Brief report

Dyadic Flexibility during the Face-to-Face Still-Face Paradigm: A dynamic systems analysis of its temporal organization

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Abstract

A dynamic systems analytical model was used to characterize infant–caregiver regulatory dynamics. Though stable, there was an increase in dyadic flexibility following a perturbation. Dyadic flexibility was positively related to infant negativity during the perturbation. Findings were qualified by infant sex and maternal depressive symptoms.

The infant–caretaker interactive system has been characterized as a tightly coupled, mutually regulated, dynamic open system (Feldman, 2007; Fogel & Garvey, 2007; Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001; Tronick & Beeghly, 2011). Although the interaction is constantly changing few studies have used analytic techniques to characterize and quantify the actual moment-by-moment flow of parent–infant interactive behavior. Guided by principles from dynamic systems (DS) theory, this study utilized State Space Grid (SSG) analysis (Lewis, Lamey, & Douglas, 1999) to characterize infant–caregiver interactional dynamics before and after a social stressor (maternal still-face), the stability and change of its dynamics, and the relation of the dynamic variables to the stressful effects of the social stressor.

Matching and synchrony are two measures that have been used to measure the temporal dynamics of interactions (e.g., Feldman, 2003; Moore & Calkins, 2004; Tronick & Cohn, 1989) but both have limitations. Matching, defined as the frequency or proportion of time in which an infant and caregiver engage in the same behavior or affect at the same time (e.g., mutual gaze or smiling, Tronick & Cohn, 1989), is actually a relatively static measure that does not adequately capture the ongoing moment-by-moment process that led to those states or the content of those states. Synchrony evaluates the level of dyadic coordination (correlation) of behavior or affect over time, and is typically reported as a proportion of the variance accounted for but does not identify the specific behaviors or affect making up that flow. In contrast, SSG methodology captures both the temporal flow and the behavioral or affective content of that flow. Furthermore, by generating multifactorial dyadic variables, an SSG analysis can characterize different temporal features of the interaction with quantitative measures of

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stability, uncertainty and variability (Hollenstein, 2007). Dyadic flexibility is one such SSG dynamic construct. It is descriptive of how members in a dyad adapt to each other during an interaction.

Perturbations are a critical technique for DS analysis of a system because they reveal the functional dynamics of a system. A perturbation, such as the still-face manipulation, disrupts the current organization of a dyadic system and sets in motion a dynamic (re)organization process that reveals otherwise cryptic characteristics of the dyadic system more fully than when the system is in a stable attractor state (Granic & Lamey, 2002). For example, using SSG methodology, the system's recovery from a perturbation, the nature of the recovery process and how that process relates to the dyad's typical dynamic characteristics (e.g., its flexibility) can be evaluated. In this study an important goal was to evaluate the effect of a perturbation, the caregiver still-face, on the temporal (re)organization of infant–caregiver dyadic interaction in relation to its earlier and ongoing organization.

The SSG technique has been used to study the dynamics of dyadic behavior with and without perturbations in a variety of populations including interactions between parents and their older children (Granic & Lamey, 2002; Hollenstein, Granic, Stoolmiller, & Snyder, 2004; Lichtwarck-Aschoff, Hasselman, Cox, Pepler, & Granic, 2012) and peer–peer interactions (Dishion, Nelson, Winter, & Bullock, 2004). Infant–caregiver dynamics described by SSG measures in 6–month-old infants were related to attachment quality (Cerezo, Trenado, & Pons-Salvador, 2012). However, this technique has yet to be used to describe regulatory dynamics using a perturbation paradigm with infants. The first aim of this study was to characterize the dynamics of the interaction as indexed by dyadic flexibility in a sample of mothers interacting with their three-month-old infants during the Face–to–Face Still-Face paradigm (FFSF) (Adamson & Frick, 2003; Mesman, van IJzendoorn, & Bakermans-Kranenburg, 2009; Tronick, Als, Adamson, Wise, & Brazelton, 1978), and to evaluate the change and stability in dyadic flexibility of infant–mother dyads following exposure to the perturbation of the maternal still-face during the FFSF. Based on the dynamic systems principle that perturbations constrain and therefore reduce variability in a system we hypothesized that dyadic flexibility would be greater in the initial play interaction in comparison to the reunion play interaction following the still-face. Further, we assessed if infant sex or maternal depressive symptoms moderated change in dyadic flexibility during the FFSF. These variables have often been studied in relation to traditional measures of early dyadic interaction (Forbes, Cohn, Allen, & Lewinsohn, 2004; Weinberg, Olson, Beeghly, & Tronick, 2006; Weinberg, Tronick, Cohn, & Olson, 1999) but their impact on dyadic dynamics remain uncertain. Based on these studies, however, we expected to see different temporal dynamics in mother–son and mother–daughter interactions particularly in relation to maternal depression.

The second aim was to investigate whether dyadic flexibility during the first play episode was associated with infants' negative reactivity during the still-face perturbation (see Adamson & Frick, 2003; Mesman et al., 2009, for reviews). Based on prior results that associate greater dyadic flexibility with more desirable child outcomes (Cerezo et al., 2012; Granic & Lamey, 2002; Granic, O'Hara, Pepler, & Lewis, 2007; Hollenstein et al., 2004), we hypothesized that greater dyadic affective flexibility in the first play would be related to lower infant stress-reactions (negative affect) during the still-face perturbation.

Analyses were based on data collected on 124 first-time mothers and their healthy full-term 3-month-old infants (65 male) participating in a larger longitudinal study of the effect of maternal depressive symptomatology on infant–mother interactive behavior during the first 12 months postpartum (Weinberg et al., 2006). To be eligible to participate, dyads met a set of low-risk socio-demographic and medical inclusion criteria to minimize the confounding influence of factors, such as young age and single parenting known to affect maternal and infant functioning. Mothers in the present sample were all adults at the time of the infant's birth (M age = 32 years, range 21–40), well educated (M = 16 years, range 12–23 years), and primarily Caucasian. Families ranged in socio-economic status (SES) from working to upper-middle class (M Hollingshead SES = 54.99, range 28.00–66.00). All infants were full term and healthy at delivery as determined by pediatric examination. During the 2-month recruitment telephone interview, mothers were screened for the level of their depressive symptoms using the Center for Epidemiological Studies Depression Scale (CES-D) (Weinberg et al., 2006). All mothers meeting the inclusion criteria with CES-D score of 16 or higher (clinically significant symptomatology) or 0–13 ("normative" level of depressive symptoms) were recruited into the study. 41 of the 124 mothers (33.1%) in the present study had a CES-D score at or above the clinical cut off of 16.

Following standard procedures, at 3 months postpartum, infant–mother dyads came to the laboratory and after signing consent forms, were videotaped during the FFSF (see Weinberg et al., 2006, for a more detailed description of methods). The FFSF included three successive 2-min episodes: (1) an initial play episode in which mothers were instructed to play with the infant as they normally would at home, (2) a still-face episode in which mothers were asked to keep a still, expressionless face while looking at the infant and refrain from smiling, vocalizing, or touching the infant, and (3) a reunion episode in which mothers resumed their normal interaction with the infant.

Infant and maternal facial affect was scored from videotapes of the FFSF in 1-second intervals using Izard's AFFEX system (Izard & Dougherty, 1980) by a team of coders masked to the study's hypotheses and maternal depressive symptom status. Prior to scoring, all coders were trained for reliability in AFFEX (kappa ≥ .70) (Cicchetti & Feinstein, 1990; Cohen, 1960). Maternal and infant affect was scored independently. The AFFEX system identifies 10 discrete facial expressions (i.e., joy, interest, sadness, anger, surprise, contempt, fear, shame, distress, and disgust) as well as blends of facial expressions. To assess inter-observer reliability 20% of the face-to-face play, still-face, and reunion episodes were selected randomly and recoded independently by different coders. The mean kappa was .76 for infant AFFEX codes and .82 for maternal AFFEX codes.

The dependent variables in this study were derived from each dyad's state space grid (SSG). A dyadic state space can be visualized along a two-dimensional grid, the SSG, where each axis represents the different affective states each member of
the dyad can be in (Hollenstein, 2012). For example, the X-axis of the grid may represent a set of orthogonal states of the infant (joy, interest, etc.) and the Y-axis may represent the set of orthogonal AFFEX states of the mother (joy, interest, etc.). The cells of the grid then represent all the possible dyadic states that a dyadic system can attain (infant joy/maternal interest). The dynamic trajectory of dyadic interaction based on the change in these states can be plotted on this two-dimensional grid. The trajectory helps identify attractor and repellor states, the likelihood of entering specific dyadic states and the pathways between them. Based on this trajectory, a set of SSG measures used in prior studies to operationalize dyadic flexibility were derived. For this study, dyadic flexibility was conceptualized as the degree of structural variation in a dyad’s moment-by-moment affective exchange as members in the dyad adapt to the other during the interaction (Hollenstein, 2007).

Based on the temporal affective sequence coded in the infants and mothers during the initial and reunion play episodes of the FFSF, a dyadic trajectory in the SSG comprised of all the dyadic affective states was generated using GridWare (Laney, Hollenstein, Lewis, & Granic, 2004). The following five SSG measures were derived to characterize dyadic flexibility: (1) Dispersion: a measure of the spread of the dyadic interaction within the state space grid. The values range from 0 (all behavior in one cell – no dispersion) to 1 (maximum dispersion – all cells occupied); (2) Fluctuation: a measure of the number of discrete visits to each of the dyadic affective states in the state space grid; (3) Range: a measure of the number of unique affective states in the state space grid occupied by the dyad; (4) Stickiness: a measure of the tendency of the dyad to get stuck in a limited number of affective states. It is the average of the mean durations in each affective state during the observed period of dyadic interaction; (5) Unpredictability: a measure derived from the Shannon’s entropy for the dyad. Entropy is a measure of disorderliness in the dyadic interaction across transitions from one state to another and was calculated as Shannon’s entropy (Dishion et al., 2004) with the formula: Entropy = Sum of P(i)ln(1/P(i)) = Σ(P(i)ln(1/P(i))), where P is a conditional probability: the ratio of the number of times a particular state was visited to the total number of visits (Dishion et al., 2004; Hollenstein, 2012; Laney et al., 2004). Greater dyadic flexibility is associated with greater dispersion, fluctuation, range and unpredictability, and lower stickiness. Note however, that these measures may or may not be independent of one another.

Given the possible interdependence of the 5 SSG variables their intercorrelations were evaluated using bivariate correlation results. The bivariate correlations among the five measures of dyadic flexibility revealed that they were moderately to very highly intercorrelated within each interactive context (r (initial play) range .86-.94; r (reunion play) range .57-.94). A Principal Component Analysis (PCA) was then run on the five measures of dyadic affective flexibility from each episode, which resulted in a one factor solution accounting for 81.86 and 78.82 percent of the variance in the play and reunion episodes, respectively. Given the finding of a one factor solution for the SSG variables used to describe dyadic flexibility and to control type-I errors from multiple tests, the measure with maximum communality, unpredictability, was used to index dyadic flexibility in the subsequent analyses.

The hypotheses in the first aim that there would be change and stability in dyadic flexibility from the initial play episode to the reunion episode was evaluated using one-way repeated measures ANOVA and Pearson correlations respectively. Results of the repeated measures ANOVA tracking change in dyadic flexibility from the initial play to reunion play episodes showed that dyadic flexibility, measured in terms of affective unpredictability, increased significantly from the initial play to the reunion play episode (F(1,123) = 16.63, p < .001; partial η² = .12). In a mixed ANOVA with infant sex (2) by maternal depressive symptom status (2) by episode as a repeated measure (2), the main effect of episode found in the bivariate repeated measure ANOVA remained significant (F(1,120) = 13.32, p < .001, partial η² = .10). No significant main or 2-way interaction effects for infant sex or maternal depressive symptom status were observed. However, a significant three-way interaction was found between FFSF episode, infant sex, and caregivers’ depressive symptom status (F(1,120) = 5.35, p = .02, partial η² = .04). Results of simple effect tests indicated that dyads with caregivers with high depressive symptoms and male infants (p = .004) and caregivers with normative depressive symptoms and female infants (p < .001) showed a significant cross-episode increase in dyadic flexibility. No significant increase was observed for the other two groups (See Fig. 1). Dyadic flexibility was moderately correlated across episodes (r = .43, p < .001) indicating that dyads retained their relative rank-ordering in this variable across the two interactive contexts.

Linear regression was used to evaluate the hypotheses in the second aim; namely, whether dyadic flexibility observed during the Initial Play episode predicted higher levels of infant negativity during the Still-Face episode, controlling for infant sex and maternal depressive symptom status. Dyadic flexibility during the initial play episode and infant negativity during the still-face episode were entered in the first block, and infant negativity during the initial play episode was added in the second block. Infant sex, maternal depressive symptom status, and their two-way interaction were added to the third block. Regression results are presented in Table 1.

Greater dyadic flexibility during the initial play episode was associated with a higher level of infant negativity during the still-face perturbation. This effect remained significant even after controlling for level of infant negativity during the initial play episode. There were no main effects of infant sex or level of caregiver depressive symptoms; however, a significant infant sex x level of caregiver depressive symptoms interaction was found. Results of pairwise comparisons indicated that dyads with male infants and caregivers with clinically significant depressive symptoms displayed significantly higher infant negativity during the still-face episode than male infants of caregivers with normative depressive symptom levels.

Guided by DS principles, this study utilized the SSG methodology (Lewis et al., 1999) to characterize infant–caregiver interactional dynamics as measured by dyadic flexibility before and after the still-face perturbation. A number of measures of dyadic flexibility were generated using SSG analysis, each of which captured aspects of complexity in the temporal
organization of dyadic interaction. Given how they are calculated, some SSG measures are expected to be related whereas others will be independent. In particular, there is a mathematical overlap between measures such as fluctuation and unpredictability as they are based on the number of state transitions, as is the case with measures of dispersion, range and stickiness based on the number of unique dyadic states whereas measures of fluctuation and range, for example, are mathematically independent. In this study, the principal component analysis found that all five measures were highly related and converged into a single factor for each play episode of the FFSF. It would seem that for this sample, which is highly homogenous, these characteristics were tightly linked; that is to say that the variability of infant–caregiver face-to-face communication is consistently described in terms of the range of dyadic states occupied over the course of the interaction, average duration in these states and the propensity for transition between them. The linkage allowed for use of a single index (unpredictability) of dyadic flexibility.

Contrary to our hypothesis about the effect of the still-face perturbation, we found an increase in dyadic flexibility from the initial play to the reunion play episode. The increase in dyadic flexibility can be seen as serving a regulatory function allowing for re-regulation or reparation of dyadic organization in which the dyad tries to compensate for the extremely low entropy (high predictability) of the still-face episode. Essentially, the dyad is co-creating a novel interactional trajectory that leads them toward a new equilibrium.

The dynamic features of interaction as measured by dyadic flexibility were qualified to some extent by their relation to the stress of the still-face, sex of the infant and maternal depressive symptomatology. Dynads with caregivers with elevated

![Graph showing change in dyadic flexibility from initial play to reunion play episode of the FFSF based on estimated marginal means.](Fig. 1)

**Table 1**

Linear regression results evaluating the association between dyadic flexibility in initial play and infant negativity during the still-face episode.

<table>
<thead>
<tr>
<th>Block</th>
<th>Predictors</th>
<th>Beta</th>
<th>Sig.</th>
<th>$R^2$ squared</th>
<th>$R^2$ change</th>
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<td>1</td>
<td>Dyadic flexibility – initial play</td>
<td>.437</td>
<td>.000</td>
<td>.19</td>
<td>.19***</td>
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<tr>
<td>2</td>
<td>Dyadic flexibility – initial play</td>
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<td>.029</td>
<td>.38</td>
<td>.19***</td>
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<td></td>
<td>Infant negativity – initial play</td>
<td>.505</td>
<td>.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
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<td>.019</td>
<td>.42</td>
<td>.04*</td>
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<tr>
<td></td>
<td>Infant negativity – initial play</td>
<td>.523</td>
<td>.000</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Infant sex</td>
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<td>.288</td>
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<td></td>
<td>Caregiver depressive symptom status</td>
<td>−.022</td>
<td>.837</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Infant sex × caregiver depressive symptom status</td>
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<td>.043</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable: infant negativity during the still-face episode.

* $p < 0.05$

** $p < 0.001$
levels of depressive symptoms and male infants showed a significant increase in dyadic flexibility from the initial play to the reunion supporting our hypothesis that sons are more vulnerable to maternal depressive symptoms (Tronick & Weinberg, 1997; Weinberg et al., 2006). By contrast and perhaps inconsistent with the finding on sons, we found in this study that only mother–daughter dyads with non-depressed mothers showed a significant increase in dyadic flexibility. A possible reason is that female infants are thought to be better able to self-regulate and adapt to maternal depression (Murray, Kempton, Woolgar, & Hooper, 1993; Weinberg et al., 2006).

Nonetheless, the stability in dyadic flexibility across play episodes suggests that the process of re-organization shares a lot in common with the initial organization. In particular, the stability of dyadic flexibility across the initial play and reunion play episodes suggests that the overall dyadic reorganization of the infant–caregiver system after a perturbation is consistent with the initial dyadic organization. This stability is perhaps reflective of dyadic habits of interaction, typical ways of being with one another, where earlier patterns influence the temporal structure of subsequent interaction (Hsu & Fogel, 2003). Thus the organization of the interaction is influenced by its chronic history while at the same time evidencing a capacity to reorganize.

The hypothesis that greater dyadic flexibility during the initial play before the still-face perturbation would be related to infants’ lower negativity during the still-face episode was also not supported. Rather infants of dyads with lower flexibility displayed less negativity during the still-face episode. As opposed to the DS view that variability is typically associated with more effective re-organization, a possible interpretation is that infants in dyads with lower dyadic variability are better able to predict maternal behavior (de Weerth & van Geert, 2000) and therefore better able to self-regulate when faced with a potentially stressful situation where the mother disengages. In some ways this finding does not fit the finding of that greater flexibility was related to secure attachments (Cerezo et al., 2012). It may be that younger infants are less able to cope with greater flexibility compared to older infants. Likely there needs to be an appropriate balance between variability and expectation, but we propose that the balance will change with development and context. In addition, that sons of mothers with clinically significant levels of depressive symptoms had more distress during the still-face perturbation when compared to sons of mothers without clinically significant levels of depressive symptoms adds support to the interpretation that males have greater regulatory difficulties in the context of maternal depression.

A strength of this study is the use of a novel characterization of the infant–caregiver affective communicative organization in terms of flexibility. Though there are exceptions (Beebe et al., 2010; Cohn & Tronick, 1988), past studies have primarily assessed the unidirectional impact of infant and caregiver characteristics on the infant. This study, on the other hand, adds to our understanding by further emphasizing individual characteristics within the context of a dyadic system to get a more complete picture of the dyadic relationship. Infant sex as well as levels of caregiver depression impact the reciprocity or mutual regulatory processes of the dyadic interaction as captured through this dynamic systems model of the FFSF paradigm.

The results of this study, however, should be interpreted with caution as it is based on a low-risk homogenous sample. As noted, the finding of a single factor for the SSG variables may in part be accounted for by sample characteristics and a study of a more heterogeneous sample might find the SSG variables to be less tightly linked. The SSG model presented in this study is based on infant and caregiver affect, only one aspect of dyadic interaction. Gaze patterns and engagement behaviors, in combination with affect would provide a more comprehensive picture of the dyadic interaction. Relatedly, given the emphasis of dynamic systems theory on individual differences – the unique organization of every system – future studies should look for different subgroups within the larger group of dyads.

In conclusion, the use of a dynamic systems analysis was found to provide a unique characterization of face-to-face interactions. This study adds to our understanding of dyadic regulatory processes during early infant–caregiver communication. It further substantiates the complexity of infant–caregiver affective regulatory processes. The study raises the question of the optimal level of variability in dyadic interactions. As evidenced by the results of this study, low variability facilitates better distress tolerance in the infant. However, as de Weerth and van Geert (2000) suggest, a closed system with extreme stability may be dysfunctional and have difficulty adapting to unpredictable changes in the environment whereas extreme variability may exceed a system’s capacity for reorganization. Yet there has to be variability to leave room for innovation and adaptation to new circumstances. Perhaps dyadic flexibility may be an inverted U shaped curve where the optimal levels fall somewhere in between.

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