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Dyadic Attunement and Physiological Synchrony During Mother-Child Interactions: An Exploratory Study in Children With and Without Externalizing Behavior Problems

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Abstract We investigated whether synchrony at a physiological level (i.e., real-time correspondence of biological indices between two individuals) related to observed levels of dyadic attunement (i.e., levels of connectedness, joint attention, and reciprocity), and whether these measures could distinguish between mother-child dyads with and without clinical levels of externalizing behavioral problems. Eighty-three clinical and 35 nonclinical dyads (7–12 years-old) discussed a contentious topic preceded and followed by a positive topic while their heart rates were recorded. Changes in dyadic attunement from the last discussion relative to the first were taken as an index of how well dyads 'repaired' their relationship. Results showed that clinical dyads had lower levels of dyadic attunement across all discussions compared to nonclinical dyads. Evidence that physiological synchrony could distinguish clinical from nonclinical dyads, however, was merely suggestive. Physiological synchrony was sensitive to the emotional context of the discussions as more dyads demonstrated physiological synchrony in the last compared to the first discussion. Moreover, dyads who demonstrated physiological synchrony also showed higher levels of repair. The outcomes of this study suggest that physiological synchrony between mothers and their children is sensitive to emotional context during interactions, and particularly during periods of repair when dyads more actively reconnect with each other after a negative interaction.

Keywords Dyadic attunement · Physiological synchrony · Children · Psychopathology · Conduct disorder · Externalizing · Internalizing · Heart rate

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Introduction

The study of how mother-child relationship dynamics differ between social contexts and individuals has been of great interest to developmental psychologists (Ainsworth 1979; Bretherton 1992; Bronfenbrenner 1986; Russell 2011). Research using the dyad as the unit of analysis to study mother-child interactions has provided unique contributions to the field. Higher degrees of synchrony, mutual responsiveness, and reciprocity, for example, have been related to the quality of positive interactions, and are seen as a basis for a successful socialization throughout a child's development (Ainsworth 1979; Ambrose and Menna 2013; Sroufe 2000). In the current paper, we will refer to these processes, representative of the instantaneous and mutual coordination of behavioral exchanges between two individuals, as dyadic attunement.

Dyadic attunement has been seen as intrinsically connected to the development of an effective self-regulation (Feldman et al. 1999), which is seen as the ability to effectively modulate one's emotions and attention in relation to changing situational contexts and internal goals (Kopp 1982; Woltering and Lewis 2009). The seminal work of Edward Tronick has explicitly linked processes of dyadic attunement to self-regulation (Gianino and Tronick 1988; Tronick 1989). He views the infant and parent as part of an affective communication system and explains that emotional expressions function to regulate interactions. For example, affective displays, like smiles, provide signals allowing an infant to better evaluate when goals of affection are achieved. Such coordinated feedback systems, when reciprocal, positive, and consistently repeated throughout development, help infants to regulate their emotional state. Beatrice Beebe further investigated the relationship between attunement and self-regulation through slowing down videos of mother-child interactions and analyzing facial expressions on a moment-to-moment basis. She revealed dynamic patterns of mutual adjustment that, she believed, formed the basis for emerging self and object representations. Such representations aid with the regulation of children's emotions through the formation of expectations of how interactions should go and where they would lead to (Beebe and Lachman 1988; Beebe, et al., 2010). The concept of repair is particularly important in this context. Repair represents a dyad's ability to correct for interactive errors or conflictual interactions in the communication (Tronick 1989). Infants who experience more repair also have a sense that they themselves can be effective in repairing a distressful situation. This allows the infant to remain engaged during an interaction despite external stressors and sets the stage for the development of coping strategies that regulate perceived distress (Gianino and Tronick 1988).

The abovementioned researchers also suggested that chronically uncoordinated, or otherwise absent or abnormal communication patterns within a dyad could lead to psychopathology (Tronick 1989). Indeed, although research has shown that while high levels of dyadic attunement were associated with better self-regulation (Calkins and Hill 2007; Feldman et al. 1999.), low levels of mother-infant or child attunement, or poor repair, was associated with difficulties of self-regulation that can lead to clinical levels of externalizing and internalizing problem behaviors (Cole et al. 2003; Criss et al. 2003; Deater-Deckard et al. 2004; Hollenstein et al. 2004; Kochanska and Aksan 1995; and see Rothbaum and Weisz 1994 for review).

In recent years, physiological measures are supporting, and help validate, traditional observational measures of behavior. Such physiological measures can add unique value to observational measures due to their sensitivity to (sometimes subconscious) emotional and psychological processes that are not always readily observable. It is well-established that changes in physiological variables, such as heart rate, are sensitive to variations in emotional states underlying both overt as well as covert behavior (Kreibig 2010; Sinha et al. 1992; Cacioppo et al. 2000). In the present paper, we asked whether the interplay of emotional states, as is common with dyadic attunement, has underlying physiological correlates that are reflected in mutually co-occurring changes in heart rate. We defined physiological synchrony as the moment-to-moment interrelation of physiological signals (e.g., heart rate) between two individuals. It is possible that these physiological measures may be more sensitive to, or capture different elements of, attunement processes. This may be particularly relevant when observing behavior beyond infancy as older children are more adept at manipulating the expression of emotion. Researchers have also proposed neurobiological models explaining how processes of dyadic attunement would be reflected in a physiological synchrony (Nelson and Panksepp 1998; Feldman 2007b; Schore 2000). Ventral and medial prefrontal systems, for example, are strongly connected to the autonomic nervous system and regulate social and emotional behaviors (Chapman et al. 2010; Critchley 2005; Schore 2000).

Empirical studies investigating the quality of relationships using physiological measures at a dyadic systems level, however, are rare. Thus far, studies suggest that patterns of physiological synchrony may indeed be related to relationship quality or proxies of dyadic attunement. For example, studies have related physiological synchrony to increased levels of marriage satisfaction (Ferrer and Helm 2013; Thomsen and Gilbert 1998) and self-reports of affect (Ferrer and Helm 2013) in couples. Another study, investigating performers of a fire-walking ritual, found that spectators who were relatives or close friends of the performers showed more physiological synchrony than unrelated spectators (Konvalinka et al. 2011). We note that physiological synchrony (as opposed to asynchrony) does not necessarily relate to positive outcomes since physiological synchrony was related to negative outcomes in conflict situations (Levenson and Gottman 1983).

Feldman and colleagues (Feldman et al. 2011; Feldman 2007b) to the best of our knowledge, were the first to examine physiological synchrony in mother-infant interactions and found that physiological synchrony was associated with periods of shared affect. Interestingly, mother-infant physiological synchrony of heart beats measured at 3 and 9 months predicted self-regulation at 2, 4 and 6 years

(Feldman et al. 1999), as well as empathy at 13 years old (Feldman 2007a). While these results represent an emerging field of research, with few studies at present, there is a strong impetus to look at physiological synchrony as a useful measure of the affective dimension of human interaction, in particular as a supplement to observational and/or self-report data.

Thus far, no studies investigated the relationship between physiological synchrony and dyadic attunement in parent-offspring dyads beyond infancy. This is surprising, because childhood is a period where parent–child relationships are still developing (Collins and Russell 1991; Easterbrooks et al. 2012). Moreover, research shows that self-regulation is undergoing rapid changes in middle childhood (Raffaelli, Crocket, & shen, 2005), and that a healthy co-regulation with parents is considered an important factor for development (Colman et al. 2006; Criss et al. 2003). In addition, no studies have investigated such interactions in children experiencing problems with self-regulation. This is important, as maladaptive patterns of dyadic attunement reflected at a behavioral and physiological level can help explain factors determining the development of clinical levels of externalizing or internalizing problem behaviors (Feldman 2007b; Hum and Lewis 2012; Tronick 1989). Exploring the relationship between physiological synchrony and dyadic attunement in mother-child interactions may thus better inform researchers about the quality of relationships and could support the early identification of psychopathology.

The purpose of the present study was to investigate whether, and how, physiological synchrony relates to attunement in mother-child interactions, and between dyads with and without self-regulatory problems. Heart rates were measured from children and their mothers during a conflict resolution paradigm featuring three discussions with different emotional contexts (Forgatch et al. 1985; Forgatch 1989). A discussion on a contentious topic was preceded and followed by a discussion featuring positive topics. We referred to the contrast between the first and last discussion as the level of repair (see also, Granic et al. 2007). Our primary interest was the comparison between the first and the last positive discussion because they were equivalent in content. Dyadic attunement was operationalized by coded scores for instances of connectedness, joint attention, and reciprocity, based on video-observational measures. Physiological synchrony between mother and child heart rates was operationalized by a value representing the second-by-second synchrony in heat beats.

We had four main hypotheses. First, we hypothesized that dyadic attunement would be lower for the contentious discussion compared to the positive discussions for all dyads. In addition, we expected children with poor self-regulation to show lower degrees of dyadic attunement. Second, we hypothesized that physiological synchrony would vary with emotional context (e.g., the different discussions). More specifically, we expected higher incidences of physiological synchrony in the last compared to the first discussion because dyads would typically be more active in trying to re-engage after the negative emotion induction (see concept of repair explained in Granic et al. 2007). Third, in accordance with the observational literature (Deater-Deckard et al. 2004; Rothbaum and Weisz 1994; Tronick 1989), and assuming physiological synchrony is a reflection of the dyadic attunement, we expected physiological synchrony to be lower for our clinical than our nonclinical sample. Fourth, we hypothesized higher levels of dyadic attunement and levels of repair in dyads to relate directly to the presence of physiological synchrony. One reason is that the extant literature suggested that increased levels of dyadic attunement were associated with physiological synchrony in non-conflict situations. We also expected relationships between physiological synchrony and dyadic attunement to be weaker for clinical dyads than for nonclinical sample. This would be particularly true when analyzing levels of repair because studies have shown that low levels of repair in parent–child interactions were associated with externalizing behavior problems (Hollenstein et al. 2004).

Methods

Participants

The data from this analysis were taken from a larger study investigating individual differences in, and intervention effects of, the neural correlates of self-regulation in children. A total of 118 children (86 % boys) between 7 and 12 years old and their mothers from whom both heart rate data were collected were included in this study. The clinical group consisted of 83 children (84 % boys; mean age=9.5 years old) and their mothers were recruited from two children's community mental health agencies that offered a combined parent management therapy/Cognitive Behavioral Therapy treatment for children with severe behavioral problems and aggression and their families. Children were referred to these agencies for aggressive problems either by a mental health professional, parent, or teacher. In addition, 35 (88 % boys; mean age=9.9 years old) typically developing children and their mothers, matched at a sample level for age and gender, were recruited through local newspaper ads. Upon first contact, a research assistant explained the study and asked if the parent and child were willing to participate. The clinical dyads, as referred to them in the present study, were all tested approximately 2 weeks before treatment started.

The inclusion criteria for the clinical group was a score above 64 (98th percentile, clinical range) on the Externalizing subscale of the Child Behavior Checklist (CBCL: Achenbach, 1991) along with sufficient English language skills to allow the unassisted completion of self-report questionnaires. Exclusion criteria consisted of any significant cognitive impairment, such as a persistent developmental delay. Table 1 shows the sample demographics, separate for the clinical and nonclinical group.

Procedure

The participants (mother and child) visited the university research location where they were welcomed by a research assistant who directed them to the observation room. Once seated and acclimatized, various questionnaires were completed by the parent. The questionnaires, which assessed levels of externalizing and internalizing problem behavior, included parent reports of problem behaviors as well as demographic data. In addition, a written informed consent was obtained from the mother and an assent form was read to the child, and signed by the researcher upon verbal consent. The study was approved by the Research Ethics board of the University of Toronto.

In the observation room, the child and his/her parent were seated opposite of each other in comfortable chairs and both the parent and the child were connected to the ECG acquisition unit. The observational procedure involved the discussion of different topics between the child and their parent. The procedure was captured via a pair of cameras behind a one-way mirror. Parents and children were asked to discuss, in the exact order: a – randomly assigned - positive topic out of two topics (You will be taken to live on an island paradise that has nothing on it - you can take anything you want with you - use your imagination to talk about what you would take; you have won the lottery, what are you both planning to do with the money?), a personally relevant negative topic that both the parent and child independently listed was anger-provoking and had not been resolved, and lastly, another positive topic. The negative topic was chosen by a research assistant among a list of issues where parent and child rated issues with a 5-point scale for severity (e.g., time for going to bed, fighting with brothers/sisters, doing homework; see supplements for the complete Issues Checklist) and indicated whether an issue was resolved or not. The research assistant picked from any topic that was listed by both the parent and child as unresolved and highest in severity (score of 4–5). The first and final discussions were 4 min long and the contentious discussion was 6 min. Four minutes into the middle discussion, a research assistant knocked on the door, reminding the subjects that there are 2 min left and reminded the dyad that they should 'try and end on a positive note.' This was also explained to the participants beforehand.

Table 1 Demographic characteristics (frequencies and percentages) for the clinical and nonclinical group

	Clinical group (*n*=84)	Nonclinical group (*n*=35)
Living arrangements		
Both parents	29 (36 %)	17 (49 %)
With step-parent	11 (14 %)	1 (3 %)
Mother only	30 (38 %)	13 (37 %)
Other	10 (12 %)	4 (11 %)
Ethnicity		
European	60 (76 %)	17 (49 %)
African/Caribbean	12 (15 %)	6 (17 %)
Latin American	2 (2 %)	3 (9 %)
Asian-Canadian	–	4 (11 %)
Other	5 (7 %)	6 (14 %)
Mother's education[a]		
High school, or less	35 (44 %)	6 (17 %)
Community college	27 (34 %)	9 (26 %)
University, or higher	15 (19 %)	19 (54 %)
Other/Unknown	3 (4 %)	1 (3 %)
Father's education[a]		
High school, or less	29 (53 %)	7 (26 %)
Community college	17 (32 %)	3 (11 %)
University, or higher	6 (11 %)	16 (59 %)
Other/Unknown	2 (4 %)	1 (3 %)
Family income (CND$)		
0–29,9999	27 (36 %)	7 (20 %)
30,000–59,999	15 (20 %)	15 (43 %)
60,000 or above	34 (44 %)	13 (37 %)

[a] Mother's/Father's education is highest level completed. *=Chi-square, $p<.05$. ** $p<.01$

Clinical Questionnaire Measure

Reports of Externalizing Behavior from parents of child conduct problems were obtained from the CBCL (Achenbach, 1991). The CBCL consists of 113 items and assesses multiple problem areas on a 3-point scale. Parents were asked to rate their child's behavior prior to the start of treatment. The CBCL is a standardized, highly reliable and valid measure of children's emotional and behavioral problems and yields a standardized T-score for Externalizing Problems as well as Internalizing problems in general. For Internalizing and Externalizing scales, the cut-off point for the normal range is a T-score <60, borderline is from 60 to 63, and the clinical range is ≥64.

Observation Measures

A global video rating scale, developed by the Granic coding lab (Rubin-Vaughan 2010), was used to capture the impression of dyadic attunement during the entire duration of the discussions. The scale is comprised of three items that were rated on a nine-point scale which ranged from '1' (not at all), through '5' (somewhat), and '9' (very much), indicating the extent of which a particular behavior was present. Dyadic attunement scores were computed by the sum of all subscales. The subitems were: 1) Engagement/connectedness; measured the degree of which the dyad was 'in tune', 'connected' and 'interested' in each other, 2) Joint attention/shared focus; measured the degree of which dyads were following the same topic, and were flowing together in conversation, and, 3) Balance/reciprocity; measured the degree of balance of the participation in the discussion as well as conversational turn-taking. The interactions were coded by a group of four intensively trained undergraduate students blind to the hypotheses of the study. The internal consistency of the items was found to have Cronbach's alpha's of 0.76 in first discussion, 0.83 in the second, and 0.84 in the third. Inter-rater reliability, based on 20 % of the data, was tested through intraclass correlation coefficients (0.89). Coders met weekly to avoid coder-drift.

The levels of repair in the dyad were tested by comparing differences during the last discussion while co-varying out dyadic attunement in the first. These contrasts were chosen as both positive discussions are similar in all respects, but the last discussion occurs after a dyad has just discussed a contentious topic. The level of repair can represent an ability of being able to overcome negative occurrences which could lead to more flexibility in conflict resolution – a key concept in the measurement of self-regulation (Granic et al. 2007). During this conversation, the dyads, after they had discussed a negative topic, needed to recover from any lingering negative emotions and reconnect to discuss the next positive topic. Though the term 'level of repair' may imply that repair behavior necessarily takes place, for clarification we point out that dyads may display much lower degrees of dyadic attunement in the last compared to the first discussion. This was considered low levels of repair.

Psychophysiological Measurements

Electrocardiography (ECG) data were acquired at a sampling rate of 1000 Hz using a BIOPAC MP150 system (Biopac Systems Inc., Goleta, CA), with electrodes positioned diagonally across the heart in a standard Lead II configuration. Data processing was conducted using ANSLab software (Wilhelm et al. 1999). The first phase of the data processing transformed the raw ECG signal into time series of interbeat intervals (IBI) and heart rate indices. R-waves, caused by contraction of the ventricular walls, represent the strongest measurable electrical response of heart beat and form a distinct peak in the raw ECG. After automatic R-wave detection in ANSLab, each file was carefully inspected by two trained research assistants. In accordance with standard procedures, 'peak markers' were added when it was clear a peak was erroneously missed or deleted when it was clear a peak had been erroneously registered. Because synchrony analysis requires time series to be continuously clean, files that contained noisy heart rate signal or smaller signal-abnormalities not related to ECG that could not be corrected, were excluded from further analysis. Eleven clinical dyads had to be excluded from the synchrony analysis for this reason. They did not differ on CBCL from the included group. The R–R interval series was then converted into a time series. These data were used to determine IBIs, representing the time in milliseconds between successive R-waves in the ECG. To convert the time into the more familiar beats per minute (BPM), the number 60,000 (Total amount of milliseconds in a minute: 60 s in a minute times the 1000 milliseconds in a second) was divided by the IBI. Heart rate during discussions was measured as the average HR during 4 min. The last 2 min in the middle discussion were discarded to keep all discussions of equal length.

Physiological Synchrony The second phase of the data processing prepared the IBI times series representing the heart rate from both mother and child to determine whether both time-series were synchronous or not. After the heart rates from mother and child were exported from ANSLab into time-series, the physiological synchrony analysis was conducted in 'R' (R Development Core Team, 2008) by means of a Structural Heteroscedastic Measurement-Error (SHME) model (McAssey et al. 2013). This method is ideally suited to determine synchrony between two IBI time series because heart beats are measured at discrete intervals that do not necessarily overlap in time. The SHME model is able to detect linear associations between two discrete time series, such as heart rate, and takes variability (e.g., lags) between series of discrete heartbeats into account. That is, the method discerns whether the heart rate of one member of a dyad tends to increase (or decrease) steadily as the heart rate of the other member increases, that is, synchrony. The method involves first cutting the lengths of both time series to the first and last heartbeat, after which the two time series were divided into shorter segments of 5 s each. Within each of these intervals, the average heart rates and their standard errors are computed (as standard errors vary for each segment, there is heteroscedastic measurement error). A slope value is then estimated, representing the tendency for the mother and child heart rates to decrease or increase in synchrony. If there was sufficient evidence for a linear association, at a significance level of 0.05, a dyad was considered to be in synchrony. As a consequence of the embedded statistical test for synchrony, which is conducted directly on the standard errors of the data, outcomes for our Synchrony Status variable are dichotomous. We note in particular that this method does not require the assumption of stationarity for both time series and that it poses an improvement over previously used methods which do not correct for lags when looking at cross-correlations. Physiological synchrony measures were computed across

4 min for each discussion separately. For a detailed description of this method we refer to the methodology paper by McAssey et al. (2013). Figure 1 shows a sample of data of a dyad that was considered synchronous and another not considered synchronous.

Statistical Analysis

Data points that were three standard deviations removed from the mean were regarded as outliers and were discarded from the analysis. Standard mixed model ANOVAs were used to test for differences in means. A binary logistic regression of Synchrony Status was used to test for relationships with predictor variables whereby dummy variables were used to test for contrasts between discussions. Greenhouse-Geisser corrected statistics were reported when assumptions of sphericity were violated. Data point loss for any variable larger than 10 % of the total sample will be reported in the text, otherwise we will refer to the degrees of freedom for each analysis to any gage data loss. Because the study was mainly exploratory in nature, marginally significant effects were reported and interpreted. Partial η^2 values were computed to ascertain effect sizes (Eta squared). According to Vacha-Haase and Thompson (2004), $\eta^2=0.01$ corresponds to a small effect, $\eta^2=0.10$ corresponds to a medium effect, and $\eta^2=0.25$ represents a large effect.

Results

Questionnaire Measures

Questionnaire measures were used to confirm the assumption that the clinical group had higher externalizing problem behaviors than the comparison group. Indeed, with respect to the CBCL, the clinical group reported significantly more externalizing, $t(111)=14.63$, $p<.001$, as well as internalizing, $t(111)=6.25$, $p<.001$, problem behaviors as shown by independent samples t-tests. The CBCL scores in the clinical group for externalizing scores, $M=71.1(SD=6.2)$, as well as internalizing scores, $M=65.4(SD=9.4)$, were above clinical levels of impairment. The comparison group had scores below the clinical range for externalizing, $M=49.7(SD=9.0)$, as well as for internalizing problem behaviors, $M=53.2(SD=9.8)$.

Heart Rate Measures: Effects of Group and Discussion

To support assumptions that the contentious discussion was more negatively arousing, heart rate measures were compared between discussion type. When examining heart rate, a 2 (Group: clinical, nonclinical) by 3 (Discussion) mixed-model Repeated Measures ANOVA was used. For children's heart rate, a significant quadratic main effect for Discussion, $F(1,96)=4.12$, $p<.05$, eta squared=0.04, was found, showing an overall increase in heart rate during the second, contentious, discussion. No other Group or interaction effects were found. For mothers' heart rate, a significant effect of Discussion was found, $F(2, 101)=11.22$, $p<.001$, eta squared=0.18, whereby post-hoc analyses showed that heart rate was lower from the first to the second, and from the second to the third discussion (all p's<.01). No Group or Interaction Effects were found.

Observational Measures: Dyadic Attunement

Our first hypothesis stated that we expected our clinical sample to show lower dyadic attunement compared to the nonclinical sample. Video observational measures were used to test for differences in dyadic attunement. As was assumed from the literature, a main effect of Group, $F(1,112)=4.83$, $p<.05$, eta squared=0.04, and Discussion, $F(2,111)=13.84$, $p<.001$, eta squared=0.20, was found for dyadic attunement as shown by a 2 (Group) by 3 (Discussion) mixed model Repeated Measures ANOVA. The clinical group showed lower amounts of dyadic attunement than the nonclinical group across all discussions. For Discussion, pairwise comparisons confirmed that the contentious discussion showed less dyadic attunement than the positive discussions (p's<.001). The average scores (also displayed in Table 2) suggested that the level of dyadic attunement was generally high. No significant

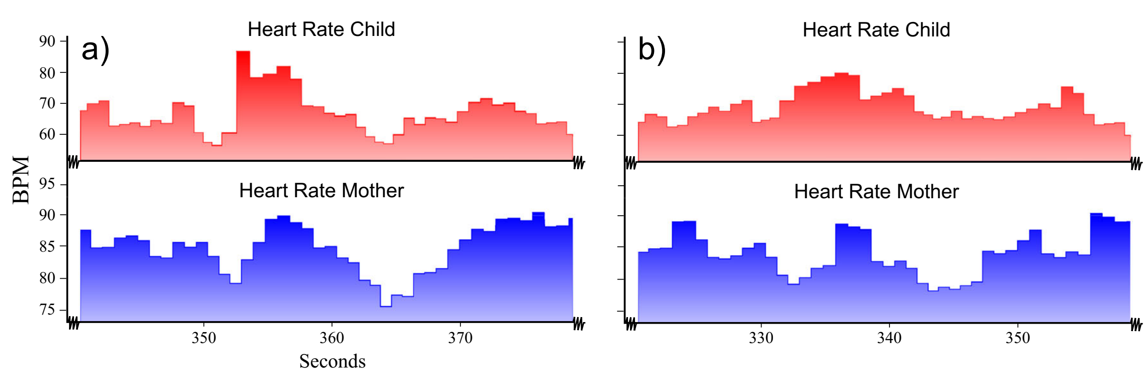

Fig. 1 Example of a dyad's heart rates "in synchrony". *BPM* Beats per minute

Table 2 Dyadic attunement per discussion and levels of repair (operationalized as a difference measure) means and standard deviations for the clinical and nonclinical dyads for physiological synchrony status

	Clinical		Nonclinical	
Physiological synchrony	Phys. Sync	No Phys. Sync	Phys. Sync	No Phys. Sync
Dyadic attunement				
Discussion 1	20.0(4.0), n=17	20.3(3.4), n=46	21.3(2.3), n=8	21.6(2.8), n=25
Discussion 2	18.8(4.8), n=22	17.2(4.2), n=42	21.4(3.5), n=13	19.0(4.8), n=22
Discussion 3	20.0(3.7), n=28	19.7(4.5), n=34	21.6(3.5), n=14	20.0(4.4), n=20
Repair	−0.14(3.3), n=28	−0.68(2.8), n=34	0.14(1.8), n=14	−1.7(2.9), n=20

differences were found between the first and the last positive discussion. Figure 2 shows the dyadic attunement values (means and standard errors) for each group and each discussion. An ANCOVA testing for differences in levels of repair, the measure that estimated how well dyads recovered from the contentious discussion, showed no significant Group difference.

Physiological Synchrony

For the physiological synchrony, we hypothesized that degree of physiological synchrony would vary with emotional context and that the clinical sample would demonstrate less physiological synchrony than the nonclinical sample. A Logistic regression of synchrony status with Group, Discussion (3 levels), and the interactions as predictors produced a model with non-significant interactions for Group as well as Group-by-Discussion. A new model adding Discussion as the single predictor of the regression showed a marginally significant overall effect of Discussion, $\chi^2(2)=5.58$, $p=.061$. As hypothesized, there was a significant effect for the contrast between the first and the last discussion, $\chi^2(1)=5.52$, $p=.019$, showing that the odds of dyads being in synchrony increased by a factor of 2.03 from the first to the last positive discussion.

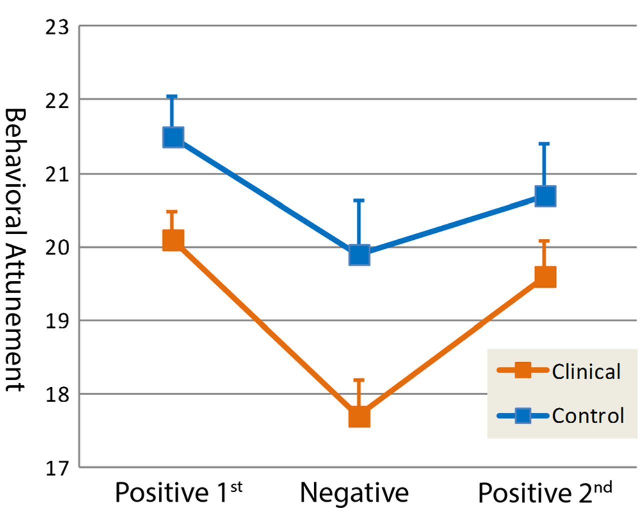

Fig. 2 Amount (and *error bars*) of dyadic attunement for the clinical and nonclinical sample for each discussion

Contrary to our hypotheses, however, physiological synchrony measures did not differ between clinical and nonclinical dyads. Consistent with our main effect, Fig. 3 shows the comparison of both positive discussions for the percentage of physiological synchrony for clinical and nonclinical dyads.

Dyadic Attunement and Physiological Synchrony

Our hypotheses stated that dyads who show physiological synchrony would have higher levels of dyadic attunement, and that this relationship be stronger for the nonclinical sample.

Dyadic Attunement and Physiological Synchrony To directly test for differences in the amount of dyadic attunement between Group and Synchrony Status, 2 (Group) by 2 (Synchrony Status), ANOVAs were run for each discussion separately. The first and last discussions showed no main or interaction effects. However, for the second distressful discussion, a main effect for Synchrony Status was found, $F(1,95)=4.18$, $p<.05$, eta squared=0.04, showing that those dyads who were synchronized at a physiological level displayed the largest amounts of dyadic attunement. The null-effects for the first and last discussion were unexpected, as we predicted higher levels of dyadic attunement to be associated with dyads that also demonstrate physiological synchrony across all discussions. Furthermore, no effects of Group were found.

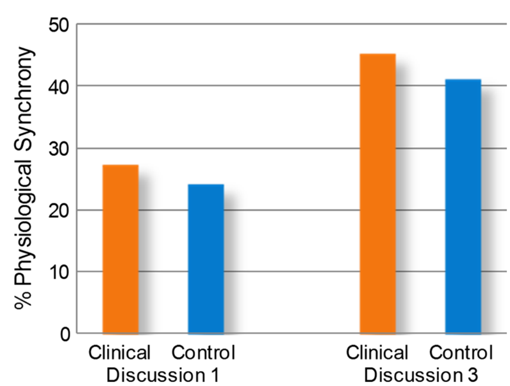

Fig 3 Percentage of the clinical and nonclinical sample displaying significant levels of physiological synchrony for the first and last positive discussion

Levels of Repair and Physiological Synchrony We were particularly interested in whether the level of repair was different between clinical and nonclinical dyads and between dyads with and without physiological synchrony in the last discussion. A 2 (Group) by 2 (Synchrony Status) ANCOVA showed a marginally significant main effect of Synchrony Status, $F(1,91)=3.45$, $p=.066$, eta squared=0.04, whereby dyads with physiological synchrony showed higher levels of repair. Although the Group-by-Synchrony Status interaction was not significant, the pairwise comparisons suggested that this difference, as hypothesized, was mainly driven by the nonclinical group, $p=.076$, instead of the clinical group, $p=.48$. However, these effects were weak and their interpretation is merely suggestive. Table 2 shows the values for dyadic attunement and levels of repair (here displayed as difference measures for readability) broken down for by group and physiological synchrony status.

Discussion

The current study utilized a combination of observational and psychophysiological measures to explore the relationship between physiological synchrony and dyadic attunement in mother-child dyads.

The observational measures showed that dyads displayed more dyadic attunement during the positive discussions compared to the negative one. This finding suggests that the measure of dyadic attunement is related to higher levels of positive affect (Ambrose and Menna 2013; Maccoby 1984), whereas the negative discussion resulted in a decrease of dyadic attunement. Furthermore, clinical dyads showed less dyadic attunement across all discussions than the nonclinical dyads. This confirmed our first hypothesis and notions in the field that lower levels of dyadic attunement in mother-child dyads are related to, and could possibly form an explanation for, externalizing and internalizing problem behavior even in middle childhood (Deater-Deckard et al. 2004).

Our second main hypothesis - that physiological synchrony would vary within discussion - was also confirmed. Indeed, dyads were found to be over twice as likely to show physiological synchrony during the last discussion compared to the first. We assumed that dyads were trying to reconnect and repair their relationship after having experienced a negative event, and that these efforts would be responsible for the concomitant increased amounts of physiological synchrony. This latter notion was further supported by our finding that suggested physiological synchrony directly related to observed levels of repair: dyads that were synchronized at a physiological level showed higher levels of repair compared to those dyads that were not. These data suggest that dyads who are physiologically in sync are better at recovering from a negative interaction.

Our third hypothesis was not confirmed. Clinical dyads were similar to nonclinical dyads in their physiological responses on all accounts suggesting that the measure of physiological synchrony simply was not sensitive enough to capture any effects at a dyadic level. This was surprising considering the relationship between autonomic nervous system variables and differences in self-regulation capacity (Beauchaine et al. 2007; Calkins and Hill 2007; Chapman et al. 2010). Considering the exploratory nature of our study, we do wish to point out a pattern in the data showing that the clinical dyads were not contributing as much to the effects concerning the relationship between the level of repair and physiological synchrony as the nonclinical dyads did. This suggests that, despite a lack of group differences in overt observed levels of repair, dyads whose physiological synchrony directly related to observed levels of repair were more likely to be nonclinical. We do caution further interpretation because this intriguing pattern, although hypothesized, did not reach standard levels of significance and was based only on marginally significant post-hoc tests.

Our fourth and last hypothesis were only partially supported. Measures of dyadic attunement in the last discussion were not related to physiological synchrony. However, a direct relationship between physiological synchrony and dyadic attunement was found during the negative discussion. We could speculate that dyads able to display dyadic attunement, even during a negative discussion, had such a strong empathic connection that these effects also became evident on a physiological level at that time.

To conclude, the present study explored dyadic attunement and physiological synchrony, and their relationship, in dyads with and without externalizing behavior problems. Although our findings showed that dyadic attunement, measured at a behavioral level, was better able to distinguish clinical from nonclinical samples, we did demonstrate physiological synchrony was sensitive to emotional context during mother-child interaction. For example, our results suggested that physiological synchrony in mother-child interactions were associated with high levels of repair - an ability that represents how well a dyad recovers from a negative event. Furthermore, during the distressful discussion, only dyads that showed a physiological synchrony were able to show higher dyadic attunement suggesting these dyads were more in tune with each other in the face of negative distress. Physiological synchrony, depending on the emotional context provided by discussions, could be a useful measure to characterize mother-child interactions during middle childhood.

The present study was exploratory and we should consider a number of limitations for the interpretation of the results and the design of future studies. First, considering the relatively open-ended and unstructured nature of the discussion task, it is hard to pinpoint exactly what emotions were present. Furthermore, heart rate mostly indexes arousal, and is, by itself, generally considered nonspecific to the valence of emotion (Berntson et al. 2007). These constraints make it hard to interpret what precise psychological process the physiological synchrony could be attributed to. However it is likely that positive affect, such as enthusiasm and excitement, was underlying our effects, because the context of the discussions was mostly positive in nature. Second, our clinical group constituted of a heterogeneous sample and was not based on a formal diagnosis of disruptive behavior disorders which limits the clinical relevance of the study. Moreover, we observed that the current sample, which was selected on the basis of their externalizing problem behavior related to aggression, also showed high clinical levels of internalizing problem behavior. It is thus conceivable that children with pure externalizing (or pure internalizing problem) behaviors could show a different pattern of results. Third, our clinical group differed from the nonclinical group in variables related to socio-economic status, sex and other demographics. Furthermore, it is possible that mother-daughter or father-child dyads may show different patterns of communication. All of these factors may have concealed possible group differences. Future studies should match for demographics and could further investigate different dyad-compositions in terms of sex. Last, an equal number of subjects in each group may have yielded more reliable results.

This study constituted the first exploration of physiological synchrony of heart rate in mother-child interactions. Findings have implications for developmental researchers studying dyads at a systems level as physiological synchrony could function as a marker for the quality of affective behavior. Furthermore, these findings may provide insights into the mechanisms of how relationships develop, and function, in typical and atypical families. Based on the current results, there is no strong evidence that physiological synchrony could distinguish clinical from nonclinical dyads, however, future studies could re-evaluate this question using different paradigms as well as other psychiatric populations.

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Conflict of Interest Steven Woltering, Victoria Lishak, Brittney Elliott, Leonardo Ferraro and Isabela Granic declare that they have no conflict of interest.

Experiment Participants All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research ethics board committee at the University of Toronto and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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