judgment task served as a control task to examine whether social feedback exerts cardiac effects over and beyond those associated with nonsocial feedback.

A trial started with a fixation cross having a variable duration between 450 and 1,550 ms (1,000 ms average), which served as intertrial interval. The fixation cross was followed by a 3,000 ms cue displaying a neutral face, which remained on the screen until the end of the trial. During the cue display, participants were instructed to respond "yes" or "no," depending on the specific instructions of the task. "Yes" and "no" responses could be made using the index and middle finger of the dominant hand, by pressing the "b" or "m" key of a computer keyboard. Responses that were not made within a 3,0000-ms time frame elicited the feedback "Too Slow," signaling the end of the trial. Participants' choices ("Yes"/"No") that were made within time appeared on the left of the face on the screen, during a fixed delay of 1,000 ms, and remained on the screen until the end of the trial. During the 2,000-ms feedback period, feedback ("Yes" or "No") appeared on the right of the face on the screen (see Gunther Moor, Crone, & van der Molen, 2010; Somerville et al., 2006).

Experimental Design

Task order was counterbalanced across participants. In both tasks, facial stimuli and feedback type were presented in a random order. Participants received "Yes" feedback on half of the trials (60) and "No" feedback on the other half (60). This generated four judgment by feedback conditions: "Yes-Yes," "Yes-No," "No-No," and "No-Yes," resulting in, respectively, expected social acceptance, unexpected social rejection, expected social rejection, and unexpected social acceptance task conditions in the social-judgment task and expected older, unexpected younger, expected younger, and unexpected older task conditions in the age-judgment task. It should be noted that the tasks differed in communicating negative feedback. In the social-judgment task, the participant received negative social feedback in the "Yes-No" and "No-No" conditions—"No" communicating social rejection. In the age-judgment task, negative feedback was conveyed in the "Yes-No" and "No-Yes" conditions, in which participants incorrectly estimated the person to be 10 or 13 years or older ("Yes-No") or younger than the specified age ("No-Yes"). To test our predictions concerning heart rate slowing to unexpected peer rejection, the critical comparisons are between the "Yes-No" condition of the social-judgment task with (a) the other conditions of the social-judgment task, and (b) the "Yes-No" and "No-Yes" conditions of the age-judgment task (see Gunther Moor, Crone, & van der Molen, 2010). See Table 1 in the online supplemental materials for descriptive information about the mean number of trials per feedback condition for each task across participants.

Procedure

All participants were tested individually in a quiet room in the participating schools and each session began with a rehearsal of the cover story. To familiarize participants with the task, they received one block of 10 practice trials in advance. Each task consisted of 120 trials, separated in three blocks of 40 trials with short breaks in between. At the end of the experiment, the experimenter asked participants about their thoughts about the experiment. None of the participants expressed doubts about the cover story. Debriefing took place by letter; in this letter it was made explicit that feedback was generated randomly by the computer.

Data Recording and Analysis

During both experimental tasks, each participant's electrocardiogram (ECG) was recorded continuously, using a sample frequency of 400 Hz, from three Ag-AgCL electrodes attached via the modified lead-2 placement. The ECG-signal was filtered with a High-Pass filter of 0.5 Hz to stabilize baseline. Recorded interbeat intervals (IBIs; i.e., the time interval between individual heart beats in milliseconds) were visually screened for physiologically impossible readings and movement artifacts, and corrected when necessary. Six IBIs were selected around the feedback; the IBI concurrent with the feedback (IBI 0), one IBI preceding the feedback (IBI-1) and four IBIs following the feedback (IBI 1 to IBI 4). In order to obtain a sensitive index of phasic heart rate change, IBI difference scores were referenced to the IBI preceding the feedback (IBI-1). Statistical analyses on IBI-1 values did not result in differences between feedback conditions in both tasks (ps > .47).

Thus, baseline values were not sensitive to any experimental manipulation before feedback presentation. As expected, the main effect of age group on IBI-1 values yielded significance in the social-judgment task, $F(1, 97) = 11.68$, $p = .001$, $p\eta^2 = .11$, and in the age-judgment task, $F(1, 97) = 9.78$, $p = .002$, $p\eta^2 = .09$. These results show that IBI length was on average shorter for 8- to 10-year-olds than 11- to 14-year-olds (see Table 2 in the online supplemental materials). No main effects of gender on baseline values were found.

IBI responses to feedback were evaluated statistically by using multivariate mixed measures analyses of variance (MANOVAs) with sequential IBI difference scores as within-subject variable (IBI 0 to IBI 4). Age group (2) and Gender (2) were used as between-subjects factors. MANOVAs were carried out because the assumption of sphericity was violated and a univariate approach was therefore less suitable (Jennings, 1987). In the behavioral analyses, response tendencies for "Yes" or "No" choices were examined by repeated-measures ANOVAs. In these analyses, the gender of the faces was added as an additional within-subject factor. It should be noted that this factor was not used in the cardiac analyses associated with feedback processing, since these results would then be based on an insufficient number of observations for each feedback condition. All analyses were considered significant when the *p* value was equal to or less than .05. Bonferroni correction was used for post hoc analyses.

Results

Behavioral Results

To test for developmental and gender differences in response tendencies for "Yes" and "No" choices, we submitted the number of choices to a 2 (Age Group; 8–10 and 11–14 years) × 2 (Gender-Participant; boys and girls) × 2 (Response Type; yes and no) × 2 (Gender-Picture; male and female) repeated-measures ANOVA. For the data obtained using the social-judgment task, this analysis revealed significant interaction effects of Response Type × Gender-Picture, $F(1, 97) = 19.05$, $p < .001$, $p\eta^2 = .16$, and Response Type × Gender-Picture × Gender-Participant, $F(1, 97) = 47.51$, $p < .001$, $p\eta^2 = .33$. These effects were qualified by a four-way interaction of Response Type × Gender-Picture × Gender-Participant × Age Group, $F(1, 97) = 5.77$, $p = .018$, $p\eta^2 = .06$. As can be seen in Figure 1A, both 8- to 10- and 11- to 14-year-old girls more often predicted to be liked by girls and to be disliked by boys. The 8- to 10-year-old boys showed a similar tendency to expect to be disliked by opposite-sex peers but the 11- to 14-year-old boys showed less differentiation in expectations of social evaluation. Post hoc comparisons for each group (Bonferroni corrected) yielded a two-way interaction of Response Type × Gender-Picture in both the 8- to 10- and 11- to 14-year-olds girls, respectively, $F(1, 24) = 39.55$, $p < .001$, $p\eta^2 = .62$, and $F(1, 26) = 20.61$, $p < .001$, $p\eta^2 = .44$. This two-way interaction approached significance in 8- to 10-year-old boys, $F(1, 24) = 3.66$, $p = .068$, $p\eta^2 = .13$, but it was not significant in 11- to 14-year-old boys ($p = .66$).

Similar analyses were carried out for the data obtained using the age-judgment task. The results showed a main effect of response type, $F(1, 97) = 16.37$, $p < .001$, $p\eta^2 = .14$, and significant interaction effects of Response Type × Gender-Picture,

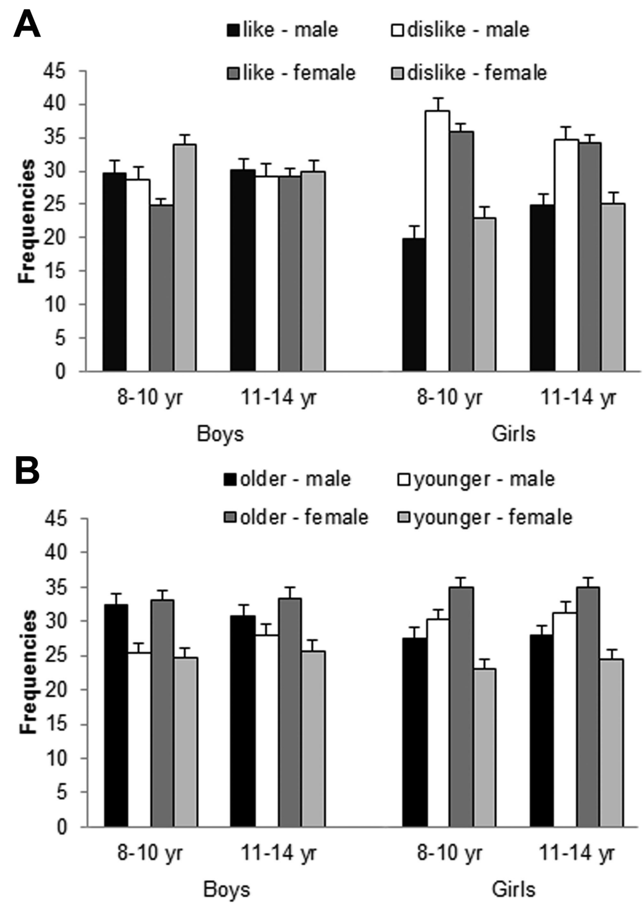

Figure 1. Frequencies of "Yes" and "No" choices separately for male and female faces of age-matched peers. Data are presented for each age group and gender for the social-judgment task (A) and the age-judgment task (B). Error bars represent standard errors of the mean.

$F(1, 97) = 35.44$, $p < .001$, $p\eta^2 = .27$, and Response Type × Gender-Picture × Gender-Participant, $F(1, 97) = 14.41$, $p < .001$, $p\eta^2 = .13$. Post hoc comparisons for each gender (Bonferroni corrected) yielded a main effect of response type in boys, $F(1, 48) = 13.37$, $p = .001$, $p\eta^2 = .22$, and a two-way interaction of Response Type × Gender-Picture in girls, $F(1, 51) = 51.98$, $p < .001$, $p\eta^2 = .51$. As can be seen in Figure 1B, girls more often predicted that girls were older and that boys were younger than the specified age. Boys on the other hand more often predicted that both boys and girls were older than the specified age. Exploratory analyses on response times for "Yes" and "No" choices in both experimental tasks are presented in the supplemental material.

Heart Rate Results

The primary goal of this study was to test for developmental and gender differences in sensitivity to peer rejection by examining beat-by-beat heart rate responses. Figure 2 shows IBI responses associated with feedback processing in the social-judgment task (Figure 2A) and the age-judgment task (Figure 2B). Separate plots are presented for each age group and gender. As can be seen in the figure, both tasks yielded the typical IBI response associated with

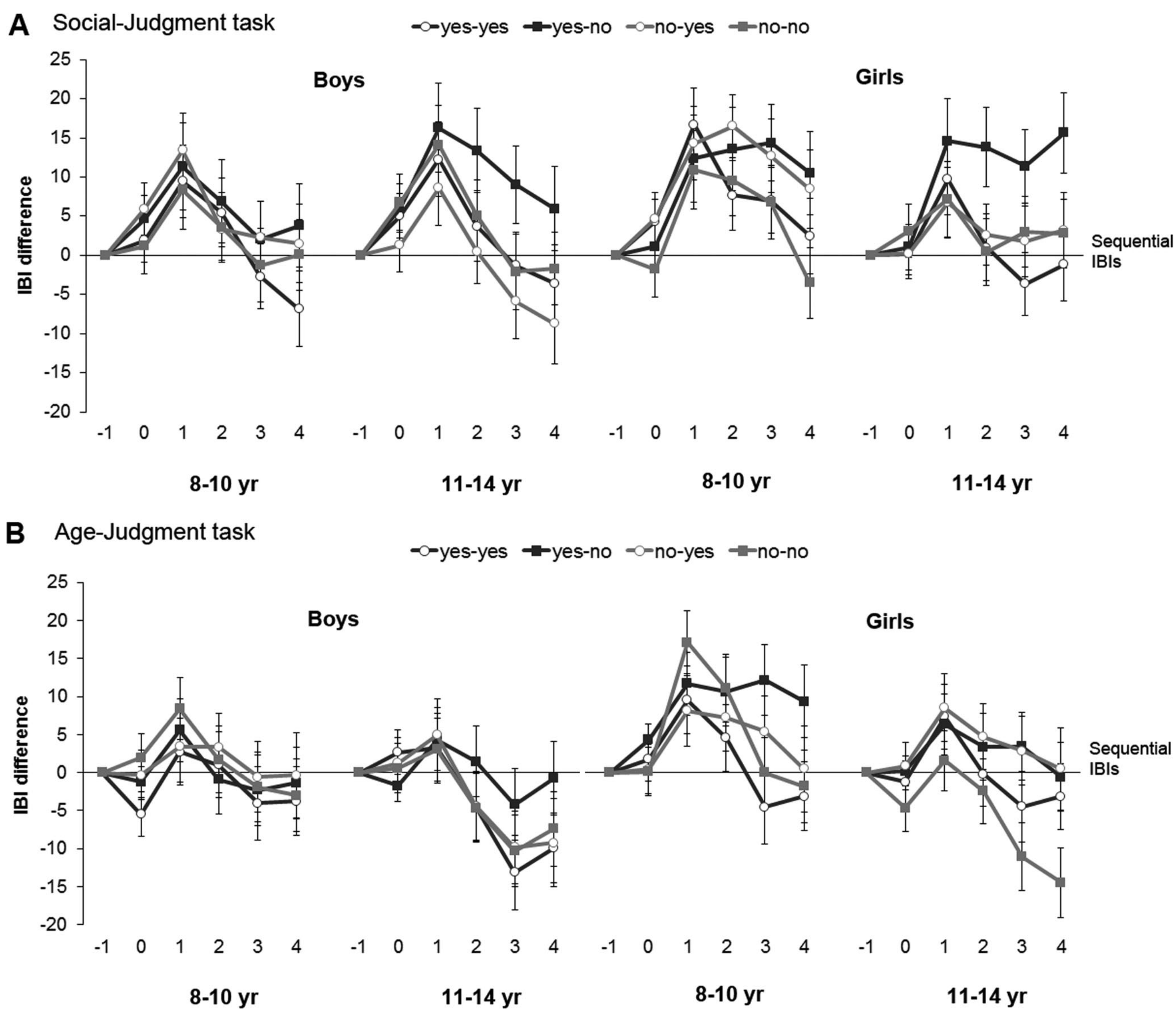

Figure 2. Interbeat-interval (IBI) response in milliseconds (referenced to IBI-1) associated with feedback processing in the social-judgment task (A) and the age-judgment task (B). The four lines represent the four feedback conditions: "Yes-Yes," "Yes-No," "No-Yes," and "No-No." Separate plots are presented for each age group and gender. Feedback processing is represented by five time points: IBI 0 (feedback presented to participants) and IBI 1 to IBI 4 (following feedback presentation). An increase in IBI difference scores indicates heart rate slowing. Error bars represent standard errors of the mean.

feedback processing. That is, IBI generally lengthened (i.e., deceleration of heart rate) to the presentation of the feedback (IBI 0), followed by a recovery (i.e., acceleration of heart rate) to baseline.

First, we tested our predictions concerning developmental and gender differences in IBI responses in the social-judgment task. The 2 (Congruency) × 2 (Feedback Type) × 5 (IBI 0-IBI 4) MANOVA with Age Group (2) and Gender (2) as between-subjects factors revealed main effects of congruency, $F(1, 97) = 7.65$, $p = .007$, $p\eta^2 = .07$; feedback type, $F(1, 97) = 4.68$, $p = .033$, $p\eta^2 = .05$; and IBIs, $F(4, 94) = 19.13$, $p < .001$, $p\eta^2 = .45$, and interaction effects of Feedback Type × Age Group, $F(1, 97) = 7.75$, $p = .006$, $p\eta^2 = .07$; Gender × IBIs, $F(4, 94) = 2.84$, $p = .028$, $p\eta^2 = .11$; Congruency × IBIs, $F(4, 94) = 3.88$, $p = .006$, $p\eta^2 = .14$; and Feedback Type × IBIs, $F(4, 94) = 3.24$, $p = .015$, $p\eta^2 = .12$. These effects were qualified by a significant five-way interaction between congruency, feedback type, IBIs, gender and age group, $F(4, 94) = 2.61$, $p = .04$, $p\eta^2 = .10$, which is plotted in Figure 2A.

To clarify this complex five-way interaction, separate MANOVAs for each group were conducted. In 11- to 14-year-old girls, this analysis yielded the expected three-way interaction between congruency, feedback type and IBIs, $F(4, 23) = 3.09$, $p = .035$, $p\eta^2 = .35$, whereas for 8- to 10-year-old girls an interaction of congruency and IBIs, $F(4, 21) = 3.53$, $p = .024$, $p\eta^2 = .40$, was found, but importantly, no interaction with feedback type. Indeed, as can be seen in Figure 2A, IBI was specifically lengthened for the "Yes-No" condition in 11- to 14-year-old girls, but not for 8- to 10-year-old girls. In 8- to 10-year-old girls, IBI was longer for the "Yes-No" and "No-Yes" conditions relative to the "Yes-Yes" and "No-No" conditions of the task. In 11- to 14-year-old boys, this analysis revealed main effects of IBIs, $F(4, 20) = 6.39$, $p = .002$, $p\eta^2 = .56$, and feedback type, $F(1, 23) = 8.26$, $p = .009$, $p\eta^2 = .26$, but did not result in interaction effects between IBIs and congruency and/or feedback type. However, as can be seen in the figure, IBI lengthening was specific for the "Yes-No" condition and not for the other feedback conditions, like in 11- to 14-year-old girls. Indeed, follow-up comparisons revealed that the IBI response for the "Yes-No" condition in 11- to 14-year-old boys was larger compared to the other conditions at IBI 3 (all $ps < .04$). In 8- to 10-year-old boys, a main effect of IBIs was found, $F(4, 21) = 6.95$, $p = .001$, $p\eta^2 = .57$, showing no differentiation between feedback conditions.

A similar 2 (Congruency) × 2 (Feedback Type) × 5 (IBI 0-IBI 4) MANOVA with Age Group (2) and Gender (2) as between-subjects factors was performed for the age-judgment task. The results that emerged from this task are presented in Figure 2B. The MANOVA done on these data showed main effects of congruency, $F(1, 97) = 6.01$, $p = .016$, $p\eta^2 = .06$, and IBIs, $F(4, 94) = 17.8$, $p < .001$, $p\eta^2 = .43$, and a two-way interaction between congruency and IBIs, $F(4, 94) = 4.97$, $p = .001$, $p\eta^2 = .18$. No interaction effects with gender and/or age group were found. Subsequent analyses were conducted to test whether the pattern of cardiac slowing to unexpected social rejection in 11- to 14-year-old boys and girls would be more pronounced than the cardiac response to negative cognitive feedback. This prediction was tested by comparing the "Yes-No" condition of the social-judgment task to the IBI response associated with the "Yes-No" (i.e., incongruent younger) and "No-Yes" (i.e., incongruent older) conditions of the age-judgment task. The IBI response to unexpected negative social feedback was larger compared to the response obtained for the "Yes-No" and "No-Yes" conditions of the age-judgment task in 11- to 14-year-old girls; respectively, $F(4, 23) = 3.37$, $p = .026$, $p\eta^2 = .37$, and $F(4, 23) = 4.44$, $p = .008$, $p\eta^2 = .44$. Thus, as anticipated, the additional transient cardiac slowing in 11- to 14-year-old girls was specific for unexpected social rejection. For 11- to 14-year-old boys, these comparisons did not differ significantly from each other ($ps > .19$).

Discussion

The goal of this study was to test for developmental and gender differences in sensitivity to peer rejection across the transition into adolescence. Participants performed two tasks with the same overall design, a social-judgment task and an age-judgment task, which served as a control task. We predicted that the alleged heightened sensitivity to peer rejection after transition into adolescence would result in larger cardiac slowing to unexpected peer rejection in 11- to 14-year-olds relative to 8- to 10-year-olds, that would be most pronounced in adolescent girls. The results of this study largely confirm these predictions. The finding showing that heart rate recovery was specifically delayed for social rejection following a positive expectation of social evaluation is consistent with previous findings in adults (Gunther Moor, Crone, & van der Molen, 2010).

At the behavioral level, the number of "like" and "dislike" expectations of social evaluation did not vary between age groups and gender. This finding contradicts our hypothesis that 11- to 14-year-olds would report higher levels of negative expectations related to social evaluation. Interestingly, group differences in response tendencies were found when considering the gender of the faces in the photographs. That is, both 8- to 10- and 11- to 14-year-old girls demonstrated a higher tendency to expect to be liked by girls and disliked by boys. Whereas 8- to 10-year-old boys showed a similar tendency to expect to be disliked by opposite sex-peers, 11- to 14-year-old boys showed less differentiation in their expectations of social evaluation. From a somewhat broader perspective, these findings could reflect gender preferences in social interactions (e.g., Bukowski, Sippola, & Hoza, 1999; Dijkstra, Lindenberg, & Veenstra, 2007; Maccoby, 1998). Further, the behavioral results show that latencies were longer for "like" compared to "dislike" expectations for faces of opposite-sex peers. Possibly, these longer latencies may reflect an initial bias for "dislike" expectations for peers of the opposite sex. In the light of this bias, participants would be slower on trials in which they expect to be liked by an opposite-sex peer (Greene, Sommerville, Nystrom, Darley, & Cohen, 2001). However, some caution is warranted in interpreting these reaction time data, since these effects were found at trend level.

Both experimental tasks yielded the typical heart rate pattern associated with feedback processing. That is, heart rate generally slowed following the presentation of the feedback followed by an acceleratory recovery to baseline (e.g., Crone et al., 2003; Somsen, van der Molen, Jennings, & Van Beek, 2000). In a previous study in adults using the same overall design, it was observed that this return to baseline was specifically delayed in response to unexpected social rejection (Gunther Moor, Crone, & van der Molen, 2010). Interestingly, short-latency decreases in heart rate are believed to be a manifestation of "orienting" that is primarily mediated by the parasympathetic nervous system (e.g., Berntson et al., 2007; Bradley, 2009; Somsen, Jennings, & van der Molen, 2004). These findings fit well with studies suggesting that parasympathetic regulation of cardiac activity may facilitate adaptive social and emotional behavior (e.g., Gyurak & Ayduk, 2008; Porges, 2003). Of particular relevance to the current study, Heilman et al. (2008) studied the psychophysiological profile of children in response to a physical and a social challenge. While heart rate increased with the physical challenge (i.e., bicycle pedaling), heart rate decreased to the social challenge (i.e., staying in a room with the experimenter while the parent exited the place), which was associated with greater parasympathetic activity. Similarly, cardiac slowing to unexpected social rejection could be interpreted as a response of the central-autonomic network facilitating the processing of significant social information (Porges, 2003, 2007; Thayer & Brosschot, 2005).

In line with our predictions, the delay in cardiac slowing to unexpected peer rejection was larger in 11- to 14-year-olds relative to 8- to 10-year-olds, suggesting an increase in peer rejection sensitivity after transition into adolescence. A close inspection of the data further revealed that the cardiac response to unexpected peer rejection was larger in 11- to 14-year-old girls relative to 11- to 14-year-old boys. Importantly, we found that this cardiac response in girls was larger than heart rate changes associated with other conditions in which the feedback was not aligned with the expectations of the participant (i.e., unexpected acceptance, incongruent older, incongruent younger), confirming that this effect was specific to unexpected social rejection. The results of this study support the hypothesis that peer rejection may be particularly salient in adolescent girls. There is evidence that adolescent girls place great emphasis on interpersonal relationships and peer support, and express more concern about social evaluation than boys (e.g., Guyer et al., 2009; Rose & Rudolph, 2006; Rudolph & Conley, 2005). Further, the pattern of results that emerged from our study suggests that the heightened sensitivity to peer rejection in adolescent girls operates in a context-sensitive manner. That is, heart rate was specifically delayed for unexpected rejection and not for expected rejection. This finding is important in showing that adolescent girls are particularly sensitive to peer-related rejection feedback that most urgently alerts them to adjust future actions, rather than being hypersensitive to any type of negative feedback.

A question that remains unanswered in the current study is whether the heightened sensitivity to peer rejection in adolescents may be the result of biological processes associated with puberty or whether these changes are driven by psychosocial or environmental factors. That is, at the same time important biological changes take place, early adolescence is marked by a dramatic set of challenges, such as the transition from primary to secondary school, a greater degree of autonomy, and the influence of a peer group (Steinberg & Morris, 2001). The co-occurrence of these changes requires great precision to unravel the underlying mechanisms. Future studies could benefit from longitudinal designs to track both biological and environmental influences on peer rejection sensitivity in the same participants over time. We believe this line of research is essential to further test theoretical models on adolescent brain development, in which often a key role for puberty is suggested (Blakemore, Burnett, & Dahl, 2010). In particular, these models emphasize that adolescent social and affective behavior is strongly influenced by pubertal hormones due to a reorganization of brain regions (e.g., Crone & Dahl, 2012; Nelson et al., 2005; Steinberg, 2008).

Finally, the results of this study could help generate new hypotheses for clinically oriented research. Prior studies demonstrated that greater emotional reactivity to peer rejection among adolescents is associated with lower feelings of social connectedness in daily life and an increased risk for depression (Masten et al., 2011; Silk et al., 2012). One potentially interesting direction for future research would be to test whether individuals learn to expect rejection based on frequent rejection experiences by significant others. Given the observation of the present study of pronounced heart rate slowing to *unexpected* social rejection, it could be beneficial for some adolescents to expect rejection as a form of self-protection. Indeed, researchers proposed that a violation of social expectations (i.e., being included) is inherent in the affective experience of rejection (Bolling, Pitskel, Deen, Crowley, McPartland, et al., 2011; Somerville et al., 2006). The "rejection sensitivity model" developed by Downey and Feldman (1996) would be an interesting framework for understanding these individual differences. According to this model, people who are high in rejection sensitivity show a heightened tendency to expect, readily perceive and overreact to social rejection, which may be the result of prior rejection experiences. While this sensitivity may initial be functional in helping to defend against rejection, there is evidence that it can ultimately set up a vicious circle by damaging interpersonal relationships and by causing more rejection (Berenson et al., 2009). High rejection sensitivity is believed to be an important risk factor for depression, especially in females (Ayduk, Downey, & Kim, 2001). We believe research on the combination between biological susceptibility, rejection sensitivity and psychosocial stressors may yield important insights in the sharp increase in depression rates among adolescent girls (Oldehinkel & Bouma, 2011).

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