PHYSIOLOGICAL CONCORDANCE: RECOMMENDATIONS FOR STATISTICAL APPROACHES

by

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(Under the Direction of Anne Shaffer)

ABSTRACT

In this paper mother-child concordance of heart rate was examined in a middle childhood sample. Previous research was mixed with regard to the 'harmful' versus 'beneficial' function of physiological concordance. Two person-oriented approaches that allowed for examination of multiple types of concordance – dyadic indices and model based cluster analyses – were used to compare relations between concordance and behavioral observations of emotion-related, dyadic relationship characteristics. Similar relations between multiple types of concordance (as measured by multiple dyadic indices) and relationship characteristics suggest that the mix of relations previously found in the literature is not due to differences in statistical measurement. Cluster analyses of average reactivity revealed two distinct clusters (mutual high and mutual low reactivity). Compared to mutual high reactivity dyads, mutual low reactivity dyads demonstrated greater positive relationship characteristics. Combined these results suggest that the implications for concordance may be different when considering the degree of similarity compared to the nature of the physiological activity experienced by both dyad members. Future research would benefit from inclusion of continuous heart rate measurement, comparison of inter-system similarities in concordance, and examination of developmental changes in concordance.

INDEX WORDS: Physiological concordance, Heart rate, Middle childhood, Attachment, Dyadic Indices, Model-based cluster analyses

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DEDICATION

I dedicate this paper to my family and friends. My family has continued to provide unconditional love and support without which I would never have pursued and achieved my goals. I am also forever indebted to people like Tamar Shovali, Ali Watts, and Brendan Beal for listening to me complain and reminding me what is truly important in life: jello wrestling, filming movies, rock band parties, and just enjoying the company of others.

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CHAPTER 1

INTRODUCTION

In recent decades, research on relational processes has uncovered a pattern of coordination beyond that of externally observable behavior. Specifically, researchers have found similarities in physiological activity and reactivity within several types of dyads (e.g., mother-child, husband wife). This similarity, labeled in this paper as physiological concordance, has been linked to both intra- and interpersonal processes suggesting that it may serve a variety of functions. One of its primary functions, for example, may be promotion of attachment security (e.g., Field, 1985). Unfortunately, a majority of research on mother-child physiological concordance focuses on infancy or early childhood leaving questions unanswered as to developmental changes in the function. Additionally, current conceptualizations and statistical analyses of this construct are quite varied further precluding definitive conclusions about the implications of concordance. In this paper I review current conceptualizations and statistical analyses of physiological concordance. Then, I recommend two person-centered statistical analyses that, when employed in the examination of physiological concordance, will allow researchers to overcome the limitations of current techniques. Before describing these specific statistical techniques, a theoretical context for understanding physiological concordance is provided.

Attachment: Historical Roots & Contemporary Perspectives

Historical roots

Formation and maintenance of attachment bonds are arguably two of the most important tasks in childhood. Early attachment theory (Bowlby, 1969/82) describes all mammals, including human infants, as having innate abilities and motivation to form attachment bonds. These attachment bonds serve a protective role, particularly for species whose offspring are born motorically altricial such as humans (Bowlby, 1973, 1980). Protection is achieved when attached individuals engage in proximity seeking behavior during times of threat or danger**.** Additionally, during times of non-threat caregivers serve as a secure base, providing a presence that gives their offspring a sense of security making exploration of the environment possible (Bowlby, 1988).

Bowlby's early observations of mothers and their infants led to identification of a bi-phasic response to separation: initial protest followed by despair (Bowlby, 1969/82). This bi-phasic response to separation and reunion then became the focus in early measurement of attachment (Strange Situation procedure; Ainsworth, Blehar, Waters, & Wall, 1978). Using this procedure, mother-infant dyads can be classified as being either securely or insecurely attached. Secure attachment was identified for infants who used their mother as a secure base, exploring their environment and sometimes strangers while 'checking in' with mother now and then. These infants were upset during periods of separation but were able to be calmed by seeking comfort during reunion. Two types of insecure attachment also emerged through this measurement: insecure-resistant and insecure-avoidant. Insecure-resistant infants were more hesitant to explore their environment and strangers, sticking close to mother while she was present. During periods of separation these infants showed great distress and during reunion were ambivalent - seeking proximity but resistant to physical contact. Insecure-avoidant infants did not use mother as a secure base and, in fact, paid her little attention during periods of togetherness or reunion. Additionally, these infants demonstrated little distress during separation. Later work added a fourth attachment classification, disorganized, that is characterized by inconsistent behaviors during periods of togetherness, separation, and reunion (Main & Solomon, 1986). Instead of engaging in systematic behaviors (e.g., proximity seeking or avoidance during reunions) these infants engage in a variety of strategies (e.g., proximity seeking and avoidance) and/or appear disorganized (e.g., undirected movement, disorganized movement sequences) during periods of separation and reunion.

Attachment security has been found to be a relatively stable construct, leading to positive outcomes for children throughout development. A large longitudinal study found that compared to their insecurely attached counterparts, children who show secure attachment in infancy (e.g., 12-18 months) were better adjusted and more socially skilled in early (e.g., Waters, Wippman, & Sroufe, 1979) and middle childhood (e.g., Elicker, Englund, & Sroufe, 1992). Similarly, other samples have demonstrated links between secure attachment and harmonious relationships with peers (e.g., Sroufe, Egeland, & Carlson, 1999), better emotional competence (e.g., Kochanska, 2001) and modulation (e.g., Easterbrooks & Goldberg, 1990), and fewer behavior problems (e.g., Shaw & Vondra 1995). In contrast, children who show insecure attachment have been shown to be at risk for becoming hostile and aggressive in middle childhood (e.g., Lyons-Ruth, Easterbooks, & Cibelli, 1997).

Early work proposed attachment bonds to originate from cognitive representations of self and others, termed internal working models (Bowlby, 1973; Bretherton, Ridgeway, & Cassidy, 1990; Bretherton & Munholland, 1999). Formation of these models is based on experiences during which trust and expectations for others is established. In infancy, this trust is developed from sensitive and responsive parenting (Ainsworth et al., 1978; De Wolff & van IJzendoorn, 1997; Isabella & Belsky, 1991). Sensitive and response caregivers express positive affect and affection toward their infant, engage in smooth, reciprocal interactions with their infant, respond quickly and appropriately to their infant's needs, frequently engage their infants, and create structured interactions with their infant (De Wolff & van IJzendoorn, 1997). Insecure attachment, in contrast, has been found to originate from caregiver emotional unavailability and indifference (e.g., Campbell, Cohn, & Meyers, 1995; Isabella, 1993), overstimulation (e.g., Belsky, Rovine, & Taylor, 1984), inconsistency in caregiving (e.g., Isabella, 1993; Isabella & Belsky, 1991), and distressing, frightening, or abusive behavior (e.g., Carlson, 1998; Cyr, Euser, Bakermans-Kranenburg, & Van Ijzendoorn, 2010; Schuegnel, Bakermans-Kranenburg, & van Ijzendoorn, 1999). Although much research focuses on maternal characteristics that promote attachment security, some researchers have emphasized infant characteristics (e.g., temperament) as the primary determinants of security (e.g., Kagan, 1982). Thorough examinations of both mother and infant characteristics reveal that, above and beyond the effects of these factors separately, the interaction between these characteristics – termed goodness of fit - is the best predictor of attachment security (e.g., Mangelsdorf, McHale, Diener, Goldsetein, & Lehn, 2000; Mangelsdorf, Gunnar, Kestenbaum, Lang, & Andreas, 1990). Thus, some level of matching or concordance between maternal and infant characteristics appears to be an important element for positive developmental and relational outcomes.

Contemporary perspectives

Contemporary theorists extended this early work on attachment to include physiological activity and coordination as an important element in the process of attachment formation (Field, 1985; 1996). Researchers used animal models to examine Bowlby's bi-phasic response to maternal separation (i.e., protest and despair) on the physiological level (Hofer, 1983; Kuhn, Pauk, & Schanberg, 1990; Laudenslager, Reite, & Harbeck, 1982; Reite & Snyder, 1982). Both of these phases were characterized by changes in not only externally observable behavior (e.g., distress vocalizations during agitation) but also physiology (e.g., increases in heart rate during agitation) in offspring. These early findings led researchers to theorize that while together, mothers and their infants provide “meaningful stimulation and arousal modulation” to one another and when separated this loss of stimulation and arousal modulation leads to disorganization in behavior and physiology (Field, 1978; 1996). This meaningful stimulation and arousal modulation is believed to promote behavioral and physiological concordance between mothers and their infants and in turn support secure attachment (Field, 1985).

In her Psychobiological Theory of Attachment, Field (1985) proposed that it is both behavioral coordination - the synchronization of behaviors between mother and child (Isabella & Belsky, 1991) – and physiological coordination that promote attachment security. Field suggested that during interactions mother-child pairs engage in coordinated ‘dances’ of behavior and physiology during which behavior of one member modulates the behavior and arousal of the other dyad member and that this multi-level coordination is important for establishing the attachment bond. A mother’s positive touch may elicit an infant’s smile, for example, and these behavioral exchanges may elicit physiological changes in both members (e.g., Feldman, Singer, & Zagoory, 2010).

More recently, Feldman, Magori-Cohen, Galili, Singer, and Louzoun (2011) also found a relation between behavioral coordination and physiological concordance. In this study, these researchers measured heart rate continuously in mothers and their infants (mean age three months) before and during a free-play interaction. They later coded this interaction for instances of behavioral synchrony. Specifically, researchers calculated the proportion of time mother and infant spent looking at each other and the proportion of time they matched positive affect and positive vocalizations. Using time-series analyses, these researchers found that coordination of heart rate was related to behavioral synchrony. Particularly, during times of vocal and affective synchrony, concordance of heart rate increased significantly.

Developmental Changes in concordance and Related Outcomes

Links between concordance and the mother-infant attachment bond suggest it to be a positive characteristic with anticipated positive outcomes for the dyad. Indeed, additional research has linked concordance to a number of positive outcomes including behavioral empathy in therapist-client dyads (Marci & Orr, 2006), positive parenting practices in mother-child dyads (van Bakel & Riksen-Walraven, 2008), and friendship strength in peer-peer dyads (Goldstein, Field, & Healy, 1989). Alternatively, physiological concordance may represent a negative characteristic, such as an inability of one dyad member to buffer a negative influence of the other dyad member. Additional research relates concordance to negative correlates such as poor maternal mental health (Laurent, Ablow, & Measelle, 2011), harsh/restrictive parenting (Hibel, Granger, Blair, & Cox, 2009), exposure to interparental aggression (Gordis, Margolin, Spies, Susman, & Granger, 2010) intimate partner violence (Hibel et al., 2009), marital dissatisfaction (Levenson & Gottman, 1983; Saxbe & Repetti, 2010), and shared negative affect (Papp, Pendry, & Adam, 2009), supporting the notion that it may represent a negative construct. One potential explanation for the striking difference in related constructs may be that concordance has different implications for different dyad types. Although systematic examination of different dyad types or age of child in mother-child dyads has yet to be completed, there is reason to believe that physiological concordance may serve different functions for different dyad types or across developmental periods.

Infancy and early childhood

In addition to promoting attachment, concordance in infancy may serve as a method for development of infant physiological regulatory skills (e.g., Feldman, 2007; 2009). Concordance in infancy has been found in many forms, including similarities in arousal states during co-sleeping (McKenna et al., 1994; McKenna et al., 1993). Feldman (2007, 2009) suggests that during close physical contact, children entrain their developing physiological rhythms (e.g., heart rate, respiration) to their mothers' rhythms. This entrainment may be particularly beneficial to young infants, and those born preterm, as these infants often have poor regulatory skills and underdeveloped neural structures (e.g., hippocampus; Knickmeyer et al., 2008) that support circadian and other biological rhythms. This idea of maternal influence on child biological rhythms, whether it be intentional or non-intentional, is supported by evidence in both the human and non-human animal literature that maternal presence and touch facilitate the development of rhythmic behavior and physiology in their offspring (e.g., Feldman, Weller, Sirota, & Eidelman, 2002; Hofer, 1994). This developmental pattern of maternal influence on regulation is also found in the emotion regulation literature. During infancy and early childhood, the emotion regulation process transitions from caregiver-directed to co-regulatory to child-directed (Calkins & Hill, 2007; Sroufe, 1997). Early in this process, mothers exert a strong influence on infant regulation (e.g., by soothing using physical touch) but as infants and toddlers begin to develop self-regulation skills, maternal influence wanes.

Middle childhood and adolescence

For dyads with older children or romantic relationship dyads, it may not be as beneficial for one dyad member to exert such an influence on the physiological activity of the other. In these cases, it may be more beneficial for dyad members to experience periods of both concordance and non-concordance to prevent contagion of maladaptive physiological activity/reactivity patterns such as heightened basal levels (e.g., Lorber, 2004), heightened reactivity (e.g., Matthews, Woodall, & Allen, 1993), or delayed recovery (e.g., Chida & Steptoe, 2010; Linden, Earle, Gerin, and Christenfeld, 1997). The middle childhood period is one characterized by transition, particularly in terms of mother-child attachment bonds, and thus may be a period of transition for the function and/or benefits of physiological concordance.

Middle childhood is a developmental period during which attachment bonds begin to undergo significant changes (see Kerns & Richardson, 2005). These changes are strongly associated with other developmental changes occurring during this time such as advances in emotional competence, perspective taking, and behavioral autonomy. Three primary changes include a) change in attachment-promoting behavior, b) shift in attachment promoting responsibility from parent to child, and c) transitions to attachment bonds with non-caregivers. These changes are described below.

As previously noted, in infancy and early childhood synchronous mother-child interactions are important experiences during which children develop trust and expectations for their mothers. This trust then leads to feelings of security and attachment (e.g., De Wolff & van IJzendoorn, 1997). These synchronous interactions are characterized by positive maternal affect, appropriately timed maternal touch, and mutual gaze (e.g., Isabella & Belsky, 1991). During middle childhood, however, positive mother-child interactions rely less on these micro-level coordinated behaviors. Instead, behaviors that convey security and comfort can be as subtle as a quick, mutually understood glance. Additionally, as children develop understanding of the world around them, situations or persons that constitute threat become less threatening leading attachment promoting behaviors (e.g., proximity seeking) to become in-frequent and less urgent (Bowlby, 69/82; Mayseless, 2005).

Relatedly, during this time the responsibility of engaging in attachment supporting behaviors shifts from primarily caregiver-directed to more mutually shared (Bowlby, 69/82; Mayseless, 2005). Whereas in infancy and early childhood offspring are dependent upon mothers for maintaining physical proximity and safety, in middle childhood children are able to better able to moderate their interactions with mothers and seek physical proximity when it's needed. Additionally, during this time physical proximity is not always needed to ensure security. A feeling of insecurity at a new friends' house, for example, may be soothed by a comforting call home. These behaviors can all be initiated by the child and s/he is able to modulate the amount and intensity of interactions needed.

Finally, an important shift in attachment during middle childhood is the addition of attachment (sometimes referred to as *affectional*) bonds with non-caregivers (Ainsworth, 1989, 1991; Weiss, 1991). During this time, relationships with peers become quite important. Similar to mother child relationships, peer relationships in middle childhood have been described as strengthened by reciprocity and mutual trust (e.g., Youniss, 1980). Additionally, these peer attachment bonds are characterized by proximity seeking, care and protection for one another, security during presence, and discomfort and grief during separation (e.g., Weiss, 1982). Thus, the focus on behaviors promoting mother-child attachment seen in infancy and early childhood wane as children begin to spend more time with peers (e.g., Berlin & Cassidy, 1999).

It is important to note that middle childhood is seen as a phase of transition and that mother-child attachment promoting behaviors seen in early childhood are not completely lost during this time. Early work by Maccoby (1992; Maccoby & Martin, 1983) and later work by

Kochanska (1997, 2002) identifies reciprocal, mutually guided interactions between a mother and her child as an important type of interactional coordination beyond infancy (i.e., mutually responsive orientation; Kochanska, 1997). The mutual responsiveness of such a relationship is characterized by willingness and sensitivity from both mother *and* child in providing appropriate responses to each other's needs, signals of distress, unhappiness, or attempts to exert influence (Kochanska, 1997; 2002). This mutuality is coupled with context-appropriate displays of shared positive affect – natural, genuine, positive emotions experienced by both dyad members. These positive, mutual interactions have been associated with positive developmental outcomes, including committed compliance and development of conscience (e.g., Kochanska & Murray, 2000). Specifically, children who experience these types of parent-child interactions are more willing to accept and internalize their parents' standards for behavior. In turn, children become more willing to do as their parents say and better able to regulate their behavior in the absence of parental control.

Few, if any, studies have examined physiological concordance in mother-child dyads specifically with children in middle childhood. In a study of mother-adolescent dyads, Papp and colleagues (2009) measured cortisol levels in mothers and their adolescents (15 years of age) across multiple days. As an indicator of attachment, adolescents reported their perceived level of attachment to their mother using the Inventory of Parent and Peer Attachment (IPPA; Armsden & Greenberg, 1987). Additionally, both mothers and adolescents reported positive and negative affect during collections of physiological samples. Concordance in cortisol levels were not related to attachment—as had been reported in younger samples—but was linked to moments of shared negative affect. Similarly, in a study of married couples, Saxbe and Repetti (2010) examined the extent to which similarities in cortisol levels were related to momentary reports of negative mood and overall reports of martial dissatisfaction. They found marital dissatisfaction to be positively related to similarities in cortisol levels; that is, greater dissatisfaction similarity was associated with greater physiological similarity. Additionally, couples who demonstrated similarities in cortisol levels also demonstrated similarities in negative mood. One plausible explanation for these findings is that marital satisfaction could be a protective factor guarding one spouse from another spouse's negative mood and heightened arousal. More specifically, perhaps spouses in satisfied marriages are protected from the negative influences of stress (and related heightened arousal) experienced by the other spouse.

Summary

It is possible that middle childhood may be a transition period during which the function and/or benefits of physiological concordance undergo change. This is not to say that there are no benefits of physiological concordance post-infancy. Instead, it may be that the type of concordance experienced or the context in which it is experienced plays a stronger role later in development. Unfortunately, the depth of knowledge on mother-child physiological concordance in middle and late childhood is shallow. Furthermore, current operationalizations of concordance are limited and statistical examination of the construct is discrepant (Bright, n.d.). Such discrepancies may lead to an inability to replicate or compare findings across studies, misinterpretation of findings, or overgeneralization of found patterns. Thus, the current paper aims to address these discrepancies, along with other methodological limitations, by suggesting two techniques for analyzing physiological concordance. First, existing operationalizations and related analyses are discussed. Then, two statistical techniques - dyadic indices and model-based cluster analyses - will be described in terms of their utility for assessing physiological similarity within dyads. The techniques will also be used to examine how concordance might be suggested as a ‘beneficial’ compared to ‘harmful’ construct based on the analyses used. To illustrate use of these techniques, a secondary analysis will be conducted on a dataset of mothers and their 8- to 11-year-old children. Finally, results using these methods will be compared and discussed in terms of their differences for identifying implications of the concordance process during middle childhood.

CHAPTER 2

LITERATURE REVIEW

The mix of findings regarding the benefits or harm of physiological concordance is clouded by the fact that researchers often use different operationalizations and statistical techniques - each of which measure a different way in which dyads can demonstrate concordance. To make comparisons across samples and to determine which types of concordance may be more or less beneficial than others, research on this construct would benefit from analytic methods that allow for examination of multiple types of concordance. Moreover, the relational nature of the construct warrants methods that focus on the dyad as the unit of analysis (e.g., Maguire, 1999). Developmental and family research often examines relational processes of mutuality, reciprocity, and synchrony, and as a result, this area has received a strong push from researchers to use dyad-oriented methods and analyses (e.g., Maquire, 1999; Whiteman & Loken 2006). These methods are likely applicable to the analysis of physiological concordance as well, and should be considered when identifying techniques for examination of this construct. Some of the ways in which researchers have focused on the dyad in behavioral research are described below.

Methods in Behavioral Research

Many researchers have used dyadic measurement in their behavioral coding schemes (e.g., Aksan & Kochanska, 2006; Minnesota Longitudinal Study of Parents and Children, 2005). In their work on mutually responsive orientation, for example, Aksan and Kochanska's (2006) examined behavior of a both parents and their young child as they interacted during snack time, playing with toys, and other routine activities. Researchers rated each interaction on a global scale, assigning a rating score for the entire interaction as opposed to counting the frequency of behavior. To capture the dyadic nature of these interactions, researchers coded for constructs that accounted for behavior from both individuals. One of the constructs comprising mutual responsive orientation - mutual cooperation – for example, was measured as the extent to which "parent and child are psychologically in tune with each other" or "parent and child adopt a receptive, willing stance toward each other's influence."

Another way researchers code dyadic behaviors is by using a time sampling technique (e.g., Belsky, Gilstrap, & Rovine, 1984; Belsky, Taylor, & Rovine, 1984). Using this technique, researchers break down large periods of continuous interaction into smaller blocks of time (generally every 10 seconds). For each block researchers use contingency tables to assess the probability of a behavior from one dyad member to precede or follow behavior of the other dyad member. In a study of parent-infant dyads, for example Belsky and colleagues (1984) used this technique to determine the likelihood of both individual (e.g., "infant fuss or cry") and dyadic behaviors (e.g., "mother smiles at, kisses, or hugs baby") during mother-infant interactions. Time series and cross-spectral analyses are other useful methods for examining how activity is coordinated in time (e.g., Gottman, 1981; Mcleary & Hay, 1980). To use these techniques, researchers plot each dyad member's activity over time. From this plot, researchers can determine oscillations (i.e., changes over time) in activity for each dyad member and then compare these oscillations between dyad members. Researchers can, for example determine if dyad members demonstrate increases or decreases at the same time, if dyad members spend similar amounts of time in the same level or state, and if dyad members show similar rates of change in activity. Researchers can also determine the likelihood of change in one dyad member given change in another member as well as how these related changes are coordinated in time. This element may be critical in determining which dyad member (if either) consistently demonstrates changes before the other dyad member. That is, this element will allow researchers to investigate which dyad member may be "leading" the relational process. In their work, Field and colleagues (Field, Healy & LeBlanc, 1989; Field, Healy, Goldstein & Guthertz, 1990) have used second by second behavioral coding to measure amount of time mother-infant dyads spend in similar states as well as cross-spectral analyses to measure coherence in heart rate for mother-infant dyads. These methods are useful for examination of moment to moment or real-time coordination but not for global measures of concordance. With regard to physiological concordance, this technique would require relatively high numbers of repeated samples that is best achieved with physiological data collected continuously (e.g., continuous heart rate).

In addition to a dyadic focus at the measurement level, many developmental and family researchers use statistical analysis techniques specific to dyadic data (e.g., Baumrind, 1991; Gonzalez & Griffin, 1997; McGuire, McHale, & Updegraff, 1996). These techniques allow for comparisons among dyads or groups and, within these comparisons, account for statistical interdependence among datasets. Interdependence refers to the fact that data from participants within the sample are related to data from other participants within that sample (Card, Selig, & Little, 2008; Gonzalez & Griffin, 2000; Kenny, Kashy, & Cook, 2006) – a phenomenon inherent in relationship-focused research. In this type of research, behavior of one individual is seen as a function of that individual, of their partner, and of the relationship between them (Social Relations Model; Kenny, 1994; Kenny & La Voie, 1984). In the context of physiological concordance in a mother-child dyad, for example, physiological activity of a child is a function of characteristics of that child, his/her mother, and of the mother-child relationship. Dyadic relationships can be examined in terms of a) how dyad members react to a shared experience or b) how dyad members influence each other (Kenny et al., 2006). Some of the recommended statistical techniques for assessing similarity include dyadic indices (e.g., intraclass correlations), repeated measures analysis of variance, and hierarchical linear modeling (e.g., Maquire, 1999).

Other researchers have suggested pattern analytic approaches (e.g., *a priori* methods, mixture models) for identifying group differences in dyadic patterns (Whiteman & Loken, 2006). These approaches allow researchers to determine profiles within their sample based on characteristics from each dyad member. Researchers have used this technique, for example, to determine mother-infant relationship profiles based on both maternal and infant characteristics (e.g., Fish & Stifter, 1995; Fish, Stifter, & Belsky, 1993). This simultaneous consideration of multiple relational characteristics from both dyad members is a strong advantage of this method. To illustrate cluster analysis as a technique for identifying dyadic profiles, Whiteman and Loken (2006) examined sibling relationships based on levels of intimacy and negativity reported by each sibling. The cluster analysis revealed two relationship profiles; "harmonious" relationships were characterized by above average intimacy and below average negativity reported by both siblings, "conflictual" relationships were characterized by above average negativity and below average intimacy.

These approaches provide the foundation for understanding and measuring dyadic phenomena including both observable behavior and non-observable (i.e., physiological) responses. In the next sections, current operationalizations and techniques for measurement of physiological concordance are described. Then, based on limitations of these techniques, two statistical approaches previously used in behavioral research are described in terms of their utility for examining physiological concordance.

Operationalizations and Methods in Physiological Concordance Research

In the extant literature, particularly in the mother-child literature, findings of physiological concordance are typically reported as ancillary results and *a priori* operational definitions are limited. Thus, three definitions for demonstrating concordance described below are derived from interpretations of reported results. These definitions are not mutually exclusive; that is, dyads may demonstrate concordance using more than one criterion although researchers typically examine only one criterion for exhibiting concordance. Additionally, statistical analyses of concordance are generally packaged within larger, more complex analyses plans and thus are rarely justified or intended for examination of concordance specifically. Drawing from these operationalizations, as well as work by behavioral concordance researchers (e.g., Stern, 1985), the process of physiological concordance is defined in this paper as *a process by which two related individuals are coordinated in their physiological activity.*

Current operationalizations of physiological concordance

Similarity in physiological level. The first and most parsimonious definition of concordance is a demonstration of similarities in physiological activity. This definition is typically used to examine non-stimulus driven changes such as similarity in single sample levels, mean levels, total output, or rhythms of a physiological marker of interest. In a study of cortisol, for example, researchers compared three samples of diurnal cortisol levels (morning, afternoon, evening) between infants and their parents (Stenius, Theorell, Lilja, Schqynius, Alm, & Lindblad, 2008). They found positive relations between each dyad at all sample collection times, with stronger relations between mothers and infants than between fathers and infants. Strengths of this operationalization are that it is relatively simple to understand and that it can be used to examine non-stimulus driven changes (e.g., circadian fluctuations). A limitation is that although researchers may compare degree of change, they fail to consider direction of change. That is, using this definition, dyad members may demonstrate similar rates of change but in opposite directions and still be labeled as demonstrating concordance. Consider, for example, a dyad where both members demonstrate high (and similar) levels of heart rate change following a task but one dyad member demonstrates an increase in heart rate and the other demonstrates a decrease in heart rate. The implications for these changes may be different for each dyad member. Acute decreases in heart rate are associated with, among other factors, attention and focus (e.g., Ohman, Hamm, & Hugdahl, 2000; Richards, 2008) whereas increases in heart rate are associated with heightened arousal and psychological stress (e.g., Brownley, Hurwitz, & Schneiderman, 2000). Thus, it may not be accurate to describe such a dyad as experiencing similarity or concordance in physiology.

Similarity in direction or rate of physiological change. A second definition characterizes concordance as similarity in direction and degree or rate of change in physiological activity. This criterion is typically used to examine stimulus-driven changes (e.g., differences in pre- and post-task scores) but can also be used to measure non stimulus-driven changes such as circadian changes throughout the day. Researchers may describe concordance as the presence or absence of similarity in direction of change, that is, either dyads change in the same direction or they don't. Additionally, concordance may be operationalized on a continuum with some dyads demonstrating greater similarity in degree of change than others. In a study of cortisol reactivity change, for example, researchers examined the relation between maternal and infant basal levels and rates of change across task (Hibel et al., 2009). In another study of cortisol levels, researchers examined the relation between maternal and child change scores across a challenging task. Using bivariate correlations they found the relation between change scores to be positive, indicating a degree of concordance, but only for dyads that included sensitive mothers (Sethre-Hofstad, Stansbury, & Rice, 2002). In this study, sensitivity was operationalized as a mother being aware of her child's communication cues, correctly interpreting and showing empathy toward her child's emotions (as adapted from Ainsworth et al., 1978). A strength of this definition is that it considers the dynamic nature of physiology. That is, concordance is a process of change and cannot be captured with measures at a single point in time. A limitation of this definition, however, is that they fail to consider variability of activity across time. That is, it is important to consider how dyads' degree of similarity changes over time. A dyad may, for example, demonstrate high levels of similarity across all physiological sample collections during an interaction (low variability). In contrast, a dyad may show high levels of similarity during some sample collections and low levels of similarity during other sample collections (high variability). This variability index may be important in capturing profiles of dyads - perhaps physiological concordance is not a stable characteristic for some dyads.

Decrease in the difference of physiological activity. A third definition operationalizes concordance as a decrease in the difference of physiological activity over time. Using this model, researchers might compare differences in mother and child scores at multiple time points and then examine changes in this difference score over time. In a study of cortisol, for example, researchers assessed cortisol levels in mothers and their newborn infants before (time one) and 60 minutes after (time two) initiating holding (Neu et al., 2008). Researchers then calculated differences between mothers and their infants at both time points. A decrease in this difference is considered concordance and in this sample, the greatest decrease in difference was identified as the greatest level of concordance in that sample. Similar to the second operationalization, this definition considers change over time as an important element in identifying concordance. In fact, when examining physiological systems where greater discordance than concordance is expected (explained further in the next section), this operationalization may be most appropriate. Limitations of this operationalization, however, are that it doesn't allow for examination of overall similarities as in the first operationalization nor does it address similarities in pattern of change. It is possible, for example, for a dyad to demonstrate change in the same direction at the same rate and thus demonstrate no decrease in difference over time. In this case, that dyad did demonstrate similarity in one element of concordance but not another and as a result of using this model, would be considered to not demonstrate concordance.

Statistical analyses for the evaluation of physiological concordance

As previously noted, there is no current "gold standard" statistical technique for evaluating concordance. This is likely related to the fact that there is no consensus on the definition of concordance and as a result analysis techniques vary by operational definition. Because choice of technique is generally based on sample parameters, and sample size has varied from 9 dyads with an average of 25 samples of physiological data (e.g., Berg & Wynne-Edwards, 2002) to 702 dyads with 3 samples of physiological data (e.g., Hibel et al., 2009), current techniques utilized vary from bivariate correlations to regression to multi-level modeling (see Table 1). Use of the bivariate correlation yields three possible outcomes. One outcome is characterized by increases in one dyad member associated with increases in the other dyad member (positive relation). A second outcome is characterized by increases in one dyad member associated with decreases in the other dyad member (negative relation). A final outcome is characterized by changes in one dyad member not associated with changes in the other dyad member (no relation). This statistical method is helpful when researchers are interested in a "big-picture" idea of the degree of similarity between groups of related individuals. Upon closer inspection, however, it is evident that this method does not just identify states of concordance. Namely, a negative relation outcome seems to characterize something other than concordance. That is, if groups are demonstrating similar levels but different patterns of change, is that really concordance? Additionally, these group-level analyses yield only a single measure of similarity meant to represent the concordance of all mothers and children. Use of this type of measure suggests that all dyads are expected to demonstrate the same degree and type of concordance and fails to account for the possibility for dyadic differences. That is, it may be that all dyads demonstrate similarity but that the type of similarity differs between dyads – some dyads may demonstrate similar high levels of activity/reactivity whereas others may demonstrate similar low levels of activity/reactivity. Related, but less commonly used, analyses include repeated measures analyses to assess a decrease in difference between dyad members over time (Neu, Laudenslager, & Robinson, 2009) and regression analyses predicting maternal scores from child scores or vice versa (van Bakel et al., 2008). Similar to bivariate correlations, these analyses are often computed at the group-level and yield results only about groups of related individuals.

An extension of the simple regression, hierarchical linear modeling (HLM), has also been used to test the predictive value of one dyad member's physiology on the other member's physiology while nesting samplings within individuals and individuals within dyads (e.g., Cohan, Booth, & Granger, 2003; Powers, Pietromonaco, Gunlicks, & Sayer, 2006; Saxbe & Repetti, 2010). In their study of mother-adolescent dyads and diurnal cortisol levels, for example, Papp and colleagues used HLM to predict adolescent cortisol levels from mother cortisol levels while nesting sample time (14 total) within individual and individual (mother, adolescent) within dyad (Papp et al., 2010). Analyses revealed a significant relation between mother and adolescent at each time period, even after controlling for diurnal variations in cortisol throughout the day. HLM has clear advantages for evaluating concordance. One advantage is that it allows for repeated measure nested relationships such as multiple sampling points from related individuals. It also allows for prediction of one dyad member's physiology (e.g., member #1) from both time-varying (e.g., member #2 physiology) and time constrained (e.g., moderators such as relationship quality) variables. Missing data from each dyad member is also permissible, even if the time points for which data is missing differs for dyad members. Finally, HLM allows time between sampling collections to vary (see Raudenbush, Brennan, & Barnett, 1995). A potential limitation of using HLM is the required sample size. Although there is no published "rule of thumb" for the appropriate sample size, for reasons of statistical power analyses will benefit from greater number of dyads and greater within-individual samplings. Current research using HLM to examine physiological concordance includes sample sizes ranging from 30 dyads with 12 samples of physiological data to 124 dyads with 7 samples of physiological data.

Other research groups have utilized structural equation modeling (SEM) when examining concordance. In a large scale study of family relationships (Booth et al., 2003), for example, researchers operationalized concordance as a family-level latent construct. In this study, cortisol levels were assessed on multiple days from four members (mother, father, two children) of 400 families. After finding cortisol levels to be positively related within all dyads, researchers used structural equation modeling (SEM) to examine the extent to which each family member, modeled as manifest variables, contributed to a "family-level" cortisol latent variable. Analyses revealed significant contributions from each family member. Additionally, researchers examined factors associated with differences in family level and found high levels of family conflict to be associated with high levels of "family-level" cortisol levels. This multi-level modeling approach has its clear advantages with the ability to examine the relations between multiple variables at different levels. Additionally, an improvement over the previously described bivariate correlation is that it can be used to examine both similarity in level (often examined as similarity in intercept) and change (slope) over time. A disadvantage of this method, however, is that some types of multi-level modeling require a relatively large sample size (e.g., recommendations made for at least 200 cases when using SEM; Barrett, 2007). Because measurement of physiological processes can be costly, large sample sizes or high repeated measures sampling are often not possible.

Table 1.
Description of papers examining physiological concordance

Dyad type	Sample	Orientation	Analyses	Citation
Mother-infant	*N* = 152 dyads	VO	Bivariate correlation comparing baseline RSA and HP during interaction.	Moore et al., 2009
Mother-infant	*N* = 16 dyads	VO	Time-series spectral analysis comparing HR cyclicity during interaction.	Field et al., 1989
Mother-infant	*N* = 40 dyads	PO	Time-domain time-series analysis comparing heart rhythms during interaction.	Feldman et al., 2011
Mother-infant	*N* = 35 dyads	PO	Spearman correlation coefficients comparing HR levels during task.	Zelenko et al., 2005
Mother-infant	*N* = 702 dyads	PO	Bivariate correlation comparing pre-task and reactivity scores. Latent growth curve modeling comparing intercepts (baseline) and slopes (change) of cortisol levels across task.	Hibel et al., 2009
Mother-infant	*N* = 20 dyads	PO, VO	Paired-samples *t*-test comparing change in difference between cortisol levels over time.	Neu et al., 2008
Mother-infant	*N* = 25 dyads	VO	Bivariate correlation comparing mean cortisol levels.	Spangler, 1991
Mother-infant	*N* = 63 dyads	VO	Bivariate correlation comparing baseline and change in cortisol levels.	Thompson et al., 2008
Mother-infant	*N* = 32 dyads	VO,PO	Spearman's *rho* correlation comparing waking and post-waking as well as diurnal change in cortisol levels. Intra-class correlation coefficient comparing diurnal variation of cortisol.	Bright et al., 2011

Mother-infant	*N* = 53 dyads	VO	Bivariate correlation comparing baseline cortisol levels.	Feldman et al., 2010
Mother-toddler	*N* = 86 dyads	VO	Regression predicting child cortisol levels from parent levels.	Laurent et al., 2011
Mother-child	*N* = 24 dyads	VO	Bivariate correlation comparing LF/HF heart rate ratio.	Arai et al., 2009
Mother-child	*N* = 64 dyads	VO	Pearson partial correlation comparing change in cortisol levels.	Sethre-Hofstad et al., 2002
Mother-child[a]	*N* = 83 dyads	VO	Regression predicting child change in cortisol levels from parent change levels.	vanBakel et al., 2008
Mother-child	*N* = 62 dyads	VO	Bivariate correlation comparing pre- and post-task cortisol levels.	Granger et al., 1998
Mother-adolescent	*N* = 45 dyads	PO, VO	HLM assessing within individual change and similarity across dyads in cortisol levels.	Papp et al., 2009
Mother-infant, Father-infant	*N* = 51 dyads	PO/VO[c]	Bivariate correlation comparing morning, afternoon, and evening as well as diurnal change in cortisol levels.	Stenius et al., 2008
Mother-child, Father-child, Sibling-sibling	Multiple samples	PO	Intra-class correlation comparing cortisol levels.	Schreiber et al., 2006
Mother-adolescent, Father-adolescent	*N* = 62 triads	VO	Zero order and partial correlation coefficients comparing sAA levels pre-task baseline, post-task, and total output.	Gordis et al., 2010
Friend-friend (toddlers/ preschoolers)	*N* = 40[b]	PO	ANOVA comparing within-group variance in heart rate and cortisol levels.	Goldstein et al., 1989
Girlfriend-boyfriend	*N* = 124 dyads	PO	HLM assessing change within individuals and similarity across dyads in cortisol levels.	Powers et al., 2006
Wife-husband (newlyweds)	*N* = 92 dyads	PO	HLM assessing change within individuals and similarity across dyads in testosterone levels.	Cohan et al., 2003
Wife-husband	*N* = 30 dyads	PO	HLM assessing change within individuals and similarity across dyads in cortisol levels.	Saxbe et al., 2010

Wife-husband	*N* = 30 dyads	PO	Bivariate time series comparing heart rate, pulse transmission time, skin conductance, and general somatic activity during interaction.	Levenson et al., 1983
Mother- father	*N* = 9 dyads	PO	Bivariate correlation comparing testosterone, cortisol, and estradiol levels during pregnancy and after birth.	Berg et al., 2002

[a]Sample included 2 father-child dyads
[b]Multiple dyads tested within pre-determined sociogram.
[c]Researchers imply person-oriented analyses but results suggest variable oriented.
Note: PO = Person-oriented, VO = variable-oriented, HR = Heart rate, HP = Heart period, RSA = Respiratory sinus arrhythmia, HLM = Hierarchical linear modeling.

Recommendations and Proposed Statistical Analyses

Current statistical techniques for examining concordance would benefit from additional approaches that allow for examination of multiple types of concordance. As noted above, researchers have operationalized a few ways in which dyads can demonstrate physiological concordance: similarity in overall level, similarity in patterns of change, and a decrease in difference of level. Dyads can also demonstrate concordance in their variability across time (described in the next section), although this type of similarity has not yet been explicitly examined in the physiological concordance literature. A preferred statistical technique that accounts for multiple types of concordance would allow for examination of what elements or ‘types’ of concordance are beneficial or harmful for the dyad. Perhaps, for example, it is not as harmful for dyad members to demonstrate similar change in heart rate but it is problematic for them to demonstrate similar overall heart rate levels. One technique, dyadic indices, has been used to examine multiple types of dyadic concordance in behavior (e.g., Harvey, 2000; Wakimoto & Fujihara, 2004) and thus will likely serve as a useful tool in the examination of physiological concordance.

Physiological concordance literature would also benefit from a pattern analytic approach similar to those used in behavioral research (e.g., Baumrind, 1991; Whiteman & Loken, 2006).

Recall that these techniques (e.g., cluster analysis, mixture models) allow for examination of dyadic profiles within a sample. Perhaps, for example, all dyads demonstrate similarity in heart rate level but some exhibit similar high levels of change and others exhibit similar low levels of change. Depending on the physiological marker of interest, mutual heightened reactivity may lead to different outcomes, or stem from different precursors than mutual flattened reactivity. High levels of cardiovascular reactivity in children, for example, are associated with elevations in blood pressure throughout development (see Mathews et al., 1993), carotid atherosclerosis in adulthood (see Kamarck, Everson, Kaplan, Manuck, Jennings, Salonen, & Salonen, 1997), as well as aggression, internalizing symptoms, and conduct problems (Lorber, 2004). In adults, high levels of reactivity are also associated with poor health outcomes including borderline and essential hypertension (Fredrikson & Matthews, 1990). Thus, in a case of mutual heightened reactivity it may be that concordance is associated with negative outcomes because of the nature of the shared physiology and not the mere presence or degree of similarity.

To test the utility of these approaches in examining physiological concordance, two statistical techniques were chosen. First, dyadic indices were chosen to identify multiple elements of physiological concordance. Second, cluster analysis was chosen to identify dyadic profiles of physiological concordance. These techniques are described further below.

Proposed techniques

Dyadic indices. Dyadic indices have been described by Kenny and colleagues (2006; Kashy & Kenny, 2000) as techniques to examine how dyad members react to a shared experience. There are six common dyadic indices to be used when direction of influence between dyad members cannot be determined. Determining which index to use is based on a) whether dyads are expected to demonstrate similarity or dissimilarity, and b) how dyads are expected to demonstrate similarity or dissimilarity.

The choice of similarity or dissimilarity is based on theory and should correspond with the hypotheses to be tested. That is, if dyads are expected to show greater discordance than concordance in physiology, then measures of dissimilarity (e.g., discrepancy, distance, absolute value of difference) are most appropriate. In the previously described studies of cortisol levels during holding, for example, researchers operationalized concordance as a decrease in the difference between parents and children over time (Neu et al., 2008). Thus, measures of dissimilarity were most appropriate. Conversely, if dyads are expected to show greater concordance than discordance in physiology, then measures of similarity (e.g., bivariate correlation, intraclass correlation) are most appropriate.

Dyads may demonstrate three non-mutually exclusive types of coordination: similarity/dissimilarity in a) overall mean or output, b) direction or pattern of change, or c) variability across time (e.g., Cronbach & Gleser, 1953). In relation to dyadic indices, these types of coordination are described as measures of level, shape, and spread, respectively.[1] These three types of similarity/dissimilarity are illustrated using hypothetical data from one individual (Figure 1). In this figure, heart rate was measured five times as indicated by the solid black line. For this individual, their mean heart rate (level) over these five samples was 67.00 beats per minute (bpm). The standard deviation of this heart rate (spread) was 2.00 bpm. Finally, this individual demonstrated periods of increase and decrease with the lowest drop in heart rate at the fourth sample (shape).

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[1] Other terminology used for level includes elevation; other terms used for spread include scatter (Furr, 2010).

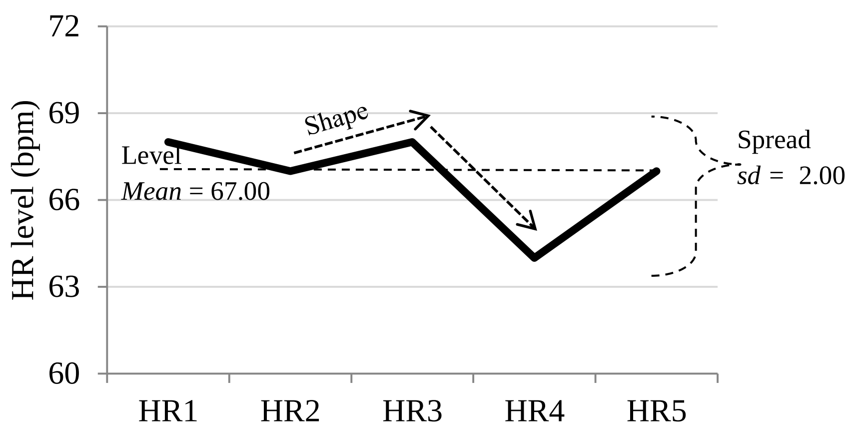

Figure 1. Illustration of three types of similarity in physiological concordance: level, shape, and spread. Adapted from Figure 2 in Furr (2010).

Choice of index is also dependent upon the primary type of similarity/dissimilarity of interest. Some indices can be used to examine multiple types of coordination whereas others are useful for only one type (Kenny et al., 2006). In a recent review, Furr (2010) recommends that multiple indices are necessary to effectively test for multiple types of similarity. That is, no single index is most appropriate if the researcher is interested in all three types of similarity/dissimilarity: level, shape, and spread. Following these recommendations by Furr (2010), three indices were chosen for measurement of each type of similarity/dissimilarity. First, an absolute difference score as a measure of dissimilarity in level was chosen. This index is computed as the sum absolute difference of each sample point divided by the number of samples or the absolute difference of the mean levels of physiological activity for each dyad member (Furr, 2010; Kenny et al., 2006). Second, bivariate correlations were selected (Pearson's *r*) for the measurement of similarity in shape. Third, an absolute difference score as a measure of dissimilarity in spread was chosen. Similar to the index for level, this is computed as the absolute difference of the variance in physiological activity for each dyad member. Choosing three indices as opposed to one will also allow for examination of how each type of concordance relates to outcomes differently. That is, perhaps similarities in peaks and lows of heart rate (shape) between dyad members relate to relational outcomes differently than similarities in mean heart rate levels (level). These indices and their formulas (adapted for application to physiological concordance) are outlined in Table 2.

Table 2. *Adapted equations for computing dyadic indices of physiological concordance.*

Type of Similarity	Measurement	Adapted Equation
Shape	Correlation (Pearson's *r*)	$r = \frac{N\Sigma_{mc} - (\Sigma_m)(\Sigma_c)}{\sqrt{[N\Sigma_{m^2} - (\Sigma_m)^2][N\Sigma_{c^2} - (\Sigma_c)^2]}}$
Spread *(scatter, variance)*	Absolute difference of variance	$d = \lvert\sigma_m^2 - \sigma_c^2\rvert$
Level *(elevation, mean)*	Absolute difference of mean	$d = \lvert\bar{x}_m - \bar{x}_c\rvert$

Note: m = mother, c = child, N = # of physiological samples

A strong advantage of dyadic indices over previously described methods is the ability to compute with limited sample size (Kenny et al., 2006). With dyadic indices, sample size refers to the number of physiological samples collected, not participants. Indices of dissimilarity, for example, can be computed with only one physiological sample data point. It is important to consider, however, the theoretical implications of suggesting presence/absence of concordance – a dynamic construct by nature - with only one sample. Although simulation studies are needed to support a 'rule of thumb' for required sample size, Kenny and colleagues suggest researchers use no less than four and ideally at least eight sample points. Additionally, dyadic indices – particularly those described here – are relatively intuitive and easy to use. Finally, using multiple indices allows for examination of multiple types of concordance, an important feature when trying to determine what types of concordance may be more or less beneficial than others.

Model-based cluster analyses. Model-based cluster analysis was chosen to examine profiles of dyadic concordance. Model-based cluster analysis is an inferential statistical technique for identifying “types” or subgroups within a sample (Hicks, Vaidyanathan, & Patrick, 2010). This technique identifies these types based on patterns of variables. Clustering solutions are determined by examining the fit statistic (BIC) and certainty of cluster assignments. Better fit is indicated by greater BIC indices and greater differences between indices of different models with differences of 0-2, 2-6, and 6-10 indicating weak, positive, and strong evidence of fit, respectively. Certainty of cluster assignment is then examined based on the posterior probability of cluster assignment for each participant.

A benefit of this technique over other clustering techniques is that the number of clustering solutions are determined by the distribution of the variables entered and thus do not need to be specified by researchers in advance. This element is particularly helpful in research areas such as physiological concordance where exploration of types is relatively uncharted. Additionally, model-based clustering allows for simultaneous comparison of multiple clustering solutions and tests the validity of these clusters using a goodness-of-fit statistic (Bayesian Information Criterion [BIC], Raftery, 1995). Finally, this technique can be used with relatively small sample sizes (currently reported as low as n = 36; Mun, von Eye, Bates, & Vaschillo, 2008) as long as the identified clusters are approximately equal in size (e.g., Lo et al., 2001).

Brief Background of Dataset and Variables

Data for this paper originate from a study that examined a number of elements within the mother-child relationship including child behavior, parenting practices, and relationship quality.

Of interest in this paper was the examination of observed characteristics of the dyadic relationship: dyadic cooperation, shared positive affect, conflict resolution ability, and overall relationship quality (described further in the method section). These relationship characteristics represent the dyadic, bi-directional nature of the mother-child relationship and were chosen based on previous reports of relations between concordance and similar dyadic constructs such as attachment security (Zelenko, 2005), relationship (marital) dissatisfaction (Saxbe & Repetti, 2010), behavioral coordination (Feldman et al., 2010), and shared negative affect (Papp et al., 2009). As physiological concordance has been previously operationalized as one component of an overall process of 'reciprocal interchange between partners' (Saxbe & Repetti, 2010), relations are expected between variables that represent this interchange on both physiological and behavioral levels. The proposed statistical techniques – dyadic indices and model based cluster analysis - will be used to address the following research questions and aims.

Research Questions, Aims, and Hypotheses

Question I: What are person-oriented approaches to examining multiple elements of the physiological concordance process using a small sample size?

Aim I: Demonstrate methods for examining physiological concordance using two person-oriented techniques that allow for examination of multiple characteristics of the concordance process.

a. Describe the process of computing each technique and subsequent indices produced.

b. Discuss and test assumptions of the each technique.

c. Identify characteristics of the concordance process (based on previously described criteria) for each index and their implications for understanding concordance.

Question II: Do the relations between concordance and outcome variables vary based on how concordance is measured?

Aim II: Compare how each measurement technique reveals relations between concordance and relationship characteristics (measured through behavioral observations of cooperation, shared positive affect, conflict resolution ability, and overall relationship quality).

Hypothesis I. Techniques for measurement of concordance will reveal different relations between concordance and mother-child relationship characteristics thus implying different implications of concordance. Because the existing literature is mixed with regard to the relations between concordance and ‘positive’ versus ‘negative’ constructs, the proposed analyses are exploratory in nature. If concordance (as indicated by dyadic indices and a clustering solution of these dyadic indices) is negatively associated with behavioral observations of positive relationship indicators of cooperation, conflict resolution, shared positive affect, and overall relationship quality, then these relations would support previous findings of concordance as a negative relationship characteristic. If, however, concordance is positively associated with behavioral observations of cooperation, conflict resolution, shared positive affect, and overall relationship quality, then these relations would support previous findings of concordance as a positive relationship characteristic.

It is expected that the model-based clustering using average reactivity, however, will reveal that only certain types of concordance relate positively to measures to dyadic relationship characteristics. Because the clustering solution is determined by the data (and not predetermined by the researcher), specific clusters of shared reactivity are unknown. It is expected, however, that the clustering solution will yield distinct clusters of either concordance or discordance. That is, dyads will either show concordant high reactivity, concordant low reactivity, or discordant reactivity (i.e., mother and child show opposite patterns of reactivity). It is expected that dyads characterized by concordant high reactivity will experience fewer positive outcomes (i.e., lower shared positive affect, cooperation, conflict resolution ability, and overall relationship quality) than dyads characterized by concordant low reactivity.

CHAPTER 3

METHOD

Participants

Sixty-four mother-child dyads participated in this study. All children (38 males) were between the ages of eight and eleven years (*M* = 9.45, *SD* = 1.04). Mothers were between the ages of 25 and 59 years (*M* = 37.27, *SD* = 8.32). Of the adult participants, 92% identified themselves as the participating child's biological mother, 2% as a stepmother, and 6% reported their relationship to the child as "other" (grandmother). All adult participants reported acting as a primary caregiver to the child and all are referred to in the current paper as mothers. Most mothers identified themselves as Caucasian (45%) or African-American (50%), the remaining mothers identified themselves as Hispanic or other. Fifty-eight percent of mothers reported completing at least some college and an additional 38% reported a high school or equivalent education. Nearly half the sample (47%) reported household incomes of less than $20,000 per year while 30% reported household incomes at or above $50,000 per year.

Recruitment and Screening

Participants were recruited through flyers displayed in the community. During a telephone screening, mothers verified that their child was between eight and eleven years of age, that both she and the child were fluent in English, and that the child had lived with her for at least the past two years. During the laboratory visit, mothers provided written informed consent and children provided written assent. All families received $40 for their time and each child received a small toy. All procedures were approved by the University Institutional Review Board.

Procedure and Measures

As part of a larger study protocol, mother-child dyads participated in four four-minute interaction tasks intended to mimic common daily activities: imaginary happenings, conflict discussion, etch-a-sketch, and logic puzzle. During the imaginary happening task, dyads predicted what their neighborhood might be like 50 years in the future. During the conflict discussion, dyads discussed a mutually decided topic of disagreement. During the etch-a-sketch task, dyads worked together to create an image of a house using an Etch-a-Sketch™. During the logic puzzle task, dyads worked together to solve a homework-like activity sheet. Interactions were video-recorded and coded later for child and parent behavior.

Physiological measures. Before and after each of the four tasks (for a total of five measures), heart rate was measured from both mothers and their children. Discrete measures of cardiovascular functioning were collected using an Omron HEM-907 sphygmomanometer, an inflatable cuff that is worn on the upper arm. Mothers wore standard-sized cuffs; children wore smaller cuffs made specifically for children. Baseline scores were computed from an average of three measures taken before beginning tasks. Reactivity scores were computed for each task by subtracting that baseline score from the post-task measure. Because neither mothers $F(3, 50)$, = .65, $p = .59$, nor children $F(3, 38)$, = 1.36, $p = .27$ demonstrated differences in their reactivity across tasks, pulse reactivity from all tasks were averaged. The absolute value of this mean was then computed to indicate a deviation from baseline regardless of direction. These analyses were conducted for mothers and children separately. In summary, the cardiovascular scores of interest in this study included baseline and each post-task score (to be used in indices of concordance) and average reactivity.

Heart rate data was used to compute concordance in level, shape, and spread. Concordance in level was computed using absolute difference of mean heart rate (between mother and child). Concordance in spread was computed using absolute difference of variability. Concordance in shape was computed using a Pearson's r bivariate correlation. Computation of these indices are described further in the results section.

Behavioral observation measures. Behavioral observation measures were used to make comparisons between outcomes of each analysis technique. Behavioral observations were coded using the scales described below. Scales were developed for the current study and adapted from previously developed observational codes (Minnesota Longitudinal Study of Parents and Children, 2005). A team of trained researchers coded all behaviors. Observations were coded and conferenced for agreement by at least two raters. Using 53% of the sample, intra-class correlations were computed as measures of inter-rater reliability; correlation coefficients are reported below.

Dyadic conflict resolution. This scale assessed a dyad's ability to reach a resolution during the conflict discussion task. Resolution was coded on a seven point likert-type scale (from 1 – low/no satisfaction, to 7 – high satisfaction) such that dyads scoring high on this scale exhibited high levels of resolution whereas dyads scoring low on this scale exhibited low levels of resolution. Indicators of resolution/satisfaction included understanding, sensitivity, and open communication. Reliability for this scale was .85.

Dyadic collaboration/cooperation. This scale assessed a dyad's overall level of cooperation in completing tasks. Cooperation was coded on a bi-polar scale (from -3 – very low collaboration, to 3 – highly collaborative) such that dyads scoring high on this scale exhibited high levels of cooperation whereas dyads scoring low on this scale exhibited low levels of cooperation and high levels of opposition. Indicators of cooperation included striving for mutual understanding, positive responses to ideas, and a lack of opposition. Reliability for this scale was .78.

Dyadic shared positive affect. This scale assessed a dyad's overall level of shared positive affect. Shared positive affect was coded on a seven point likert-type scale (from 1 – very low, to 7 – very high) such that dyads scoring high on this scale exhibited high levels of shared positive affect whereas dyads scoring low on this scale exhibited low levels of shared positive affect. Indicators of positive affect included well-coordinated instances of mutual smiling or laughter. Reliability for this scale was .93.

Overall relationship quality. This scale assessed a dyad's overall relationship quality. Relationship quality was coded on a seven point bi-polar scale (from 1 – very negative, to 7 – very positive) such that dyads scoring high on this scale exhibited high levels of positive relationship quality whereas dyads scoring low on this scale exhibited high levels of negative relationship quality. Indicators of positive relationship quality included positive interactions and engagement/attachment. Indicators of negative relationship quality included detachment, hostility, rejection, or indifference. Reliability for this scale was .87.

CHAPTER 4

RESULTS

Analytic Plan

To demonstrate methods for examining physiological concordance (Aim I), the process of computing dyadic indices using three dyadic coefficients (Pearson's *r*, absolute difference of mean, absolute difference of variance) and two model-based cluster analyses (one using three dyadic indices and one using average heart rate reactivity) are described. The assumptions for each technique are then tested and discussed, and descriptive statistics are computed.

To compare how each measurement technique reveals relations between concordance and behavioral observations of emotion-related relationship characteristics (Aim II), bivariate correlations relating dyadic indices of concordance to behavioral observations of cooperation, shared positive affect, conflict resolution ability, and overall relationship quality are computed. For model-based clusters, independent-samples *t*-test are computed to assess how clusters of concordance differ in their relation to behavioral observations of cooperation, shared positive affect, conflict resolution ability, and overall relationship quality.

Primary Analyses

Aim I: Demonstrate methods for examining physiological concordance.

Dyadic indices. Three dyadic indices were computed to assess concordance in level, shape, and spread. Concordance in level was computed as the absolute difference of mother and child mean heart rate. Concordance in shape was computed using a bivariate correlation of mother and child heart rate. Concordance in spread was computed as the absolute difference of mother and child standard deviation of heart rate.

An example of how dyadic indices were computed is provided in Table 3. In this table, heart rate data from each of the four tasks (and a baseline measure) from the mother and child of dyad 1are presented. First, with the five data points for mother assigned as variable X and the five points for child as variable Y, a bivariate correlation is computed between these variables (r_{xy}) as an indicator of concordance in shape. Second, the mean and standard deviation for each dyad member is computed. Finally, the absolute difference in means and the absolute difference in standard deviations are computed as indicators of discordance and spread, respectively. These indices were then added as new variables to the existing dataset for future comparisons between concordance and relationship characteristics.

Although level and spread were assessed using discordance statistics (absolute difference), for ease of interpretation these indices are discussed in terms of concordance when possible. Descriptive statistics for these indices can be found in Table 4. Comparisons among demographic characteristics revealed no relations between concordance indices and child race, gender, maternal age, race, education level, relationship status, or household income, all *p*s =ns. There were negative relations, however, between child age and discordance in level (r = -.27, p = .03) and discordance in spread (r = -.25, p = .05), indicating that dyads with older children demonstrated greater concordance.

Table 3. *Sample computation of dyadic indices*

	Dyad 1	
Sample	Mother (x)	Child (y)
HR 1	68.00	72.33
HR 2	67.00	72.00
HR 3	68.00	77.00
HR 4	64.00	78.00
HR 5	67.00	74.00
Mean	67.00	75.00
Standard deviation	2.00	3.00
Discordance in level	8.00	
Discordance in spread	1.00	
Concordance in shape	-.56	

Note: discordance in level = absolute difference in means, discordance in spread = absolute difference of standard deviations, concordance in shape = bivariate correlation (r_{xy}).

Table 4. *Descriptive statistics for dyadic indices and average heart rate reactivity*

	M	*SD*	Range
Concordance in level	11.51	8.14	.60 – 30.00
Concordance in shape	.13	.55	-1.00 – .99
Concordance in spread	2.32	2.46	.09 – 11.50
Average HR reactivity[a]			
Mother	4.14	3.91	.00 – 21.08
Child	4.15	3.07	.00 – 15.50

[a]Absolute value

Note: Because level and spread were computed as difference scores, lower scores are indicative of greater concordance.

Model-based cluster analysis**.** To examine profiles of concordance, two model-based cluster analyses were executed using the *MCLUST* program developed specifically for *R* software (Fraley & Raftery, 2006). First, profiles of *general* concordance were tested using the three dyadic indices described above as the input variables in the cluster analyses. Second, profiles of *reactivity* concordance were tested using the absolute value of average heart rate reactivity for mother and for child. Average reactivity, as opposed to reactivity for each of the four interaction tasks, was chosen based on non-significant differences in reactivity scores between tasks for both mother and child, all *p*s = ns[2]. Descriptive statistics for average reactivity can be found in Table 4.

The best cluster solution is determined by examining the fit statistic (BIC), ability to assign each dyad to a cluster, and certainty of cluster assignments. Better fit is indicated by greater BIC index distance from zero and greater differences between indices of different models; differences between indices of 0-2, 2-6, and 6-10 are indicative of weak, moderate, and strong evidence of fit respectively. Ability to assign clusters is based on the percentage of dyads who are assigned and certainty of cluster assignments is determined by examining the posterior probability of cluster assignment for each dyad.

General concordance. The chosen cluster solution for general concordance had a BIC of -841.54 with a distance of 2.17 and 11.69 from the first and second closest models, respectively. Using this solution, 63 (98%) dyads were able to be categorized. Certainty of cluster assignment was then examined based on the posterior probability of cluster assignment for each dyad. Using this cluster solution, 61% of dyads had a probability ≥ .95 of being a member of their assigned cluster and 75% of dyads had a probability ≥ .90.

[2] For exploratory purposes, clustering solutions were tested using all four tasks. Because of substantial missing data, however, only 34 (53%) dyads were able to be categorized using the best fitting model.

Clustering analyses revealed two distinct profiles of concordance. The first profile (*n* = 12, "Primarily discordant" dyads) was characterized by above average concordance in shape (*M* = .20, *SD* = .26), above average discordance in level (*M* = 13.30, *SD* = 57.17) and above average discordance in spread (*M* = 5.70, *SD* = 7.64). That is, dyads in this cluster were similar in their patterns of heart rate change but dissimilar in their overall heart rate and dissimilar in their heart rate variability. The second profile (*n* = 51, "Primarily concordant" dyads) was characterized below average concordance in shape (*M* = .10, SD = .30), below average discordance in level (*M* = 10.71, *SD* = 64.48) and below average discordance in spread (*M* = 1.25, *SD* = .86). That is, dyads in this cluster were dissimilar in their patterns of heart rate change but similar in their overall heart rate and similar in their heart rate variability. These clusters are illustrated in Figure 2.

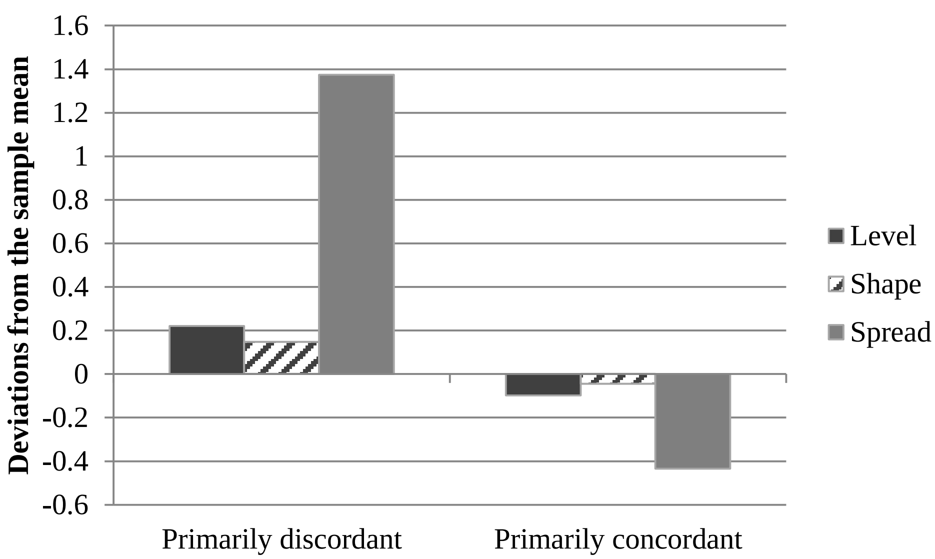

Figure 2. Profiles of concordance based on dyadic indices.

For a more thorough analysis of the clustering solution, independent samples *t*-tests were conducted to compare dyadic indices between the profiles. If the clusters do represent unique profiles of dyads, then they should differ significantly in variables composing them**.** Dyads in the primarily discordant cluster had greater concordance in spread (t[61] = 12.21, p = .000) but not level (t[61] = .62, p = .54) or shape (t[61] = .71, p = .48), suggesting that differences in concordance of heart rate variability is the only strong differentiating factor for these profiles. Comparisons among demographic characteristics revealed no relations between profiles and child age, race, gender, maternal age, race, education level, relationship status, or household income, all *p*s =ns.

Reactivity concordance. The chosen cluster solution for reactivity concordance had a BIC of -653.07 and a distance of 2.88 and 6.65 from the first and second closest models, respectively. Using this solution, all dyads were able to be categorized. Based on the posterior probability of cluster assignment for each dyad, 72% of dyads had a probability ≥ .95 of being a member of their assigned cluster and 80% of dyads had a probability ≥ .90. Clustering analyses revealed two distinct profiles of reactivity. The first profile (n = 45, “low reactivity” dyads) was characterized by below average mother reactivity (M = 2.18, SD= 1.45) and below average child reactivity (M = 3.30, SD= 1.81). The second profile (n = 19, “high reactivity” dyads) was characterized by above average mother reactivity (M = 8.21, SD= 3.78) and above average child reactivity (M =5.94, SD= 4.32). These clusters are illustrated in Figure 3.

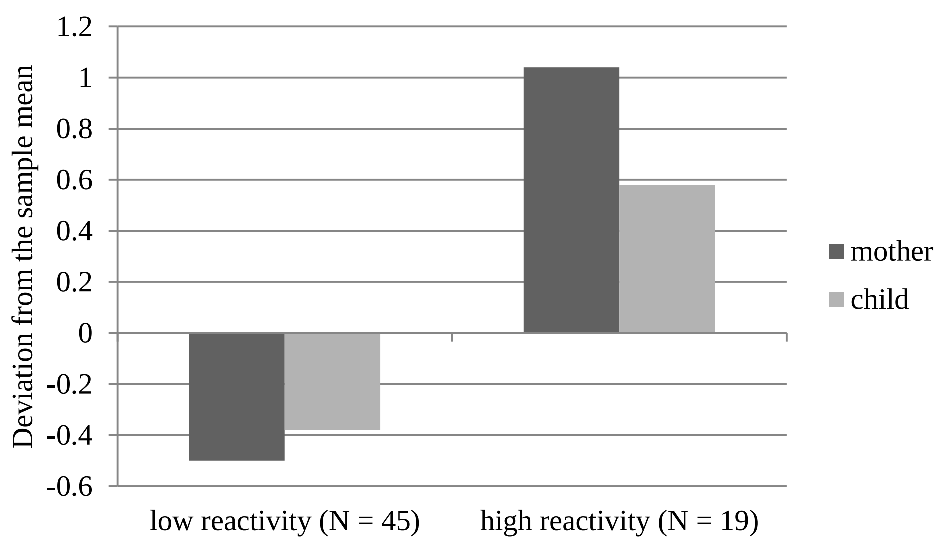

Figure 3. Profiles of concordance based on average heart rate reactivity for mother and child.

An independent sample *t*-test revealed that compared to the low reactivity cluster, the high reactivity cluster had greater average mother reactivity, $t(62) = -10.41$, $p = .000$ and child reactivity, $t(62) = -3.82$, $p = .000$ - further illustrating the differences in these groups. Comparisons among demographic characteristics revealed no relations between profiles and child age, race, gender, maternal age, race, education level, relationship status, or household income, all *p*s =ns.

Aim II: Compare how each measurement technique reveals relations between concordance and behavioral observations of relationship characteristics.

***Dyadic indices*.** Bivariate correlations were conducted to test the relations between dyadic indices and dyadic relationship characteristics (conflict resolution, shared positive affect, collaboration, and overall relationship quality). Dyadic conflict resolution was negatively related to concordance in shape ($r = -.29$, $p = .023$) but not significantly related to discordance in level or discordance in spread (*p*s = ns). In other words, greater conflict resolution was associated with lower similarity in heart rate change. Dyadic shared positive affect was negatively related to concordance in shape ($r = -.25$, $p = .055$) but not significantly related to discordance in level or spread (*p*s = ns). That is, greater shared positive affect was associated with lower similarity in heart rate change. Dyadic collaboration/cooperation was positively related to discordance in level ($r = .25$, $p = .054$) and negatively related to concordance in shape ($r = -.30$, $p = .019$), but not significantly related to discordance in spread (*p*s = ns). That is, greater collaboration was associated with lower similarity in overall heart rate level and heart rate change. Overall relationship quality was negatively related to concordance in shape ($r = -.25$, $p = .048$) but not significantly related to discordance in level or spread (*p*s = ns). That is, greater relationship quality was associated with lower similarity in heart rate change. These results are presented in Table 5.

Table 5. *Intercorrelations among dyadic indices and outcome variables*

	1.	2.	3.	4.	5.	6.	7.
1. Discordance in level	-	-.04	.14	.21	.16	.25†	.21
2. Concordance in shape		-	.05	-.29*	-.25†	-.30*	-.25*
3. Discordance in spread			-	-.07	-.19	-.12	-.19
4. Dyadic conflict resolution				-	.55**	.55**	.76**
5. Dyadic shared positive affect					-	.76**	.72**
6. Dyadic collaboration						-	.78**
7. Overall relationship quality							-

*p<.05, **p<.01, †p<.10

Note: Because level and spread were computed as difference scores, lower scores are indicative of greater concordance.

Model-based cluster analysis. Independent samples *t*-tests were conducted to assess differences in relationship characteristics based on dyadic profiles of concordance.

General concordance. The two profiles of concordance based on dyadic indices (Primarily concordant, Primarily discordant) did not differ with regard to dyadic relationship characteristics, all *p*s = ns. These results are presented in Table 6.

Table 6.
Independent sample t-tests comparing dyadic profiles of general concordance (N = 64)

		Mean (*SD*)		95% Confidence Interval	
Variable	*t*	Group 1	Group 2	Lower	Upper
Dyadic conflict resolution	-.13	3.92 (1.51)	3.98 (1.49)	-1.03	.90
Dyadic shared positive affect	-.37	4.08 (1.38)	4.24 (1.35)	-1.03	.71
Dyadic collaboration	.22	.92 (1.31)	.84 (1.11)	-.66	.82
Overall relationship quality	-.20	5.08 (1.38)	5.16 (1.23)	-.89	.73

Reactivity concordance. Comparisons between profiles based on average reactivity revealed significant differences between groups. Similar patterns were found in each of the four relationship characteristics. First, compared to high reactivity dyads (*M* = 3.33, *SD* = 1.09), low reactivity dyads demonstrated higher levels of conflict resolution (*M* = 4.20, *SD* = 1.50), *t*(60)= 2.17, *p* = .034. Second, compared to high reactivity dyads (*M* = 4.39, *SD* = 1.34), low reactivity dyads demonstrated higher levels of overall relationship quality (*M* = 5.41, *SD* = 1.13), *t*(60)= 3.07, *p* = .003. Trends were found for shared positive affect and dyadic collaboration. Compared to high reactivity dyads (*M* = 3.67, *SD* = 1.19), low reactivity dyads demonstrated higher levels of shared positive affect (*M* = 4.36, *SD* = 1.43), *t*(60)= 1.82, *p* = .073. Additionally, compared to high reactivity dyads (*M* = .39, *SD* = 1.09), low reactivity dyads demonstrated higher levels of dyadic collaboration (*M* = 1.00, *SD* = 1.14), *t*(60)= 1.94, *p* = .057. These results are presented in Table 7.

Table 7. *Independent sample t-tests comparing high and low dyadic HR reactivity on relationship characteristics (N = 64)*

		Mean (*SD*)		95% Confidence Interval	
Variable	*t*	Low reactivity	High reactivity	Lower	Upper
Dyadic conflict resolution	2.17*	4.20 (1.50)	3.33 (1.09)	.07	1.67
Dyadic shared positive affect	1.82†	4.36 (1.43)	3.67 (1.19)	-.07	1.46
Dyadic collaboration	1.94†	1.00 (1.14)	.39 (1.09)	-.02	1.24
Overall relationship quality	3.07**	5.41 (1.13)	4.39 (1.34)	.35	1.69

p<.05, ***p*<.01, †*p*<.10

Although both clusters represent two types of concordance in average reactivity (low and high), they may also include dyads that demonstrated discordance. That is, although a mother and child may both demonstrate low levels of reactivity, one dyad member may demonstrate a low level increase in heart rate and the other may demonstrate a low level decrease in heart rate. For a more critical analysis of dyads who demonstrated concordance in their reactivity, direction of change in heart rate was examined. It was observed that of the 45 dyads in that demonstrated similar low reactivity 24 of them demonstrated similarity in their direction of heart rate change. That is, in three ‘low reactivity’ dyads, one dyad member’s average heart rate change score was negative (indicating a decrease in heart rate) and the other member’s change score was positive (indicating an increase in heart rate). Similarly, of the 17 high reactivity dyads, 13 demonstrated similarity in their direction of change (see Figure 4).

		Direction of change	
		Similar	Non-similar
Dyadic reactivity	Low reactivity	24[a]	21[b]
	High reactivity	13[c]	6[d]

Figure 4. Number of dyads within each cluster type that demonstrate similar or dissimilar patterns of change.

Relations between group membership and dyadic relationship characteristics were then tested again using only dyads that demonstrated similarity in their direction of change (n = 37). A similar pattern of results was found. Compared to high reactivity dyads (M =3.31, SD = 1.18), low reactivity dyads demonstrated higher levels of conflict resolution (M = 4.50, SD = 1.69), t(35)= 2.25, p = .031. Additionally, compared to high reactivity dyads (M =4.38, SD = 1.50), low reactivity dyads demonstrated higher levels of overall relationship quality (M = 5.42, SD =1.25), t(35)= 2.24, p = .032. Counter to previous findings, compared to high reactivity dyads (M = 4.71, SD = 1.52), low reactivity dyads demonstrated lower levels of shared positive affect (M = 3.69, SD = 1.03), t(35)= 2.15, p = .038. Finally, There were no group differences in dyadic collaboration, t(35)= 1.48, p = .148. These results are presented in Table 8.

Table 8. *Independent sample t-tests comparing high and low dyadic HR reactivity on relationship characteristics using only dyads demonstrating similar direction of change (n = 37)*

		Mean (*SD*)		95% Confidence Interval	
Variable	*t*	Low reactivity	High reactivity	Lower	Upper
Dyadic conflict resolution	2.25*	4.50 (1.69)	3.31 (1.18)	.12	2.27
Dyadic shared positive affect	2.15*	3.69 (1.03)	4.71 (1.52)	.06	1.97
Dyadic collaboration	1.48	1.00 (1.22)	.38 (1.19)	-.23	1.46
Overall relationship quality	2.24*	5.42 (1.25)	4.38 (1.50)	.10	1.97

p<.05, **p<.01, †p<.10

CHAPTER 5

DISCUSSION

Middle childhood may be a transition period during which the function and/or benefits of physiological concordance undergo change. Specifically, it may be that the type of concordance experienced or the context in which it is experienced plays a stronger role during this developmental period. In the existing literature, reports of mother-child physiological concordance in middle and late childhood are sparse. Additionally, conceptualizations of concordance are limited and operationalizations vary greatly making comparisons across studies difficult. As a beginning to addressing these limitations, the aims of this paper were to a) demonstrate methods for examining physiological concordance using techniques that allow for examination of multiple characteristics of the concordance process and b) compare how these techniques reveal relations between concordance and behavioral observations of emotion-related relationship characteristics of mother-child dyads (i.e., dyadic conflict resolution, shared positive affect, dyadic collaboration, and overall relationship quality). Additionally, these relations were examined in a middle childhood sample to explore how the function and/or benefits of concordance may change during this developmental period.

Summary of findings

Aim I: Demonstrate methods for examining physiological concordance

Dyadic indices and model-based cluster analyses were chosen as effective techniques for identifying multiple types of physiological concordance. Using three dyadic indices allowed for isolation of each type of concordance – dissimilarity/similarity in physiological level, shape, and spread. That is, dissimilarity/similarity in overall mean, change over time, and variability.

Additionally, creating a clustering solution based on qualities of both mother and child allowed for examination of profiles based on the match between dyad members. This element was particularly important as previous researchers have established that it is not the behavior of the mother or of the child individually but instead of the fit between them that best predicts outcomes for that dyad (Manglesdorf et al., 2000; Manglesdorf et al., 1990).

Aim II: Compare how each measurement technique reveals relations between concordance and behavioral observations of emotion related relationship characteristics

Dyadic indices. It was expected that different types of concordance served different functions or benefits to the dyad and as a result each dyadic index would relate differently to relationship characteristics. This hypothesis was not supported. Dyadic indices of concordance in level, shape, and spread related similarly to dyadic relationship characteristics. Specifically, discordance in level and concordance in shape were negatively related to dyadic conflict resolution, shared positive affect, dyadic collaboration, and overall relationship quality suggesting that concordance may not be a beneficial or positive process during middle childhood. Although the relations were statistically non-significant, concordance in spread was also negatively related to these relationship characteristics.

As previously described, the existing literature is mixed with regard to its relations between degree of physiological concordance and other relational processes (e.g., harsh/restrictive parenting practices, maternal sensitivity). One potential explanation for the difference in these relations is that researchers have measured different types of concordance, each of which differs in terms of a “negative” or “positive” construct. One aim of this paper was to isolate three types of physiological concordance and compare their relations to behavioral observations of relationship characteristics. Each of the three indices related similarly to behavioral observations, however, suggesting that a previous mix of positive and negative relations in the literature is not likely due to differences in operationalization of concordance.

These negative relations between concordance and positive relationship characteristics found here are similar to those found in studies of mother-adolescent dyads (Papp et al., 2009) and of romantic relationship dyads (Cohan et al., 2003; Saxbe & Repetti, 2010). As previously described, advances in emotional competence, perspective taking, and behavioral autonomy during middle childhood are associated with changes in the function of mother-child attachment and related attachment promoting behaviors (Kerns & Richardson, 2005). As a result of this developmental transition, the implications of mother-child physiological concordance in middle-childhood may be less similar to those of mother-child concordance in early childhood (e.g., promoting attachment) and more similar to those of concordance in romantic relationship dyads (e.g., reciprocal negative interactions).

Researchers who study married couples have found concordance to be linked to escalating reciprocal negative affect and to be a risk factor for relationship distress or marital dissatisfaction (negative affect reciprocity model; Gottman, Coan, Careere, & Swanson, 1998; Levenson & Gottman, 1983). From this perspective, concordance emerges when dyad members become ‘too coordinated’ and unable to disengage from their partner’s negative affect or conflict. From this research, Saxbe and Reppetti (2010) suggest that compared to a constant matching of physiology, dyad members may benefit more from periods of both physiological match and mis-match. These fluctuations reflect the ability of individuals within the couple to regulate each other’s mood and physiology (Sbarra & Hazan, 2008); similar to how mothers use affectionate touch and smiling to regulate their infant’s mood and physiology (Field, 1978; 1996).

Results using dyadic indices support the idea that high degrees of similarity in physiological activity, whether it be level, shape, or spread, are not associated with positive relationship processes for mother-child dyads in middle childhood. Findings from the clustering solution, however, suggest that researchers should consider not only the degree of similarity in physiological activity but the nature of the physiological activity shared.

Clustering. Clustering analyses based on these dyadic indices revealed two profiles of general concordance – one characterized by above average concordance in shape, above average discordance in level, and above average discordance in spread and the other characterized by below average concordance in shape, below average discordance in level, and below average discordance in spread. This clustering solution was weak in several ways: the difference between the BIC index of this model and the next best model was low, the posterior probabilities of cluster assignment were low, and the profiles were not well distinguished by their differences in concordance in level or spread. Given these features, it should not be surprising that there were no significant differences between these profiles in terms of dyadic relationship characteristics.

It was expected that if the clustering solution revealed dyadic profiles of mutual high reactivity versus mutual low reactivity, then mutual low reactivity dyads would demonstrate more positive relationship characteristics than their counterparts. This hypothesis was supported. Clustering analyses based on average heart rate reactivity revealed two profiles of reactivity concordance – one characterized by above average maternal reactivity and above average child reactivity and the other by below average maternal reactivity and below average child reactivity. This clustering solution was an improvement from the solution of general concordance in that a) the difference between the BIC index of this model and the next best model were higher (albeit still only moderate), b) the posterior probabilities of cluster assignments were higher, and c) the profiles were well distinguished by their differences in average heart rate change for both mother and child. Comparisons between profiles revealed that dyads that experienced mutual low reactivity demonstrated more positive relationship characteristics. Specifically, dyads that experienced mutual low reactivity were characterized by higher scores in dyadic conflict resolution, shared positive affect, dyadic collaboration, and overall relationship quality. These findings are similar to reports of physiological reactivity in individuals where compared to low reactivity, high physiological reactivity is associated with negative physical and behavioral outcomes (e.g., Fredrickson & Matthews, 1990; Lorber, 2004; Matthews et al., 1993). Additionally, research on dyads has found low physiological reactivity to be associated with higher levels of physical and mental health (King & Levenson, 1996; McCarthy, King, & Levenson, 2002). Furthermore, other researchers have found that during conflict discussions among married couples, transitions from high physiological arousal to low physiological arousal were associated with increases in positive emotional behavior (Yuan, McCarthy, Holley, & Levenson, 2010). These researchers suggested that positive mood has an 'undoing' effect on negative physiological arousal, but this explanation is limited without use of experimental design.

Limitations and future directions

A primary limitation of this dataset is the use of discontinuous heart rate levels. In the physiological concordance literature, heart rate is primarily measured using continuous measures (e.g., Arai et al., 2009; Feldman et al., 2011; Field et al., 1989) making comparisons between the current findings and those studies difficult. Additionally, use of discontinuous measurement in this study yielded only five data points for computation of concordance. Although this number met the standards of the statistical techniques used (Kenny et al., 2006), additional data points would have increased the likelihood of capturing the true concordant or discordant nature of the dyads. In future research, use of continuous heart rate would also allow for examination of real-time changes in concordance. As previously described, time series analyses would be appropriate techniques for continuous measurement of physiological activity (Gottman, 1981; Mcleary & Hay, 1980). From time-series plots, researchers can determine real-time changes in physiology for each dyad member then compare these oscillations between dyad members.

Other limitations include the moderate sample size and cross-sectional design of the dataset. The moderate sample size was suitable given the relatively simple analyses conducted but ‘borderline’ non-significant relations may have been bolstered with a larger sample. Additionally, the cross-sectional design of the dataset precludes suggestions of causal relations between concordance and behavioral observations of relationship characteristics. It may be, for example, that positive interactions (as indicated, for example, by high collaboration or high shared positive affect) lead to similarities in low physiological arousal (as indicated by mutual low reactivity). It may also be the case, however, that similarities in low physiological arousal allow dyads to engage in positive interactions. Although causality cannot be determined without true experimental manipulation, future studies with longitudinal designs will help elucidate these pathways.

Relatedly, from this study it is impossible to speculate about why dyads are or are not concordant in their physiology. It may be, for example, that discordant dyads are not ‘tuned in’ to one another because of a) a lack of interest or care for one another or b) as a means for self-protection against the other dyad member’s negative arousal. These possibilities are difficult to tease apart for multiple reasons, one being that dyad members may not understand or be able to express why they aren’t ‘tuned in’ to their partners. One way to begin exploring these ideas may be to examine engagement (with the task or partner) close in time to measurement of physiological data. If discordant dyads also demonstrate low engagement, then perhaps discordance is related to a lack of interest or care. If, however, discordant dyads demonstrate high engagement then it may be that discordance is a means for self-protection.

Another potential limitation of this paper is the underlying assumption that the relational process of physiological concordance can be operationalized as a combination of individual characteristics. This assumption has been used by other researchers in their operationalization of dyadic constructs (Cohn & Tronick, 1988; Tronick, Als, & Brazelton, 1980). In studies of mother-infant interactions, for example, researchers have measured mother and infant behavior separately and then computed the likelihood of mother's behavior given her infant's behavior. Supported by Kenny's Social Relations Model (Kenny, 1994; Kenny & La Voie, 1984), other family and developmental researchers conceptualize dyadic processes as greater than the sum of their parts and measure them more holistically (e.g., Hsu & Fogel, 2003; Isabella & Belsky, 1991). That is, each dyad member's behavior should be considered simultaneously when measuring dyadic constructs. In their examination of mother-infant communication, these researchers used dyadic behavioral codes to capture the state of the dyad given both members' behavior. Although theoretically sound, this perspective is difficult to apply to the construct of physiological concordance. The best way, and potentially only way, to consider physiological activity in both dyad members simultaneously may be to use continuous measurement and corresponding time series or spectral analysis. By using continuous measurement, researchers would be able consider the changes of one dyad member within the context of changes in the other dyad member. This method, however, is only applicable to physiological systems that can be measured continuously (e.g., heart rate, skin conductance).

An area that deserves attention for future concordance research is developmental changes and stability. Short term stability could be measured, for example, by quantifying what proportion of a sampling period a dyad spends in periods of concordance compared to periods of discordance. Additionally, long term stability could be measured by determining if dyads that demonstrate concordance in early childhood also demonstrate concordance later in development. Findings from the present paper, combined with previous reports of concordance in early childhood and romantic relationships support the notion that concordance undergoes significant changes across development. Recall that in infancy and early childhood, concordance has been associated with positive relationship characteristics such as attachment security (Zelenko, 2010), behavioral coordination (Feldman et al., 2011), and maternal sensitivity (Sethre-Hofstad et al., 2002; van Bakel & Riksen-Walraven, 2008). Later in development, such as in adolescence or adulthood, however concordance in close relationships is associated with more negative characteristics such as reciprocal negative affect (Papp et al., 2009) and inabilities to buffer against partner stress (Saxbe & Repetti, 2010). Longitudinal or broad cross-sectional designs will help elucidate how and potentially why concordance relates differently during these life stages.

Another area for future research is inter-system (i.e., physiological system) comparison. Few studies have examined attunement using physiological markers of multiple systems (Kivlighan et al., 2005; Middlemiss et al., 2011), and none have directly addressed similarities in attunement across these systems. Based on the current literature, it is evident that physiological systems do not always respond to stimuli similarly. In their study of intra-individual synchrony, Laurent and colleagues (2011) found different response patterns of the HPA axis (indexed by cortisol levels) and SNS (indexed by sAA). Other researchers have reported similar findings of asynchrony in response patterns of these systems (El-Sheikh, Erath, & Buckhalt, 2008; Fortunato et al., 2008). One explanation for this difference is that high activity in one system and low activity in another system may be a result of overcompensation of the first system (Laurent et al., 2011). Another explanation is that systems respond differently to different stimuli. Reactivity of cortisol levels, for example is relatively difficult to elicit for two reasons. First, excessive levels of cortisol can cause deleterious effects on the brain and body and as a result, is typically only elevated during times of perceived physical or social threat (Dickerson, Mycek, & Zaldivar, 2008). Second, cortisol output follows a decrease of throughout the day and thus stress-inducing stimuli are working against this natural decline. In contrast, heart rate changes are relatively easily to elicit because of the relative speed at which heart rate will return to baseline. Thus, depending on the stimuli used, reactivity may be elicited in some physiological markers but not others. By measuring multiple physiological systems simultaneously, the likelihood of capturing physiological concordance will increase. Because physiological markers demonstrate changes at different rates (e.g., changes in heart rate can be assessed in seconds whereas changes in sAA can only be assessed in minutes) multiple samples will need to be taken at various points during an assessment.

Relatedly, current studies of physiological concordance lack multi-level comparisons. Recall that some researchers speculate that physiological concordance is associated with shared emotional experiences or coordinated behavioral interactions (Feldman et al., 2011). Other researchers have reported that measures of physiological regulation and reactivity are not always matched to measures of behavioral regulation and reactivity (e.g., Ramsay & Lewis, 2003; Zalewski, Lengua, Wilson, Tancik, & Bazinet, 2011). Thus, to elucidate the associations between shared physiology, shared emotional experiences, and coordinated behavioral interactions, assessment using methods to capture each of these elements (e.g., physiological markers, self-report of emotions, behavioral observations) is warranted.

Conclusions

This paper has contributed to the literature by demonstrating methods for examining physiological concordance using techniques that allow for examination of multiple characteristics of the concordance process and comparing how these techniques reveal relations between concordance and behavioral observations of relationship characteristics of mother-child dyads (i.e., dyadic conflict resolution, shared positive affect, dyadic collaboration, and overall relationship quality). Based on results of these two techniques, two primary findings emerge. First relations between dyadic indices and relationship characteristics suggest physiological concordance to be a negative construct with higher levels of concordance relating to lower levels of positive relationship characteristics. Second, relations clustering solutions and relationship characteristics, specifically the great positive relationship characteristics for mutual low reactivity dyads, suggest that the implications for concordance may be different when considering the degree of similarity compared to the nature of the physiological activity experienced by both dyad members. Future research would benefit from inclusion of continuous heart rate measurement, comparison of inter-system similarities in concordance, and examination of developmental changes in concordance.

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