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Dynamical systems modeling of couple interaction: A new method for assessing intervention impact across the transition to parenthood

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Abstract

This study explored the use of dynamical systems modeling techniques to evaluate self- and co-regulation of affect in couples' interactions before and after the transition to parenthood, and the impact of the Family Foundations program on these processes. Thirty-four heterosexual couples, randomized to intervention and control conditions, participated in videotaped dyadic interaction tasks at pretest (during pregnancy) and post-test (1-year after birth). Husbands' and wives' positivity and negativity were micro-coded throughout interactions. Individual negativity set-points, self-regulation, and partner co-regulatory processes during interactions were examined using a coupled oscillators model. Regarding self-regulatory processes, men exhibited amplification of negativity at the prenatal assessment that did not change at the postnatal assessment; women demonstrated no significant damping or amplification at pretest, and a marginally significant change towards greater amplification at the postnatal assessment. In terms of partner-influenced regulatory dynamics, men's positive behaviors changed from damping to amplifying women's negative behaviors in the control group following the transition to parenthood, but exerted an even stronger damping effect on women's negative behaviors in the intervention group. The study highlights the advantages of dynamic modeling approaches in testing specific hypotheses in the study of self- and co-regulatory couple dynamics, and demonstrates the potential of studying dynamic processes to further understanding of developmental and intervention-related change mechanisms.

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Compliance with Ethical Standards

Disclosure of potential conflicts of interest: Dr. Feinberg is the owner of a private company that disseminates Family Foundations, which has been reviewed by the IRB and the Conflict of Interest Committee at Pennsylvania State University for potential financial gain.

Ethical approval: The Penn State IRB approved this research.

Informed consent: Participants completed IRB-approved consent forms.

Keywords

Family Foundations; Couple interaction; Dynamical systems modeling; Coupled oscillators model; Transition to parenting; functional data analysis

Over the last several decades there has been growth in the number of evidence-based prevention programs that promote positive family relationships and reduction in conflict (Van Ryzin, Kumpfer, & Fosco, 2015). Despite this proliferation, less attention has been given to the mechanisms of intervention-related change, including questions about what is driving the change and how it unfolds largely unanswered (e.g., Kazdin, 2007; Liddle, 2004). The most common approach to testing mechanisms involves assessing targeted skills (such as family management skills) as mediators of impact on distal outcomes (e.g., Sandler, Schoenfelder, Wolchik, & MacKinnon, 2011). Although important, these studies are largely based on static assessment of relationships and behavior. Yet most family programs are designed to change the patterns of interactions between family members.

Recent methodological developments have provided new opportunities for capturing the mechanisms within family dynamics (Fosco, Bumbarger, Bamberger, & Ryzin, 2015), such as daily or more frequent self-report (e.g., daily diaries), “real-time” observational techniques (Granic, O’Hara, Pepler, & Lewis, 2007), and advances in fitting dynamic models to such data (Ferrer & Helm, 2013; Ferrer & Nesselroade, 2003; Gottman, Swanson, & Murray, 1999; Gottman, Swanson, & Swanson, 2002).

In this study, we apply dynamic models to rich, micro-coded observational data of couples’ interactions before and after the birth of their first child; half of the sample was randomized to participate in a preventive intervention focused on promoting supportive couple interaction and effective co-parenting (Feinberg, 2002). The use of time-dependent, micro-level, dynamic analytic methods to understand family interaction have rarely been used in a randomized trial design or in the context of a preventive intervention. Several decades ago, studies utilizing micro-coded data were conducted in the context of couple treatment interventions; many of these studies utilized only aggregate levels of coded behaviors as outcomes, failing to examine sequences and dynamic patterns of behavior. In contrast, we illustrate the use of dynamical systems models to understand preventive intervention impact on interactive couple dynamics prior to and following the transition to parenthood. Due to the limited sample size, this work is presented as exploratory.

The Transition to Parenthood and Prevention

Overall, relationship quality for first-time parents declines more precipitously than for childless couples (Belsky, 1986; Cowan & Cowan, 2000). Moreover, levels of stress, depression, anxiety, and role overload are elevated among new parents. Coinciding with a period of vulnerability and rapid biopsychosocial development of young children, the early difficulties of parents as individuals and couples can have lasting impact on children’s well-being. Family Foundations (FF; Feinberg & Kan, 2008) is a universal prevention program aimed at helping couples navigate the transition to parenthood. FF helps couples develop mutual support, conflict-management, and problem-solving skills. In two trials, results

indicate that FF helps couples develop more cohesive relationships, reduces stress and depression, boosts parenting quality, and leads to better child self-regulation and adjustment (Feinberg et al., 2015; Feinberg, Jones, Kan, & Goslin, 2010; Feinberg, Kan, & Goslin, 2009). In this study, we aimed to understand how FF couples' interaction dynamics changed, compared to controls, across the transition.

Individual Emotional Processes as a Regulated Oscillator/Pendulum

Most work examining sequential behaviors utilizing micro-coded interaction data has focused on the transition probabilities between behaviors. However, a potentially stronger approach is to use a formal dynamic model to capture the entire trajectory of behaviors across an interaction. In this paper, we apply a particular dynamical systems model—based on conceptualizing partners' fluctuating interactional behaviors as akin to two coupled oscillating systems—to sequential observed couple data for the first time. This model has long been used in the physical sciences to describe the motion of objects such as pendulums. Variations of this model have been applied to diverse phenomena including emotion regulation (Chow, Ram, Boker, Fujita, & Clore, 2005), substance use (Boker & Graham, 1998), posture (Boker, Schreiber, Pompe, & Bertenthal, 1997), and coupling between hormone cycles and emotional eating (Hu, Boker, Neale, & Klump, 2014).

To illustrate this model, we use an analogy of a pendulum swinging back and forth in an idealized, friction-free world (see Figure 1 and the first over-time trajectory in inset). The swinging of the pendulum represents the periodic, intrinsic swings of affective behavior—for example, sequences of behavior toward a partner that move from a low level of hostility to a higher level, back to lower hostility, and so on. Each time the pendulum reaches the end point of its swing in one direction, Point A, it then starts to fall back downward along its arc. Thus, a transition probability of 1.0 represents the likelihood of the pendulum being at Point B at Time 1 based on being at Point A at Time 0. However, the pendulum swings both ways: Half the time that it is at Point B it will next move to Point A, and the other half the time it will move to Point C. Accordingly, the transitional probability of both Point C and Point A, given Point B, is 0.5; given that information, we would not understand the time-ordered nature of the pendulum's movement. In scenarios that involve friction (and hence damping in the motion of the pendulum; see last two scenarios in inset of Figure 1), the transition probabilities may be even more misleading. Consequently, we would lack sufficient understanding to intervene on the pendulum effectively.

To describe the dynamics of the pendulum in a mathematical model, two within-person, time-varying attributes are needed. These are the rate of change and acceleration of the pendulum's movement. The rate of change ("velocity" or speed when the "level" reflects distance traveled) varies over time. For example, the pendulum's speed is changing constantly: e.g., as the pendulum is swinging from Point A to C, it is initially increasing in speed due to gravity, but slows down as it approaches and passes Point B (i.e., the set-point of zero in Figure 1).

Motion in the pendulum can be described by three parameters. The *frequency* denotes how rapidly the pendulum completes one full oscillation cycle (i.e., moving from A to C back to

A). The *amplitude* is the distance the pendulum travels (i.e., magnitude of displacement) from Point B in either direction. And the set-point represents the “equilibrium” into which the pendulum eventually settles due to air resistance and friction occurring where the rope is attached to the ceiling (point B in Figure 1).

In the context of our study, frequency relates to oscillations in affective behavior; amplitude refers to the furthest extremes of affective behavior; and set-point corresponds to an individual’s trait-like disposition of negative affect intensity (Larsen, 1985; Larsen, Diener, & Emmons, 1986) reflecting stable individual differences (e.g., Moskowitz, 1982).

Amplitude—the height of spikes in affective behavior—is particularly interesting as a measure of regulation. Increasingly smaller amplitudes over an interaction are considered as “damping,” whereas increasingly larger amplitudes are referred to “amplification.”

Amplification may result from the deterioration of inhibitory control over time. We know that inhibitory control functions in some ways like a muscle, becoming fatigued with sustained use (Vohs & Heatherton, 2000); thus effort to inhibit negativity may, over the course of an interaction, deplete self-regulatory resources, yielding increasingly large spikes in negativity. Amplification could also occur with repeated triggering of negative thoughts and emotions that serve as a prime, increasing a top-down cognitive processing bias towards hostility, leading to increasingly frequent and strong negative behaviors.

Evidence that stress and conflict increase after birth would suggest that, within the context of couples’ interactions, the average set-point becomes more negative after birth. We might also expect that as a result of increased stress and depression, new parents might have reduced levels of regulatory resources resulting in greater amplification of negativity.

An individual with a low set-point may generally show low negativity, but can show rapid or slow cycling of negativity around this set-point (i.e., differences in frequency), can show small or large deviations from the set-point (i.e., amplitudes), and can show slow or quick returns to the set-point as a result of homeostatic processes. The last characteristic reflects the tendency of the oscillating process to either dampen or become amplified over time. For a concrete example, imagine a critical comment by a female partner to a male partner: the male partner’s affect becomes more negative as a result. In the oscillator model, increased negativity due to a perturbation is followed by a swing back towards the set-point. However, the return of affect may overshoot the set-point—in our example, the affect may move to the positive range as, for example, the male partner uses humor to repair the interaction. With damping, each subsequent swing in affect comes closer and closer to the set-point across oscillations. On the other hand, an amplifying process has ever greater amplitudes across “spikes,” each subsequent swing moves further away from the set-point. Over the course of a conflict discussion, one expects “spikes” and “dips” in negativity, but regulatory processes within the couple should constrain the fluctuations. In healthy conflict processes, we expect a *damping* effect. Individual differences in damping—with the magnitude of the damping parameter varying across a sample such that there may be an amplifying effect for some individuals—represents a dynamic model of a *self-regulatory* pattern.

When couples interact, regulation of negative behavior is shaped by one’s own affective processes as well as by the partners’ behavior. It is as if two pendulums are swinging near

each other and each exerts a changing force on the other depending on each one's state (e.g., position and velocity) at the moment. Considering the myriad physiological, subjective and behavioral changes that arise in a couple discussion (Ferrer & Helm, 2013; Richards, Butler, & Gross, 2003), we argue for two regulating processes: *Self-regulatory processes*, in which an individual may dampen or amplify their negativity over time; and *partner-influenced regulatory processes*, which reflect the degree to which partner behaviors are related to damping or amplification of one's affective behavior. The extent of partner-influenced regulatory processes may be interpreted as responsiveness to a partner's positive or negative expressions.

The Current Study

Given prior success modeling individual emotion with the oscillator model, we speculate that a variation of the coupled oscillators model (Boker & Graham, 1998; Boker & Laurenceau, 2007; Hu et al., 2014) may provide a reasonable description of couple interaction.

Utilizing randomized trial data (Feinberg et al., 2009) testing the efficacy of the FF program, we model couples' conflict interactions at pretest during pregnancy and again one year after birth. We then test the effect of the intervention as a two-way interaction between condition and time or wave (pretest, posttest) in a multilevel, coupled oscillators model. We propose a series of hypotheses regarding change in couples' negativity set-points and self- and co-regulation dynamics from prenatal to postnatal interactions. In particular, we propose that: (H1) husbands and wives would show increases in negativity set-points across waves; (H2a) husbands and wives would each exhibit damping of negativity within interactions; (H2b) there would be decreases in damping and/or increases in amplification across waves; (H3) there would be greater partner-influenced amplification in negativity across waves.

FF was designed to enhance parents' ability to self-regulate and calm down in the face of stress and conflict, and improve parents' coparental relationship dynamics—with the additional possibility that such impacts would enhance couple relationship quality. Results from the first trial indicate that FF resulted in reduced parent stress and mother depression and anxiety, as well as improved positive coparenting and—especially for couples with high levels of conflict before birth—reduced psychological (i.e., verbal) aggression (Feinberg & Kan, 2008; Kan & Feinberg, 2014). Consequently, we had hypothesized that the intervention would (H4) reduce or buffer any increase in negativity set-point associated with the transition to parenthood. Further, as a result of enhanced parent self-control, we expected the program to (H5) buffer against any decrease in self-regulatory damping of negativity across the transition period. Finally, as a result of enhanced self-regulation, reduced stress, and improved communication skills, we expected the intervention would (H6) buffer against any increase in partner-influenced negativity amplification (see Table 1).

Method

Participants

Participants were a randomly selected (within condition) subset of 34 heterosexual couples from the larger ($N=169$) FF study (funding limitations restricted the number of videotaped couple interactions that could be micro-coded; technical failures prevented a few selected cases from being coded). All participants were at least 18 years old, living together in rural areas, towns, and small cities in Pennsylvania, and expecting their first child. Of the 34 couples, 80 percent of them were married, and the majority of participants were non-Hispanic White (94% of wives and 100% of husbands). The remaining participants were black/African American and Asian or Pacific Islander. Average educational attainment was 15.14 years for wives ($SD=1.73$) and 14.66 years for husbands ($SD=2.18$), with a range of ninth grade to beyond college. Mean ages were 28.49 years ($SD=4.66$) for wives and 29.26 years ($SD=5.36$) for husbands.

Procedure

The Pennsylvania State IRB approved all procedures. Couples were recruited from a childbirth education program at two hospitals, or through healthcare providers, advertisements/flyers, and word of mouth. After the informed consent process and pretest data collection in the home, couples were randomly assigned to the FF or a control condition. At one year after birth, data were again collected in the homes. At both waves, we videotaped couples discussing up to three areas of conflict; the discussion topics were selected based on ratings each partner made on a list of areas in which they would like to see change in their partner. The interactions lasted around 12 minutes at the first wave and around 10 minutes at the second wave. After removing cases that did not show variability in the dependent variables (i.e., within-person over-time standard deviations in the key dependent variables of interest were zero), there were 16 couples in the intervention group, and 13 couples in the control group for model-fitting purposes.

Data were coded with the Rapid Marital Interaction Coding System (RMICS, Heyman & Vivian, 2011). The RMICS is a dual-stream coding system (i.e., both partners receive a code for each unit). Units are demarcated either by (a) a change in which partner holds the floor or, (b) in the case of a partner holding the floor for more than 30 sec, every 30 sec. If two or more codes are present for a partner during a unit, a theoretically derived hierarchy (that is, negative codes then positive codes) indicates which code to retain. A description of the coding system and information on reliability and validity has been documented elsewhere (Heyman, 2004) and the RMICS coding system has been widely utilized in the study of family systems. We collapsed across the positive RMICS codes to create a single positivity score (i.e., present=1 or absent=0 during each speaking turn) and across the negative codes to create a single negativity score. Codes collapsed into the negative behavior category were Psychological Abuse, Distress Maintaining Attribution, Hostility, and Withdrawal). Indicators of positive behaviors were Acceptance, Relationship Enhancing Attribution, Self-Disclosure, Humor, and Constructive Problem Discussion/Solution. Percent exact agreement between raters for negative codes was 92%, and G, the most robust indicator of interrater

reliability (Xu & Lorber, 2014) was .84; agreement for positive codes was 81% ($G=.63$). Agreement on unitization was 87% ($G=.73$)

Data Analysis and Model Fitting

Preliminary data treatment—For model fitting purposes, we computed windowed aggregates of positive and negative behaviors every 5 seconds, yielding approximately 144 and 120 measurement occasions for each family’s prenatal and postnatal interactions, respectively. We removed the linear time trend and standardized each time series separately using the participant’s over-time mean and standard deviation on each variable. We subsequently added the person- and wave-specific means (i.e., separately for each participant and each interaction) back to the standardized, detrended time series to enable modeling of individual differences in set-points. These preliminary data treatment procedures removed some of the inter-individual and inter-family differences in overall levels of, and variability in affective behaviors. However, we were still able to evaluate inter-individual/family differences in (within-person) relative deviations in affective behaviors, including within-individual changes following the transition to parenthood.

Derivative estimation—We used Functional Data Analysis (FDA) tools as implemented in the ‘fda’ package in R (Ramsay, Hooker, & Graves, 2009) to derive smoothed estimates of the participants’ levels, first derivatives (i.e., instantaneous change) and second derivatives (i.e., change in the instantaneous changes) of positive and negative interaction composite scores over time (see Chow, Lu, Cohn, & Messinger, 2015; Trail, Collins, Rivera, Piper, & Baker, 2013). Smoothed level and derivative estimates of a randomly selected couple are plotted in Figure 2, together with the couple’s observed (i.e., prior to smoothing) positive and negative interaction behaviors over time. To estimate the derivatives, we used penalized piecewise B-spline regression, with the knot points specified to coincide with the observed time points. Because of our interest in estimating the second derivatives, we used integrated squared fourth derivative to construct a roughness penalty to ensure the smoothness of the level and derivative estimates. The smoothing parameter, which controls the extent to which the “roughness” in the fourth derivative is weighted, was chosen separately for each individual using the Generalized Cross-Validation Index (for details see Ramsay & Silverman, 2005).

The estimates of the smoothed level and derivatives were used as manifest variables in a bivariate mixed effects model to fit ordinary differential equation (ODE) models in a two-stage process (Chow, Bendezú, Cole, & Ram, 2016) using the *nlme* routine in R (Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2014). Based on results from our graphical explorations (see supplementary materials) and our hypotheses of interest, we developed a bivariate model with the couples’ second derivatives in negative behaviors as dependent variables. The resultant coupled oscillators model captured the extent to which the rate of change in the partner’s positive behaviors influenced oscillations in the other member’s negative behaviors, expressed as:

$$\begin{aligned}
\frac{d^2 h_{neg_i}(t)}{dt^2} &= \{\alpha_h * [h_{neg_i}(t) - (h_0 + h_{1,i} * Wave_{it})] + (\beta_{1h,i} + \beta_{2h,i} * Wave_{it}) * \frac{d h_{neg_i}(t)}{dt}\} + (\gamma_{1h} + \gamma_{2h,i} \\
&\quad * Wave_{it}) * \frac{d_{wpos_i}(t)}{dt} \\
\frac{d^2 w_{neg_i}(t)}{dt^2} &= \{\alpha_w * [w_{neg_i}(t) - (w_0 + w_{1,i} * Wave_{it})] + (\beta_{1w,i} + \beta_{2w,i} * Wave_{it}) * \frac{d w_{neg_i}(t)}{dt}\} \\
&\quad + (\gamma_{1w} + \gamma_{2w,i} * Wave_{it}) * \frac{d_{hpos_i}(t)}{dt}
\end{aligned}
\tag{1}$$

where $Wave_{it}$ is a binary variable indicating time t ($0 = \text{pretest}$, $1 = \text{posttest}$) for dyad i ; $h_{neg_i}(t)$ and $w_{neg_i}(t)$ denote the smoothed levels of negative behaviors of the husband and wife, respectively, in couple i at time t ; $\frac{d h_{neg_i}(t)}{dt}$ and $\frac{d w_{neg_i}(t)}{dt}$ represent the couple's smoothed first derivatives at time t , respectively; and $\frac{d^2 h_{neg_i}(t)}{dt^2}$ and $\frac{d^2 w_{neg_i}(t)}{dt^2}$ denote, respectively, their smoothed second derivatives at time t . Modeling parameters that were allowed to be person- or family-specific are marked with the subscript i . Consider first the terms that are enclosed in curly brackets in the husband and wife equations. These terms define the characteristics of the two “pendulums”’ own intrinsic dynamics. Specifically, h_0 (or alternatively, w_0) describes the set-point in pretest husband (wife) negative interaction level, which was constrained to be invariant across families¹; $h_{1,i}$ and $w_{1,i}$ are the deviations in set point for the husband and wife from couple i , respectively, from pretest to posttest. The terms α_h and α_w are frequency parameters that govern, respectively, how rapidly the negative behaviors of the husbands and wives in the present sample complete a cycle, on average. These parameters define the oscillatory nature of the couples’ intrinsic dynamics. The parameters $\beta_{1h,i}$ and $\beta_{1w,i}$ govern the damping (if negative) or amplification (if positive) in the oscillatory trajectory of husband and wife in couple i , respectively, during the pretest period; whereas $\beta_{2h,i}$ and $\beta_{2w,i}$ represent the deviation in damping/amplification for husband and wife, respectively from the prenatal to postnatal wave. Collectively, the parameters for the terms included in the curly brackets define the *self-regulatory* dynamics of each of the dyad members.

¹This was justified due to the randomization procedure used to assign families to the intervention vs. the control group at pretest.

The partner-influenced regulatory parameters at pretest, γ_{1h} and γ_{1w} , represent the extent to which the oscillations (or accelerations/decelerations) in an individual's negative behavior were affected by the partner's rate of change in positive behavior during the prenatal period. A positive value of γ_{1h} or γ_{1w} indicates a negativity-amplifying partner effect, such that greater increases in the partner's positive behaviors would lead to increased accelerations in the individual's negativity—which may represent a partner-influenced *de*-regulation process. In contrast, a negative value of γ_{1h} or γ_{1w} indicates a negativity-damping partner effect, such that greater increases in the partner's positive behavior lead to decelerations in one's negativity. Capitalizing on the randomization procedure used in the FF study to assign participants to the intervention/control condition, these parameters were constrained to be invariant across couples for reasons of parsimony. The parameters $\gamma_{2h,i}$ and $\gamma_{2w,i}$ represent the *i*th couple's deviations in the partner-influenced regulatory/de-regulatory parameters for husband and wife, respectively, from prenatal to postnatal assessments. In other words, these parameters allowed us to examine the extent to which the couples differed in their abilities to show de(ac)celerations in their negativity in response to their partners' positive behaviors at posttest relative to pretest. Thus, families that showed more negative values of $\gamma_{2h,i}$ and $\gamma_{2w,i}$ can be viewed as manifesting greater improvements at co-regulating their negativity levels during the postnatal interactions compared to their interaction patterns at prenatal assessment.

In light of our hypotheses, particularly our interest in examining the effects of intervention, we proceeded to add time (0 = pretest, 1 = posttest) and condition (0 = control, 1 = intervention) as potential predictors of changes in set-points, self-regulatory processes, and partner-influenced effects across waves for both husband and wife. Based on results of our model explorations², we allowed for between-dyad random effects on four parameters that showed the greatest extent of between-couple differences, including $\alpha_{h,i}$, $\alpha_{w,i}$ (the husband and wife frequency parameters), as well as $h_{1,i}$ and $w_{1,i}$ (husbands' and wives' deviations in negativity set-point from pre- to postnatal assessment), yielding:

$$\beta_{1h,i} = \beta_{1h0} + \epsilon_{\beta_{1h,i}} \quad \beta_{1w,i} = \beta_{1w0} + \epsilon_{\beta_{1w,i}}$$

$$h_{1,i} = h_{10} + h_{11} * Intervention_i + \epsilon_{h_{1,i}} \quad w_{1,i} = w_{10} + w_{11} * Intervention_i + \epsilon_{w_{1,i}}$$

$$\beta_{2h,i} = \beta_{2h0} + \beta_{2h1} * Intervention_i \quad \beta_{2w,i} = \beta_{2w0} + \beta_{2w1} * Intervention_i$$

²We also explored the need to allow for between-couple differences in the modeling parameters by incorporating random effects in subsets of the parameters sequentially and evaluating the magnitudes of the random effects SDs as well as the changes in model fit when these random effects were included vs. excluded from the model. Even though almost all of the modeling parameters were characterized by statistically significant between-couple differences (namely, the 95% confidence intervals (CIs) of the associated random effects SDs did not include 0), we had to limit the number of random effects included in our final model due to the limited sample size of the present study.

$$\gamma_{2h,i} = \gamma_{2h0} + \gamma_{2h1} * Intervention_i; \quad \gamma_{2w,i} = \gamma_{2w0} + \gamma_{2w1} * Intervention_i; \text{ and}$$

$$[\epsilon_{h1,i}, \epsilon_{w1,i}, \epsilon_{\beta1h,i}, \epsilon_{\beta1w,i}] \sim N(\mathbf{0}, \text{Diag}[\sigma_{h1}^2, \sigma_{w1}^2, \sigma_{\beta1h}^2, \sigma_{\beta1w}^2]); \quad (2)$$

where β_{1h0} , β_{1w0} , h_{10} , w_{10} , β_{2h0} , β_{2w0} , γ_{2h0} , and γ_{2w0} each represents the intercept (or group-averaged value in the sample as a whole) of the parameter that appears on the left-hand-side of the corresponding equation. For instance, β_{1h0} and β_{1w0} represent the damping/amplification in husband and wife negativity, respectively, during the prenatal interaction in the sample as a whole; $\epsilon_{\beta1h,i}$ and $\epsilon_{\beta1w,i}$ represent the person-specific deviations (i.e., random effects) in husband and wife damping/amplification during the prenatal interaction relative to the group average values of β_{1h0} and β_{1w0} . Here, h_{10} (or w_{10}) represents the intercept of $h_{1,i}$ (or $w_{1,i}$), namely, the overall deviation in husband's (or wife's) negativity set-point from pre- to postnatal assessment across all couples in the control group; in contrast, h_{11} and w_{11} represent differences in such deviations from prenatal to postnatal assessment in the intervention group compared to the control group. A negative value of h_{11} (or w_{11}) indicates that the intervention group as a whole was associated with greater decrease in negativity set-point across waves compared to the control group. β_{2h0} and β_{2w0} represent the intercepts of $\beta_{2h,i}$ and $\beta_{2w,i}$, namely, the control group's deviations in damping/amplification for husbands and wives, respectively, from pre- to postnatal assessment. β_{2h1} and β_{2w1} capture intervention effects on such deviations in damping or amplification relative to the control group. Finally, γ_{2h0} and γ_{2w0} represent the control group's deviations in partner-influenced damping/amplification for husbands and wives, respectively, from pre- to postnatal assessment; relatedly, γ_{2h1} and γ_{2w1} represent the intervention effects on such deviations in partner-influenced damping/amplification relative to the control group.

Hypotheses concerning dynamics (H1–H3)—As summarized in Table 1, we conjectured, based on Hypothesis H1, that the couples would show increases in their negativity set-points from the prenatal to the postnatal interaction; in other words, we expected h_{10} and w_{10} to be positive and significantly different from 0. Based on H2a, which suggested that the couples would exhibit damping of negativity over the course of conflict interactions, we expected β_{1h0} and β_{1w0} to be negative in the sample as a whole. In a similar vein, following H2b, which suggested that there would be decreases in damping or increases in amplification from the prenatal to the postnatal interactions, we expected β_{1h1} and β_{1w1} to be positive and significantly different from zero. We expected – based on H3 – greater partner-influenced amplification in negativity at postnatal compared to prenatal assessments, implying that γ_{2h0} and γ_{2w0} would be positive and significantly different from zero.

Hypotheses concerning intervention impact (H4–H6)—Based on H4, which posted that the FF intervention would buffer against the hypothesized increase in negativity set-points from prenatal to postnatal interactions, we expected h_{11} and w_{11} to be negative and significantly different from zero. Building on H5, in which the FF intervention was posited to buffer against the hypothesized decrease in self-regulatory damping of negativity from

prenatal to postnatal interactions, we tested whether β_{2h1} and β_{2w1} were negative and significantly different from zero. Finally, based on H6, participation in the FF intervention was anticipated to buffer against the hypothesized increase in partner-influenced negativity amplification from prenatal to postnatal interactions. We tested this hypothesis by assessing whether γ_{2h1} and γ_{2w1} were negative and significantly different from zero.

Results

Results obtained from fitting the model in Equations (1)–(2) via Restricted Maximum Likelihood estimation are summarized in Table 2. The parameters were organized based on whether they served to influence the intrinsic, self-regulatory dynamics of each dyad member, or the partner-influenced co-regulatory dynamics.

Self-Regulatory and Partner-Influenced Process Results

Results indicated that both husbands' and wives' prenatal negativity set-points were significantly different from zero ($h_0 = 0.12$, $SE = 0.02$, $p < .01$; $w_0 = 0.16$, $SE = 0.03$, $p < .01$). Contrary to H1, the husbands, on average, did not show significant increases in negativity set-point from the prenatal to postnatal wave ($h_{10} = -0.09$, $SE = 0.05$, ns); moreover, wives in the study actually showed a significant average *decrease* in their negativity set-points following the transition to parenthood ($w_{10} = -.15$, $SE = 0.07$, $p < .05$).

Contrary to H2a, which posited that the couples would show damping in negativity over the course of the interactions, the husbands showed significant amplification in negative behaviors during the prenatal interaction ($\beta_{1h0} = 0.10$, $SE = 0.04$, $p < .05$), whereas the wives did not show statistically significant damping or amplification in negative behaviors ($\beta_{1w0} = -0.01$, $SE = 0.04$, ns). Contrary to H2b, the husbands' negativity did not show significant change in damping or amplification from prenatal to the postnatal interactions ($\beta_{2h0} = 0.02$, $SE = 0.02$, ns); however, there was marginally significant evidence for the wives to show increased amplification in negativity ($\beta_{2w0} = .052$, $SE = 0.027$, $p < .06$).

H3, focused on partner-influenced effects, postulated that greater partner-influenced amplification in negativity would be manifested during the postnatal than the prenatal interactions. H3 was partially supported with reference to wives' negative behavior trajectory. Specifically, husbands' positive behaviors had a damping effect on wives' negative behaviors during the prenatal interactions ($\gamma_{1w} = -.33$, $SE = 0.01$, $p < .05$), but amplified their wives' negativity during the postnatal interactions ($\gamma_{1w0} = .05$, $SE = 0.02$, $p < .05$). However, we did not find support for H3 in husbands' negativity. In particular, the damping effect of wives' positive behaviors on husbands' negative behavior trajectory in the prenatal period ($\gamma_{1h} = -.03$, $SE = 0.01$, $p < .01$) did not show statistically significant change, on average, from the prenatal to the postnatal period ($\gamma_{2h0} = .01$, $SE = 0.02$, ns).

Intervention-Related Effects

Contrary to H4, wives in the FF intervention group did not show a significantly greater increase in negativity set-points from pre- to postnatal assessment compared with the control group ($w_{11} = 0.15$, $SE = 0.08$, ns). Husbands in the intervention group also did not show significant differences in negativity set-points from prenatal to postnatal assessment

compared with control group ($h_{11} = 0.05$, $SE = 0.06$, ns). Contrary to H5, husbands in the FF intervention group did not show significantly different amplification in negativity from the prenatal to postnatal interactions ($\beta_{2h1} = 0.005$, $SE = 0.04$, ns). Also in contrast to H5, wives in the intervention group displayed greater amplification in negativity from the prenatal to postnatal interactions ($\beta_{2w1} = .12$, $SE = 0.04$, $p < .01$) compared with control group.

Finally, H6 was partially supported: wives in the intervention group showed damping – as opposed to amplification as in the control group – in negativity in response to their husbands' positive behaviors from the prenatal to the postnatal interactions ($\gamma_{2w1} = -.14$, $SE = 0.02$, $p < .01$). This intervention effect was not observed among the husbands ($\gamma_{2h1} = 0.03$, $SE = 0.02$, ns).

Simulated trajectories generated using parameter estimates from a final model in which only the statistically significant parameters were retained are shown in Figure 3 for a hypothetical “average couple” at pretest, as well as an average couple from the control and from the intervention condition for the posttest period—all with the same initial levels and first derivatives. During the postnatal interaction, the husbands' trajectories (see panels 3B and 3C) were not projected to show noticeable differences compared to the prenatal husband's trajectory in 3A regardless of intervention status. However, the average wife in the control group was predicted to show substantial amplifications in negativity during the postnatal interaction despite a slight decrease in her negativity set-point compared to the prenatal period. In contrast to the trajectory shown by the control group, the partner-influenced damping effect (i.e., the first derivative of the husband's positivity) was predicted to help the wife in the intervention group to buffer against amplifications in negativity, thereby leading to a less explosive trajectory and more contained fluctuations in negativity as a whole.

DISCUSSION

This exploratory study responds to a call for new methods that can advance our understanding of the processes underlying intervention change in family processes (Fosco et al., 2015). Through the application of a coupled oscillators model (Boker & Graham, 1998) (Hu et al., 2014), we examined several aspects of dyadic interactions, including individual negativity set-points, self-regulation of negative affect fluctuation, and partner co-regulatory influence.

Guided by prior work indicating increased couple conflict following the birth of a child (Belsky, 1986; Cowan & Cowan, 2000), we hypothesized normative increases in negativity set-points across the transition to parenthood. However, results failed to support this hypothesis as we did not find significant changes in men's set points, and women's negativity set points actually decreased. We note that our method captures an individual's central tendency throughout the interaction, rather than an observer's overall impression as in global observation coding methods, and this difference has implications that may account for why our findings differ from prior work. For example, a couple of brief incidents of highly negative behavior would likely have a larger impact on global coders ratings of overall negativity than on the average negativity score calculated across an interaction. This is because coding systems, training, and coders' natural reactions are highly sensitive to

spikes in negativity; global coders tend to treat a couple of spikes as more informative about overall (global) negativity than similar periods of low negativity between spikes. It may be that by differentiating between the central tendency and departures from that set point over the course of the interaction, our approach offers more precise information about the interaction process than global coding methods. Future work is needed to replicate the current findings in a larger sample and compare these methods to global observational assessments.

A strength of this study was our ability to differentiate central tendencies in behavior from self- and partner-influenced regulatory dynamics. Regarding self-regulatory behaviors, men exhibited amplification of negativity at the prenatal assessment, possibly indicating that regulatory capacity declines among men as the stress and strain of a conflict-discussion accumulates. However, there was no significant change in men's amplification of negativity across waves. Moreover, there was no change in the responsiveness of men's negativity to women's positivity from the prenatal to postnatal periods. Thus, we did not find any signs of significant change for men from the prenatal to postnatal period in set-point or in self- or partner-influenced regulation of negativity. This result suggests that men's regulatory capacity during and across a conflict-discussion, as well as men's susceptibility to influence by a partner's expression of positivity, shows minimal change across the transition to parenthood.

As distinct from men, women demonstrated no significant damping/amplification at pretest, but a marginally significant ($p=.06$) change towards greater amplification postnatally. Given the exploratory frame of this report, we believe the marginally significant finding warrants some discussion and further validation in future work. Even though we are limited by the constraints of a small sample and low power, it is nevertheless illuminating to see some preliminary evidence that women's self-regulatory capacity, analyzed in dynamical terms, seems to have decreased at the postnatal period. Such a finding would be consistent with research indicating women's increased stress and depression postnatally (Heron, O'Connor, Evans, Golding, & Glover, 2004).

Regarding partner's influence, men's positive behaviors were associated with increased swings and spikes in women's negativity in the postnatal period, in contrast to the prenatal period where men's positivity seemed to have a calming effect in reducing women's fluctuations. Thus, it appears that across the transition, women's self-regulatory capacity during a partner conflict discussion declines, and a partner's positivity in a postnatal interaction has the paradoxical effect of increasing women's negative affect dysregulation. It may be that women, experiencing increased difficulty regulating negative emotion during early parenthood, experience some partner positivity during a conflict discussion as invalidating their own feelings of stress.

The second goal of this study was to explore whether coupled oscillator methods capture changes in couple interaction dynamics due to exposure to an evidence-based, prevention program. We examined impact on negativity set points, changes in self-regulatory functioning, and changes in partner-influenced amplification. Our findings suggest that intervention condition was not related to significant changes in negativity set-points for

couples, nor did the intervention affect husbands' patterns of amplification in negativity following the transition to parenthood. However, women who participated in FF exhibited greater increases in amplification of negative affect, as well as greater damping in negativity in response to their partners' positive behaviors from the prenatal to the postnatal interactions. When adding these two parameters together, women in the intervention group showed pre- to post-intervention change towards relatively less amplification in negativity than women in the control group (see Figures 3B and C). This decreased amplification of negativity among intervention women may be interpreted as better emotion regulation in response to partner behaviors during conflict tasks. This evidence of differences in self- and co-regulatory dynamics due to the prevention program would have been obscured or bypassed if we had focused only on analyzing individual differences in mean levels.

There are several limitations to this study. Our findings warrant replication as the small sample size limited: the statistical power of analyses; the complexity of the model (e.g., the number of random effects parameters); the generalizability of findings to other families, settings, and intervention processes. This limitation also precluded us from taking the next step of testing whether intervention-related changes in couple dynamics mediated intervention impact on distal outcomes (e.g., parent mental health, coparenting relationship quality). Finally, although the sample contains a wide range of income and education, the self-selection mechanism into a randomized prevention trial may have resulted in less representation of lower income parents.

The two-stage procedure used in the present study relied on functional data analysis techniques to first generate observed derivative estimates in Stage 1 that were then used in Stage 2 to fit the hypothesized mixed effects differential equation model of interest. This enabled us to make simultaneous inferences concerning within-couple change dynamics, as well as between-couple differences in dynamics and responsivity to intervention. The two-stage procedure, while offering a practical and convenient way to fit dynamical systems models with mixed effects, has some known limitations compared to single-stage approaches. For instance, uncertainty in the derivative estimation in Stage 1 is not fully reflected in the standard error estimates obtained in Stage 2, and greater inaccuracy in parameter estimates may be expected compared to single-stage approaches. Nevertheless, simulation results reported elsewhere (Chow et al., 2016)) suggested that despite these known limitations, the extent of parameter and standard error inaccuracies remained satisfactory even in models of greater complexity than those considered in the present study, and the novel insights from the current exploratory study provide a foundation—or rather, some much needed incentives—to pursue further validation in future studies.

Despite the limitations, we showed that dynamic modeling provides a nuanced analysis of regulatory influences during interaction that are not available in more static measurement and analytic approaches. By applying dynamical systems methods, it is possible to explore interpersonal *processes* as they unfold within couples' interactions. In doing so, these methods offer a window into the family process changes that occur as a result of normative development. By leveraging study designs involving assessment of intervention impact over time, this method can provide new guidance in the refinement and strengthening of preventive interventions.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Pendulum diagram and trajectories with various levels of damping

Figure 2. Plots of the observed (prior to smoothing) levels, smoothed levels, and estimates of the smoothed first derivatives (i.e., instantaneous rates of change) and second derivatives (i.e., acceleration/deceleration) of one randomly selected dyad obtained using the penalized piecewise B-spline approach.

Figure 3.

Plots of simulated trajectories of the “average couple” during (A) the prenatal interaction and the postnatal interaction for the (B) control group and (C) intervention group.

Parameters were set to estimates from a final model in which only statistically significant parameters were retained.

Table 1

Summary of hypotheses and results

	Hypothesized Pre- to Postnatal Changes	Results for Husbands	Results for Wives
1	Increase in negativity set-point	No change	Decreased negativity set-point
2a	Damping of negativity over the course of the couples' interaction in prenatal period only	Amplification of negativity	No change
2b	Less damping (or more amplification) of negativity	No change	More amplification ($p = .06$)
3	Increased partner-influenced amplification	No change: Damping effect in both pre and postnatal period	Increased amplification: Damping in prenatal, amplification in postnatal
	Hypothesized Intervention Effects on Pre- to Postnatal Changes (Compared to Control Group)	Results for Husbands	Results for Wives
4	Less increase in negativity set-point	No effect	No effect
5	Less decrease in damping or increase in amplification	No effect	Greater amplification
6	Less increase in partner-influenced amplification	No effect	Partner-influenced damping in postnatal

Table 2

Results of the Final Coupled Oscillator Model

	Estimate	SE	CI
Intercepts			
h_0	.12**	.02	[.08, .17]
w_0	.16**	.03	[.11, .21]
h_{10}	-.09	.05	[-.18, .01]
w_{10}	-.15*	.07	[-.28, -.02]
σ_{h10}	.08**	—	[.02, .27]
σ_{w10}	.13**	—	[.06, .28]
Self-regulatory processes			
α_h	-.14**	.00	[-.14, -.13]
α_w	-.12**	.00	[-.13, -.11]
β_{1h0}	.10*	.04	[.02, .18]
β_{1w0}	-.01	.04	[-.10, .07]
$\sigma_{\beta 1h}$	.21**	—	[.16, .27]
$\sigma_{\beta 1w}$	.22**	—	[.16, .28]
β_{2h0}	.02	.02	[-.03, .07]
β_{2w0}	.05	.03	[.00, .10]
Partner-influenced effects			
γ_{1h}	-.03**	.01	[-.05, -.01]
γ_{1w}	-.03*	.01	[-.05, .00]
γ_{2h0}	.01	.02	[-.02, .04]
γ_{2w0}	.05*	.02	[.01, .09]
Intervention effect			
h_{11}	.05	.06	[-.07, .16]
w_{11}	.15	.08	[-.01, .30]
β_{2h1}	.00	.04	[-.06, .07]
β_{2w1}	.12**	.04	[.05, .20]
γ_{2h1}	.03	.02	[.00, .07]
γ_{2w1}	-.14**	.02	[-.18, -.10]
Residual error SDs			
<i>Husband</i>	.127*	—	[.124, .130]
<i>Wife</i>	.136*	—	[.129, .144]

Note:

**
 $p < .01$;*
 $p < .05$