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ORIGINAL ARTICLE

Distressed Mothers and Their Infants Use a Less Efficient Timing Mechanism in Creating Expectancies of Each Other's Looking Patterns

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Abstract The prediction of events and the creation of expectancies about their time course is a crucial aspect of an infant's mental life, but temporal mechanisms underlying these predictions are obscure. Scalar timing, in which the ratio of mean durations to their standard deviations is held constant, enables a person to use an estimate of the mean for its standard deviation. It is one efficient mechanism that may facilitate predictability and the creation of expectancies in mother–infant interaction. We illustrate this mechanism with the dyadic gaze rhythm of mother and infant looking at and looking away from each other's faces. Two groups of Hi- and Lo-Distress mothers were created using self-reported depression, anxiety, self-criticism and childhood experiences. Lo-Distress infants (controls) used scalar timing 100% of the time, about double that of Hi-Distress infants. Lo-Distress mothers used scalar timing about nine times as much as Hi-Distress mothers. The diminished use of scalar timing patterns in Hi-Distress mothers and infants may make the anticipation of each other's gaze patterns more difficult for both partners.

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The brain is specialized for the prediction of ongoing events. Predicting future events permits detection, modeling, and manipulation of the pattern of interactions with the environment (Schultz et al. 1997; Miller and Turnbull 1986). The prediction of events and the creation of expectancies about their time course is a central aspect of the infant's communicative capacity. Both mothers and infants predict when the other may vocalize, or may look and look away, and each contingently coordinates with the other's "on" and "off" behaviors (Jaffe et al. 2001; Stern 1971, 1974). In mother–infant interaction, predictability of these basic rhythms of gaze and vocalization permits a procedural (nonsymbolic) anticipation of how the other will proceed, facilitating coordination with the partner. Such anticipation facilitates information processing, memory, and the procedural representation of interpersonal events (Haith et al. 1988). But the temporal mechanisms underlying these predictions are obscure (Schultz et al. 1997; Stern and Gibbon 1978). This article examines a mechanism for how such anticipation may occur, namely scalar timing.

Experimental work documents that infants can indeed estimate durations of events and use the estimates to anticipate future events (Lewkowicz 2000; Rovee-Collier and Fagan 1981; Fagen et al. 1984; Haith et al. 1988). But relatively little work examines how infants might construct temporal expectancies in a *naturalistic*, ongoing face-to-face interaction. Only a handful of studies have linked variations in temporal expectancies to maternal distress and potential disturbances in mother–infant communication. These topics are the subject of this report.

Three previous studies set the stage for the present investigation. Stern and Gibbon (1978) argued that timing itself is a critical variable in social behavior in general, and in mother–infant communication in particular. They suggested that infants must have some way of keeping track of the timing of maternal social behaviors. They proposed that a temporal process best suited to maintain infant engagement should have sufficient regularity to allow the infant to form expectancies, but sufficient lawful variability to maintain the infant's interest. Examining three mothers playing face-to-face with their three-month infants, Stern and Gibbon (1978) showed that the durations of mothers' on–off vocal behaviors conformed to a scalar process. They inferred that infants would detect maternal scalar timing, but did not actually study the infants.

In a scalar process the ratio of the standard deviation to the mean is a constant, so that the mean itself predicts the standard deviation (*SD*). Using a scalar process, the individual can use changes in the mean duration of a behavior to anticipate changes in its variability. Stern and Gibbon (1978) reasoned that, using scalar timing, the mother could switch to any tempo and the infant would be able to readjust his expectation of the variability of the new mean duration of mother's behavior.

Gibbon (1972, 1977) described two other modes of estimating how the variability of intervals might change with changes in the duration of the interval being timed, namely, "Absolute" and "Poisson." The three modes of timing differ in the relation of the standard deviation to the mean of an estimated interval. In "absolute timing," which obtains in intervals of less than one-half sec, there is no change in variance with changes in the mean duration. In Poisson timing, the standard deviation is proportional to the square root of the mean, and in scalar timing the standard deviation is proportional to the mean (Stern and Gibbon 1978).

In general, there is no *necessary* relationship between the mean and the standard deviation of the duration of a behavior sampled across time. But when systematic relationships exist between the mean and standard deviation of a behavior, they facilitate the creation of expectancies about how variable durations will be. Significant relationships between the mean and standard deviation which deviate from scalar are also interpretable timing mechanisms, but they are more complex and less efficient than the scalar mechanism, since they require separate calculations of the mean and the standard deviation.

Aberrant coordination of interpersonal timing is an important aspect of communication disturbance. Timing of social behavior is generally out of awareness and therefore difficult to falsify (Zlochower and Cohn 1996). Distressed individuals are often noted by clinical observation to have aberrant timing patterns. Anderson et al. (1992) used speech rates to distinguish types of depression. They showed that depressed adults with slower speech rates responded to tricyclic antidepressants, whereas agitated depressive adults with normal speech rates did not.

Stern and Gibbon (1978) also hypothesized that different maternal emotional states might create characteristic distortions in timing, since "affect and timing are intimately bound" (p. 426). Zlochower and Cohn (1996) confirmed this hypothesis by showing that scalar timing characterized the vocal behavior of 20 nondepressed mothers but not that of 15 clinically depressed mothers, suggesting that infants may have more difficulty in forming expectancies when mothers are depressed. They also showed that depressed mothers had longer and more variable "switching pauses" at the point of the turn exchange than controls, a finding similar to that of Bettes (1988). But like Stern and Gibbon (1978), Zlochower and Cohn did not examine the infants.

The current study expands on the prior ones by considering infant as well as mother, in a larger and potentially more representative study. We sought to confirm and expand the Zlochower and Cohn finding of the absence of scalar timing in distressed mothers, using the modality of gaze rather than vocalization. Although both gaze and vocalization are key modalities of the exchange, gaze on–off is a more frequently occurring behavior in preverbal infants than vocalization on–off. We also speculated that gaze and vocalization might show similar organizations with respect to the scalar property because Jaffe et al. (1973) showed that mother–infant gaze and vocalization modalities shared the same mathematical (Markovian) property. Furthermore, Crown et al. (2002) showed that 6-week infants coordinated their on–off gaze behavior with the on–off vocal behavior of their mothers and of novel female partners.

Although current research rests heavily on the use of a single scale to measure maternal distress, such as maternal depression (see for example Field 1995; Field et al. 1990; Cohn et al. 1990) we wanted to use a number of different indices of maternal distress that might create a more robust index than a single scale, even though many self-report scales of distress tend to be correlated. We attempted to identify two clusters of mothers based on a number of different scales of anxiety, depressive symptoms and experiences, and childhood history, taken at both six weeks and four months. This approach taps many more sources of variance than a single-scale or single time-point approach. One scale (Epstein 1983, 1990) also assessed paternal distress.

In this article we hypothesize that more distressed mothers and their infants are less likely to use the scalar timing property than less distressed mothers and their infants. If so, the claim that absence of scalar timing is a mechanism of disturbed mother–infant communication would be bolstered. The paper has two goals: (1) the creation of a composite measure of maternal distress that includes many kinds of distress, across two time-points, six weeks and four months; (2) the examination of whether distressed mothers and their infants differ from controls in the use of scalar timing. In the second goal we also examine whether the presence or absence of scalar timing may be specific to gaze on, gaze off, or the cycle of gaze on + off; and whether distressed pairs differ in symmetrical (gaze on, off, or cycle) and simultaneous use of the scalar property.

The coordination of the timing of mother and infant behaviors is one fundamental basis for the development of communication. Mothers and infants have highly organized forms of preverbal communication which predate speech. The coordination of mother and infant vocal rhythms when infants are four months, for example, are known to predict cognitive as well as social outcomes at one year (Beebe, Alson, Jaffe, Feldstein and Crown, 1988; Beebe, Jaffe, Lachmann, Feldstein and Crown, 2000; Jaffe et al., 2001). Some of the dialogic aspects of adult speech are present as early as four months, particularly the turn exchange, regulated through the interpersonal coordination of the durations of switching pauses at the point of the turn exchange (Jaffe et al. 2001). If we can document scalar mechanisms in gaze behavior, parallel to those documented for vocal behavior (Stern and Gibbon 1978; Zlochower and Cohn 1996), we can argue that timing coordination extends across key communication modalities such as vocalization and gaze. Thus, timing coordination may provide one central mechanism organizing preverbal, as well as verbal, communication. If we can replicate and expand the findings of Zlochower and Cohn (1996), that distressed mothers as well as their infants are both less likely to use scalar timing, we can infer one mechanism of disturbed mother–infant communication, organized through both infant and mother behavior.

Method

Participants

Recruitment

Within 24 h of delivery, 152 mothers were recruited from an urban university hospital for a study of infant social development involving videotaped play. The sample were primiparous women delivering full-term, healthy, singleton infants without major complications; at least 18 years old; with home telephone; married or living with partner. All mothers meeting the criteria were consecutively approached. When infants were six weeks old, mothers were invited to participate by telephone. When infants were four months old, 132 mothers and infants came to the lab for videotaping. No differences were found in ethnicity, education, or infant gender between the 132 participants (with both six-week and four-month data) and the 152 recruited.

Demographic description

Mothers' mean age was 29 (*SD* 6.5, range 18–45). They were 53% White, 28% Hispanic, 17.4% Black, 1.5% Asian, and were educated as follows: 3.8% without High School diploma, 8.3% without college, 28.8% some college, 59.1% college degree or more). All mothers spoke English well enough to fill out the questionnaires. Questionnaires were given to the mothers at both six weeks and four months. Risk factors such as poverty, family violence, or other obvious disturbance were absent. Of the 132 infants, 58 (44%) were female. Our goal was to study the effects of maternal distress such as anxiety and depression in a sample free of other major risk indices.

Procedure

During the telephone call when infants were six weeks, several self-report distress scales were administered. Because of the time-constraints of a telephone call, only a subset of the distress scales could be administered at the six-week point. We chose to administer depression scales only (CES-D and Blatt DEQ): see below.

Scheduling of videotaping when infants were four months took into account infants' eating/sleeping patterns. If infants became hungry or distressed, sufficient time was set aside for feeding or napping prior to videotaping. Mothers were instructed to play with their infants as they would at home, for approximately 10 min, seated opposite the infant (on a table in an infant seat), without the use of toys. Two videotape cameras generated a split-screen view of the interaction. Following videotaping, mothers filled out distress scales. Because Field (1995) found confounds in the mother–infant play when mothers filled out depression scales prior to the videotaping, all scales were administered following the videotaping. Some of the scales have fewer than 132 subjects because some of the mothers failed to fill out all the scales.

Measurement of Gaze Behavior from Videotape

The first 2–1/2 uninterrupted continuous play minutes (150 s) of videotaped mother–infant interaction were coded for mother and infant gaze, using 1 s time intervals (using Tronick and Weinberg's (1990) timing rules), by two coders each for mother and infant. Coders were blind to maternal distress status. Gaze was coded on and off partner's face, separately for mother and infant, by two coders for each partner. Thirty-five randomly selected dyads were used to estimate reliability. Cohen's kappa mean for infant gaze was .80 (range .63–.95); for mother kappa mean = .83 (range .68–.97). Six measures were generated per dyad: "gaze on," "gaze off," and a cycle of "gaze on + gaze off," for mothers and for infants separately. Following Jaffe et al. (2001), who defined vocalization + pause cycles in mother–infant interaction, we define an analogous gaze on + off cycle.

Measurement of Maternal Distress

Total six-week and four-month self-report scales considered in creation of maternal distress clusters. We had available for consideration a total of 16 scales, three at six weeks and 13 at four months (described below), as listed in Table 1. Table 1 shows the means, standard deviations, and range of scores of the 16 maternal self-report distress scales. All scales were used as continuous variables; higher scores indicate higher distress. Only CES-D has a generally accepted clinical cut-off, noted below.

Maternal depressive symptoms were measured at six weeks and four months. The CES-D (Radloff 1977) measures self-reported current but nonspecific distress, rather than clinically diagnosed depression (Campbell and Cohn 1991). We thus refer to this distress as "depressive symptoms." A score of 16+ is considered to tap clinically relevant levels of depressive symptoms and is generally used as the cut-off in the literature (Radloff 1977). At six weeks, 25.8% of the sample had a score of 16 or above; at four months, 19% had a score of 16+. The correlation between six-week and four-month CES-D scores was $r = .47 (p < .01)$, consistent with Beeghly et al. (2002).

Maternal depressive experiences of self-criticism and dependency were measured at 6 weeks and 4 months. The Depressive Experiences Questionnaire (DEQ) (Blatt et al. 1976) is a 66 item self-report questionnaire that describes experiences and attitudes common to depressed people. Rather than focusing on depressive symptoms themselves, the items tap experiences of a distorted, depreciated sense of self and others, an empty, needy form of dependency, and helplessness. The items are not DSM-IV based, but are statements that are

Table 1 Descriptive statistics for maternal self-report distress scales

Variable	N	*M*	*SD*	Range
CESD-6w	132	12.33	8.42	0.0–41.0
CESD-4mo	132	9.53	8.34	0.0–35.0
SAS-4mo	121	32.31	7.87	20.0–61.0
SAT-4mo	119	33.72	9.06	20.0–60.0
DEQ-DPN-6w	126	−0.91	0.71	−3.4–0.7
DEQ-DPN-4mo	128	−0.88	0.80	−3.6–1.0
DEQ-SC-6w	126	−0.73	0.96	−2.6–1.7
DEQ-SC-4mo	128	−0.80	1.01	−3.1–2.1
EP-AMf4mo	99	48.88	9.01	27.0–65.0
EP-AMm4mo	108	48.21	10.13	19.0–65.0
EP-BMf4mo	99	38.72	8.61	10.0–50.0
EP-BMm4mo	108	42.91	7.13	17.0–50.0
EP-AFf4mo	72	49.21	8.13	28.0–65.0
EP-AFm4mo	76	47.32	8.67	25.0–65.0
EP-BFf4mo	72	39.43	9.16	10.0–50.0
EP-BFm4mo	76	42.45	6.10	25.0–50.0

Note. 6w = 6 weeks; 4mo = 4 months. CES-D = Depression scale; SAS = Spielberger Anxiety State; SAT Spielberger Anxiety Trait; DEQ-DPN = Dependence Scale, DEQ-SC = Self-Criticism Scale; EP = Epstein, scales A (parent was experienced as encouraging of independence) and B (parent was experienced as accepting and loving), filled out by both parents (M and F) with reference to each parent's own mother (m) and father (f), yielding 4 scores M(m), M(f), F(m), and F(f)

considered on a continuum of normal coping difficulties to severe depression. There are no established clinical cut-offs. Regarding construct validity, in clinical populations Dependency and Self-Criticism are related to scores on the Beck Depression Inventory; in college populations Dependency and Self-Criticism are associated with depressive affect (Zuroff and Mongrain 1987); in the current sample, 6-week Depression and Self-Criticism were associated with 4-month mother and infant self- and interactive contingencies (Beebe et al. 2007). Dependency and Self-Criticism are also related in theoretically expected ways to self-concept, self-esteem, interpersonal behavior, descriptions of parents, and dysfunctional attitudes (Blatt et al. 1976, 1982; Mongrain and Zuroff 1989; Zuroff et al. 1983). This measure yields three factors: Self-Criticism (guilt, worthlessness, perfectionism), Dependency (hopelessness, emptiness, fears of abandonment), and Low Efficacy (feelings of inadequacy, difficulty following through, helplessness). We used the first two factors, Self-Criticism (DEQ-SC) and Dependency (DEQ-DPN).

The reliability of the DEQ has been extensively documented. Blatt et al. (1976) found good split half reliability with college undergraduates, and Zuroff et al. (1990) found high internal consistency for each of the three scales (Dependency, Self-Criticism, and Efficacy), with a Cronbach alpha level of .81 for Dependency and .75 for Self-Criticism. Regarding the validity of the DEQ, the Dependency and Self-Criticism factors have correlated in the expected direction with other commonly used self-report measures of depression, including the Beck Depression Inventory and the MMPI when given to in-patients, out-patients, and non-patient undergraduate samples.

Maternal anxiety was measured only at four months. The Spielberger State-Trait Anxiety Inventory (Spielberger 1983) is a 40-item self-report measure of apprehension, worry, tension, and nervousness, with items such as "nervous, jittery, high strung, rattled, over-excited." The first 20 items evaluate how respondents feel "right now, at this moment," yielding State-Anxiety (SAS). An identical set of items evaluate how subjects "generally feel," yielding

Trait-Anxiety (SAT). SAS and SAT have been shown to be highly correlated. Test-retest coefficients for SAT range from .73 to .86 for college students but are lower for SAS as would be expected. Both forms have high internal consistency (alpha coefficients SAS .87, and SAT .90). We report on 121 mothers who completed SAS and 119 who completed SAT. There are no established clinical cut-offs in the literature. The means (and *SD*) for SAS and SAT of our sample were very close to the norms of means (and *SD*) for working adults (SAS 35.5 [*SD* 10.5]; SAT 33.75 [*SD* 9.2]). Significant correlations ($p < .05$ or better) were obtained between four-month SAS and SAT ($r = .662$); SAS and four-month CES-D ($r = .50$); SAT and four-month CES-D ($r = .65$). Maternal anxiety was not correlated with infant gender, maternal education, or maternal ethnicity.

Childhood Experiences of Parents as Loving and as Encouraging Independence was measured only at four months. The Epstein "Mother-Father-Peer" Scale (EP) (1983, 1990) is a 30-item self-report inventory asking for degree of agreement with statements about one's mother, father and peers. The peer scale was not used. Scale A measures the degree to which the person's parent was experienced as encouraging of independence (EP-A); Scale B as accepting and loving (EP-B). The scales were filled out by both parents (M and F) with reference to each parent's own mother (m) and father (f), yielding four scores: M(m); M(f); F(m); and, F(f). Test–retest reliability for college students was good (alpha coefficients of .88 and .82 for mother and father Scale A; .91 for mother and father Scale B). Significant correlations were found between the Epstein scales and Eysenck's Neuroticism/Extroversion Scale and the Guilford–Zimmerman Temperament Survey (Epstein 1983). There are no established clinical cut-offs for Epstein in the literature.

Creation of Maternal Distress Clusters

In an attempt to reduce the number of scales used in the analysis, a principal components analysis was computed. Because the number of variables was only minimally reduced by the factor analysis, we proceeded to a cluster analysis which partitions observations into non-overlapping groups.

Method of K-Means Clustering

This method partitions a set of data consisting of observations of N variables into K clusters such that a data point is nearer to the center of the cluster to which it belongs than to that of any other cluster (BMDP 1990). The center of the cluster is defined as the mean of its members, hence the name "K-means." The distance measure is N-dimensional, Euclidean.

Measurement of Presence/Absence of Scalar Timing Model

The model begins with grouping the data by dyad and computing, for each dyad, a mean (mu) and standard deviation (sigma) for the dependent variables: gaze on, gaze off, and gaze on+off cycle. The data are said to follow a scalar timing model if the regression of the *logarithm* of the standard deviations upon the *logarithm* of the means has a slope that does not differ significantly from 1. We performed this regression equation for each variable and used a t-test to evaluate the slope:

$$t(n-2) = (\text{estimated slope} - 1)/(\text{standard error of the slope}),$$

where t has a t distribution with $n - 2$ degrees of freedom and n is the number of dyads.

Results

The results of the use of the cluster technique to divide the sample into Hi-Distress and Lo-Distress Clusters is presented first. We then evaluate the Hi- and Lo-Distress Clusters for the presence of the scalar timing mechanism. Finally, we evaluate the Hi- and Lo-Distress Clusters for mother and infant symmetrical (gaze on, off, or cycle) and simultaneous use of the scalar property.

Creation of Two Clusters of Mothers: Hi-Distress and Lo-Distress (Control) Clusters

The method of K-means clustering yielded two clusters of mothers: "Hi-Distress" mothers who endorsed a high level of symptoms ($N = 47$), and "Lo-Distress" mothers (controls) who did not ($N = 84$). The analysis used 12 of the possible 16 scores of maternal self-report distress scales. Table 2 lists these 12 scales, presenting F values (all $p < .01$ or better), cluster means and standard deviations. The method of KM means clustering depends upon the geometry of the data. There are no cluster weights. There are, however, case weights, all of which were one, meaning that all variables are allowed equal influence after being normalized to zero mean and unit standard deviation. Compared to the Lo-Distress Cluster, the Hi-Distress had a strong tendency toward larger means (by 50–300%) and larger standard deviations (seven of the 12 scores had larger *SD*s by 20–125%). Assessments of maternal distress at infant age four months contributed more than those at infant age six weeks; the only significant scale assessing paternal distress contributed very little. The first eight variables (Spielberger anxiety state and trait, CES-D depressive symptoms, and Blatt DEQ depressive experiences) contributed to the definition of the clusters in an independent way. The variables from the Epstein Childhood Experiences did not differentiate the clusters as well.

Geometric evaluation of separation of the clusters on the basis of distance revealed that the Hi-Distress Cluster was further away from the origin (mean distance 3.170) consisting of

Table 2 Summary of Hi- and Lo-Distress cluster means and standard deviations

Scale	$F*$	*df*	Lo-Distress		Hi-Distress	
			M	SD	*M*	SD
SAT-4mo	154.38	1,114	28.907	4.922	42.857	7.174
DEQ-SC-4mo	100.83	1,118	−1.293	0.726	0.141	0.798
CESD-4mo	81.69	1,124	5.342	4.074	16.152	9.390
DEQ-SC-6w	70.68	1,103	−1.228	0.727	0.083	0.081
CESD-6w	69.31	1,950	7.524	5.949	18.705	9.070
SAS-4mo	64.60	1,117	28.699	5.263	38.560	8.138
DEQ-DPN-4mo	31.33	1,118	−1.156	0.759	–0.350	0.755
DEQ-DPN-6w	26.57	1,103	−1.118	0.716	–0.408	0.555
EP-AMm4mo	11.46	1,105	14.420	8.779	20.974	11.077
EP-BFm4mo	8.85	1,740	6.082	5.330	10.222	6.600
EP-BMm4mo	7.98	1,106	5.681	6.829	9.590	7.048
EP-BMf4mo	7.74	1,970	9.484	8.395	14.297	8.209

All $p < .01$; All case weights are one.
Note. The N for the Low Distress group on all the scales was 84. The N for the High Distress group on the first 8 scales was 46, and on the final 4 scales was 47. 6w = 6 weeks; 4mos = 4 months. CES-D = Depression scale; SAS = Spielberger Anxiety State; SAT Spielberger Anxiety Trait; DEQ-DPN = Dependence Scale, DEQ-SC = Self-Criticism Scale; EP = Epstein, scales A (parent was experienced as encouraging of independence) and B (parent was experienced as accepting and loving), filled out by both parents (M and F) with reference to each parent's own mother (m) and father (f), yielding 4 scores M(m), F(m), and F(f)

Table 3 Regression equations testing for scalar timing in the Lo- and Hi-Distress clusters

Cluster		N	R^2	F	Slope	Slope SE	T Statistic
Lo-Distress	Baby						
	On	78	.884	588.30	1.07	0.04	1.51[a]
	Off	78	.884	592.36	1.03	0.04	0.77[a]
	On + Off	78	.792	275.84	1.00	0.06	0.05[a]
	Mother						
	On	77	.884	545.83	0.94	0.04	−1.44[a]
	Off	77	.828	382.70	1.54	0.08	6.85
	On + Off	77	.884	543.81	1.06	0.05	1.40[a]
Hi-Distress	Baby						
	On	44	.922	538.69	1.17	0.05	3.31
	Off	44	.941	576.84	1.07	0.04	1.57[a]
	On + Off	44	.846	224.27	1.10	0.07	1.40[a]
	Mother						
	On	42	.774	136.35	0.74	0.06	−4.01
	Off	42	.689	89.17	1.19	0.13	1.51[a]
	On + Off	42	.774	131.60	0.82	0.07	−2.47

Note. The R^2 is the proportion of variance accounted for by the regression model. For all the F ratios, $p < .001$. The T Statistic is a test of the null hypothesis that the $Slope = 1$, which is the criterion for scalar timing. Those with superscript “a” indicate that the equation met the criterion for scalar timing at $p < .05$

the 12 score means, and more dispersed. The Lo-Distress mean distance from the origin was 2.615, making it more dense and coherent (more tightly grouped), as suggested by the means and *SD*’s. The 47 cases in the Hi-Distress Cluster were closer to their center than the 84 cases of the Lo-Distress Cluster; likewise the 84 cases in the Lo-Distress Cluster are closer to their center than the 47 cases of the Hi-Distress Cluster. The smaller, Hi-Distress cluster is leaner, that is, less dense and more spread out than the Lo-Distress Cluster; and the larger Lo-Distress cluster is more dense, that is, more tightly packed and with a smaller mean distance between neighboring points, than the Hi-Distress Cluster. There is no evidence of three or more clusters. Attempts to construct such clusters merely fragment the two cluster structure already identified. We conclude that the 12 variables identified significantly distinguish two clusters, the Hi-Distress about half the size of the Lo-Distress, and leaner in composition.

Effects of Hi- vs. Lo- Maternal Distress on Scalar Timing in Gaze On, Off, and On + Off

For Hi-Distress and Lo-Distress groups separately, mother and infant gaze data were separately tested for the presence of scalar timing in gaze on partner, gaze off partner, and the cycle of gaze on + off. Table 3 presents the results of the regression equations which tested the relationship between the mean and the standard deviation of the durations of the gaze behaviors. *All* regression equations showed highly significant relationships between the mean and the standard deviation, regardless of the scalar property, with R’s much greater than .85, large F-ratios, and p-values $< .001$ or better. Graphs of predicted vs. observed showed good fits, and normal probability plots were linear.[1] These significant relationships indicate that mothers and infants of both Hi- and Lo-Distress Clusters had interpretable timing mechanisms for creating expectancies about ongoing gaze behavior, whether or not the mechanism was a scalar one.

1 Graphs of these regression equations are available from the first author.

Examination of the regression equations in Table 3 revealed that the scalar property was more evident in the Lo-Distress infants (evident in 3/3 equations: gaze on, off, and on + off cycle) and mothers (2/3 equations: gaze off is not scalar) than in the Hi-Distress infants (2/3: gaze on is not scalar) and mothers (1/3: scalar only in gaze off). Hi-Distress dyads preserved a linear dependence of log sigma on log mu while tending to depart from scalar timing. These equations showing the presence or absence of scalar timing in the gaze on and off states are difficult to interpret without knowing the proportion of time they involve.

Based on the findings of Tables 3 and 4 presents the percent of time in the gaze on and off states, annotated for the presence or absence of the scalar property. For example, Table 4 shows that Hi-Distress Cluster mothers are scalar in gaze off, but gaze off represents only 9.9% of the time. In contrast, Lo-Distress cluster mothers are scalar during gaze on, which represents 87.7% of the time. On average, Lo-Distress infants (controls) used the scalar timing mechanism during both gaze on and gaze off, thus 100% of the time; Hi-Distress infants used scalar timing only during gaze off, 54.7% of the time. Thus, although infants in the Hi-Distress cluster showed 2/3 equations in which the scalar mechanism was present, when % time spent in gaze states is taken into account, the difference between Hi- and Lo-Distress infants becomes more apparent: Lo-Distress infants used the scalar mechanism 100% of the time, whereas Lo-Distress infants used it 54.7% of the time. Using the on + off cycle as an index of a nonperiodic rhythm, only the Hi-Distress mother did not show the scalar mechanism in this overall rhythm. Strikingly, Lo-Distress mothers and infants had symmetrical use of scalar timing for gaze on, whereas Hi-Distress mothers and infants had such symmetrical use for gaze off.

But this analysis does not yet determine whether the two partners were scalar *at the same time*. For this determination, the percent time in four *dyadic gaze states* was computed: joint gaze on, joint off, and either on while the other was off, as seen in Table 5. These four dyadic states are annotated for the presence or absence of scalar timing for each partner. In the Lo-Distress Cluster, mother and infant were both scalar during joint gaze on (39.8% time), and during mother-on/ infant-off (47.9% time). Thus, mother and infant had simultaneous use of the scalar mechanism 87.7% time.

In the Hi-Distress Cluster, both mother and infant *were both scalar only when off*. They spent 7.1% time during joint gaze off. Thus they had simultaneous use of the scalar mechanism 7.1% time. As noted above, infants in the HI-Distress Cluster were scalar during gaze off. Since infant off (54.7%) occurred mostly in the context of mother on /infant off (47.6%), most of the infant's use of the scalar mechanism (during gaze off) occurred when mother was on and not scalar. Thus *simultaneous* use of the scalar property occurred 87.7% of the time for Lo-Distress mothers and infants, but 7.1% for Hi-Distress pairs, and this difference sharply distinguishes the Lo- versus Hi-Distress groups.

Table 4 Percent time in gaze on, off, and on + off, in Lo- and Hi-Distress clusters and mother and baby use of scalar timing (yes/no)

Gaze type	Lo-Distress		Hi-Distress	
	Mother	Baby	Mother	Baby
On	87.7 (Yes)	42.5 (Yes)	90.1 (No)	45.3 (No)
Off	12.3 (No)	57.5 (Yes)	9.9 (Yes)	54.7 (Yes)
On + Off[a]	(Yes)	(Yes)	(No)	(Yes)

Note. The use of scalar timing is indicated in the parentheses (yes, no)
[a] on + off cycle = 100% time

"Based on the findings of **Table 3, Table 4** presents the percent of time in the gaze on and off states, annotated for the presence or absence of the scalar property."

Table 5 Percent time spent in dyadic gaze on and off states and scalar timing

Gaze type	Lo-Distress	M	I	Hi- Distress	M	I
Joint on	39.8	Y	Y	42.5	N	N
Mother off/Infant on	2.7	N	Y	2.8	Y	N
Mother on/Infant off	47.9	Y	Y	47.6	N	Y
Joint off	9.6	N	Y	7.1	Y	Y

Note. Y = yes scalar; N = not scalar

Discussion

Temporal mechanisms which facilitate the prediction of events provide the framework for the creation of models or procedural representations of the moment-to moment action-sequences of communication. Scalar timing is a particularly efficient mechanism through which representations or expectancies of the ongoing variability of behavioral durations can be created. The subject can use the mean duration of behaviors to estimate the variability of these durations. Thus, only one timing rule is necessary to estimate both means and standard deviations when the scalar timing is in play. We know from work with adults (Kristofferson 1976; Getty 1975; Stern and Gibbon 1978) that the scalar process is a good description of human timing. In our gaze data, infants used this timing process *at least as early as four months*, and maternal distress affected not only maternal use of it, but also infant use of it.

Hi-Distress mothers used scalar timing about 1/9 as much as Lo-Distress mothers. Lo-Distress infants used scalar timing 100% of the time, whereas Hi-Distress infants used it half the time, and primarily in a solo fashion, during periods when infants were not gazing at mother, and when mothers were gazing at infants but not scalar. It is striking that Lo-Distress mothers used scalar timing only during "gaze on," whereas Hi-Distress mothers and their infants used it only during "gaze-off."

Our finding that Hi-Distress mothers used scalar timing sparingly is consistent with Zlochower and Cohn's (1996) finding that depressed mothers did not use scalar timing. That infants of Hi-Distress mothers also used scalar timing less is a new finding and an important correlate of the findings that distressed mothers themselves use it less. Because our gaze data are consistent with other vocal data (Stern and Gibbon 1978; Zlochower and Cohn 1996), we suggest that our scalar timing results may transcend the gaze modality.

Although the Hi-Distress mothers and infants did show significant relationships between the mean and standard deviation of gaze behavior, these relationships in general deviated from scalar timing. Such non-scalar timing mechanisms are more complex and less efficient than the scalar one, since the means and the standard deviations have separate timing rules. Attending to two rules rather than one may sacrifice other relevant information. When timing is non-scalar, mother and infant presumably have to work harder to anticipate each other's gaze patterns.

Our work has much in common with similar animal models for temporal prediction and representation, which also make use of the scalar timing mechanism (see Gibbon 1972, 1977). For example, the study of dopamine neurons in monkeys has shown that monkeys make precise predictions of the timing of future salient events. The output of the dopamine neurons "is consistent with a scalar prediction error signal...which influences behavioral choices" (Schultz et al. 1997, pp.1597–1598). The expected time of a predicted salient event is encoded by monkeys, suggesting a form of temporal representation.

Our findings have implications for the origins of communication. For the last four decades our team has argued that the intrapersonal and interpersonal timing of moment-by-moment behaviors constitutes an early implicit/procedural communication system between mothers and infants, and a scaffolding for the subsequent development of social communication (Beebe et al. 1985, 1979, 1988; Feldstein et al. 1993; Jaffe et al. 1973; Jasnow and Feldstein 1986; Crown et al. 2002). Jaffe et al. (2001) extensively documented this proposition in predicting infant attachment and cognition outcomes from mother–infant vocal rhythm coordination. Similarly, we argue here that mother and infant use of scalar timing is one aspect of the organization of the early communication system.

In previous work we have argued that the various ways in which mothers and infants *match* timing patterns provides each a behavioral basis for knowing and entering into each other's perception, temporal world, and feeling states (Beebe et al. 1985). Forms of behavioral correspondence provide the central definition of intersubjectivity in infancy (Beebe et al. 2005). It is a common notion that similarity of language and behavior is associated with greater empathy or similarity of feeling states (see Feldstein and Welkowitz 1978; Feldstein 1998; for reviews). Based on the work of Ekman (1983) and Zajonc (1985), we proposed that, as mother and infant match each other's temporal patterns, each recreates in herself a psycho-physiological state similar to that of the partner, thus participating in the subjective state of the other (Beebe et al. 1985; Beebe and Lachmann 2002). Whereas previously our data has shown matching of durations of behavior, here we extend the concept to matching of a computational timing mechanism (namely scalar timing), a more abstract concept.

Our data documented that mothers and infants "matched" the simultaneous use of scalar timing in different interpersonal contexts (gaze on versus off), as a function of maternal distress. Not only did Lo-Distress mothers and their infants use the scalar timing mechanism a greater percent of the time, but they also both used it in a highly simultaneous fashion, and specifically during the mutual gaze encounter (both gaze on), as well as during moments in which the mother looks at the infant and the infant looks away, a frequent occurrence in mother–infant face-to-face communication. We suggest, following the above logic, that the shared use of scalar timing allows Lo-distress mothers and infants to sense each other's state during mutual gaze moments, which carry the possibility of intimacy. In addition, their shared use of scalar timing during moments when the mother is looking at the infant and the infant is looking away provide a means for mother and infant to sense each other's state even when infants are looking away. Each can rapidly recognize the partner's identical timing mechanism, and each may sense the reduction in system complexity when *in synch.* Thus we speculate that matched, or simultaneous, use of scalar timing is a facilitating form of communication.

With maternal distress, in contrast, mothers and infants used the scalar property a smaller percent of the time, and only when either partner was *gazing away* from the other. Furthermore, partners *matched* presence of the scalar property only during joint gaze off (7.1% of the time). We infer that their capacity to anticipate each other's gaze patterns is compromised. We suggest that distressed mothers and their infants tend to sense each other's state through shared use of the scalar mechanism only during mutual gaze avoidance, a more distant context. Perhaps the lowered arousal associated with looking away from the partner (Field 1981) enables distressed mothers and infants to shift into scalar timing, preserving some capacity of the system to engage in the more efficient timing mechanism.

Although timing and rhythm are often used in a global way in clinical diagnosis, this work precisely specifies one example of altered timing patterns that may underlie clinical impressions and may provide a mechanism of communication disturbance. The developmental significance of scalar timing as a simplifying and facilitating mechanism for communication could be tested by follow-up studies designed to evaluate infant social, cognitive, and speech development. The documentation that maternal distress affects these early temporal forms of preverbal communication highlights the importance of maternal emotional context in mother–infant communication, with implications for early therapeutic intervention.

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