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Parent-Child Psychophysiological Synchrony in Early Autism Intervention: A Pilot Investigation

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Parent-Child Psychophysiological Synchrony in Early Autism Intervention:

A Pilot Investigation

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by

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Osuna, A., **Tagavi, D.**, Sabini, K., Vernon T. (Under Review). A Social Media Skills Program for Young Adults with Autism: A Pilot Study of the SELFI Program.

Vernon, T., Said, S., Alison, M., Ko, J., Miller, A., Ferguson, E., **Tagavi, D.** (Under Review). Sustainable, comprehensive social gains in adolescents with autism.

Tagavi, D., Koegel, L., Koegel, R., Vernon, T. (2020). Improving conversational fluidity in adults with autism spectrum disorder using a video-feedback intervention. *Journal of Positive Behavior Interventions.*

You, C., **Tagavi, D.**, Osuna, A., Vernon, T. (2020). Internet usage, social skill, and anxiety severity in adults with autism spectrum disorder. *Journal of Emerging Investigators.*

Vernon, T., Holden, A., Barrett, A., Bradshaw, J., Ko, J., McGarry, E., Horowitz, E., **Tagavi, D.**, German, T. (2019). A pilot randomized clinical trial of an enhanced pivotal response treatment approach for young children with autism: The PRISM model. *Journal of Autism and Developmental Disorders.*

Tagavi, D., Koegel, L. (2019). First words: Introducing verbal communication. In R. Koegel & L. Koegel (Eds.), *Pivotal response treatment for autism spectrum disorders, Second edition.* Baltimore, MD: Brookes.

Ashbaugh, K., **Tagavi, D.**, & Koegel, L. (2019). Improving socialization in adolescents and adults with ASD. In R. Koegel & L. Koegel (Eds), *Pivotal response treatment for autism spectrum disorders, Second edition.* Baltimore, MD: Brookes.

Hersh, J., MacPherson, H., Ng, M.Y., **Tagavi, D.**, & Weisz, J.R. (2016). Tailoring Youth Treatment to Fit the Youth. In I. Frønes, S.K. Ertesvåg, H. Eng & J. Kjøbli (Eds.), *Risk, intervention and evidence: Challenges and strategies for child welfare, education, health and politics*. Norway: Gyldendal.

Lazenby, D., Huntington, N., Sideridis, G., Prante, M., Dale, P., Curtin, S., Henkel, L., Iverson, J., Carver, L., Dobkins, K., Akshoomoff, N., **Tagavi, D.**, Nelson, C., & Tager-Flusberg, H. (2015). Language differences at 12 months in infants who develop ASD. *Journal of Autism and Developmental Disorders*.

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Abstract

Parent-Child Psychophysiological Synchrony in Early Autism Intervention:

A Pilot Investigation

by

Daina Tagavi

Interpersonal psychophysiology is increasingly being used as a measure of engagement or attunement between two people. This construct is characterized as the relationship between two individuals' physiology over the course of an unfolding social interaction. This physiological activity can become correlative and mutually influential, which is often referred to as psychophysiological synchrony (PS). Research suggests that parent-child synchrony measured via physiological constructs can be related to the severity of autism spectrum disorder (ASD) symptoms in young children. While the symptoms of ASD appear to negatively affect parent-child PS, it may be possible to address these concerns with targeted treatments. The current study examined the efficacy of an adapted version of Pivotal Response Treatment aimed at incorporating social reinforcement into the treatment and specifically training parents on these techniques on parent-child PS. Additionally, the difference in PS levels between ASD and typically developing parent-child dyads was examined to determine if this is a promising area to target via intervention. Lastly, measures of PS were compared to behaviorally coded measures of social engagement to determine if this unique outcome can be detected visually.

Participants included 9 children with ASD and 7 typically developing (TD) children and their parents. Standardized assessments and video probes were administered before and after six months of PRT to obtain preliminary outcome data on child development, the parent-child bond, and parent fidelity of implementation. Physiological data was collected from parent-child dyads during brief family interaction videos to assess for PS. Results indicated that there were significant changes following intervention on some standardized measures of language and ASD symptoms, but not physiological measures. Additionally, there was not a significant different between ASD and TD dyads in PS levels at baseline. Finally, some measures of visually observed social engagement appear to be correlated to PS, however these correlations changed over the course of intervention.

Despite these mixed results, this pilot study indicated that the use of PS in ASD research is promising with adaptations to study design, measure conceptualization, and data analysis. Further research could serve to further refine the utilization of this more objective measure of parent-child engagement for its eventual use as a quick and unbiased predictor of treatment outcome and a construct through which to tailor intervention, which could have lasting consequences for improving long-term social outcomes of children with ASD and their families.

Introduction

A hallmark characteristic of individuals diagnosed with autism spectrum disorder (ASD) is difficulty engaging in sustained, appropriate, and reciprocal social interactions across daily contexts (APA, 2013). Although many concerns about individuals newly diagnosed with ASD usually involve language or communication challenges, these social deficits are often prevalent in the earliest years of an ASD diagnosis. These social challenges can have a profound impact on a child's overall development because of the pivotal role socialization can play on influencing a variety of other developmental domains, such as cognitive, language, behavioral, or emotional. The quality of a child's interactions and sustained relationship with their parents or caregivers (their closest social partners) can affect their ability to succeed across these domains, regardless of their disability status (Sameroff, 2009). Developmentally beneficial family interactions are possible when each member is attuned to and in sync with the other person and makes the necessary changes to keep the relationship strong. However, a child's autism diagnosis can significantly interfere with both the quality and frequency of these pivotal interactions (Freeman & Kasari, 2013). This can cause downstream effects on a child's development, leading to sustained problems throughout childhood, adolescence, and even adulthood.

Promisingly, if these crucial reciprocal social transactions are specifically targeted through early intervention, it may be possible to remediate a child's motivation for socialization and engagement. Those children can then learn to initiate and sustain appropriate interactions and relationships, leading to a more normalized and successful development overall. In regards to these early interventions, targeting parent-child interactions, specifically, has been linked to the positive development of children's cognitive abilities, language skills, and social competencies (Sameroff, 2009). These important interactions can be measured not only through observations of social behavior, but also in the ways in which their physiological arousal rises and falls together.

Physiological indicators of responsiveness to social interaction can potentially serve as an immediate and objective measure of joint engagement (Palumbo et al., 2016), which has historically been measured more subjectively through observation and behavioral coding (Feldman, 2012). This phenomenon, termed interpersonal autonomic physiology, is defined as the relationship between two people's physiology, obtained through continuous measures of their autonomic nervous system, and has been linked with favorable relational and developmental outcomes (Palumbo et al., 2016). It has been postulated that the autonomic physiological activity between two or more people can begin to move in tandem or become correlated or interdependent, which is often referred to as physiological synchrony. Examining this construct in individuals with ASD and the people they interact with most can help determine how precisely social engagement and attunement is working and changing over the course of development and how it is influencing a child's overall functioning.

Despite the fact that interpersonal physiological interactions reflect key social processes that co-occur with observable behavior, they have not been systematically applied to populations with ASD. A recent pilot study examining parent-child psychophysiological synchrony (specifically, electrodermal activity, or skin conductance) found that a child's ASD symptom severity was negatively associated with synchrony strength (Baker et al., 2015). However, while ASD symptoms appear to negatively affect parent-child attunement, it may be possible to address these concerns with targeted treatments. Examining synchrony in the context of intervention may serve to help providers assess symptomology, predict outcomes, and even inform or tailor treatment. However, no published studies have examined how autism intervention efforts might enhance synchrony in family dyads to this benefit.

Pivotal Response Treatment (PRT) is one of the few empirically supported early interventions for ASD that has been modified to specifically target early socialization skills, alongside language and behaviors. PRT is a naturalistic intervention that utilizes child centered strategies that take into account the benefits of child motivation, developmental considerations, everyday learning settings, and parental involvement (Koegel & Koegel, 2019). Outcomes associated with involvement in these sorts of naturalistic behavioral interventions are quite favorable, including more frequent early social learning experiences, increased social development, reduced likelihood of maladaptive behavior, and better generalization (Schreibman et al. 2015).

Toddlers who receive PRT often experience a significant reduction in core ASD symptoms, as well as improvements in overall social engagement (Koegel, Vernon, & Koegel, 2009; Vernon, Koegel, Dauterman, & Stolen, 2012). As the field of autism research has increasingly recognized the developmental benefits of promoting socialization, and, in particular, parent-child exchanges, steps have been taken to modify existing the PRT protocol by purposely embedding social engagement components to further increase its efficacy. In an initial investigation, traditional PRT was compared to this modified procedure, which emphasizes utilizing socially engaging activities as reinforcement, rather than traditional natural reinforcers (Koegel et al., 2009). Child participants who received this modified version demonstrated measurable improvements in social engagement, eye contact, and directed facial expressions. Another investigation examined the effects of PRT in the parent-child context and resulted in significant increases in child social responses (eye contact, verbal initiations, directed positive affect) that led to parent social responses (directed positive affect, synchronous engagement) and vice versa (Vernon et al., 2012; Vernon, 2014). In a pilot RCT, Vernon et al. (2019) found that toddlers who received the tailored version of PRT experienced changes associated with medium to large effects across a variety of standardized measures, including overall autism symptomology, cognitive abilities, overall language, and receptive language, specifically, and that the treatment was feasible across a range of domains.

While these findings from past investigations are promising, there remain unanswered questions pertaining to the role psychophysiological synchrony plays in informing early interventions for ASD, and how treatments focused on increasing social motivation and attunement might influence this unique measure of engagement over time. The present research study addressed the following aims:

1. To determine if parent-child psychophysiological synchrony will increase in children with ASD and their parent over the course of six months of Pivotal Response Treatment (PRT).
2. To examine potential differences in parent-child psychophysiological synchrony between toddlers with ASD and their TD peers.
3. To determine if levels of parent-child psychophysiological synchrony are correlated with visual observation of video recorded parent-child social engagement behaviors.

Relevant Research Literature

The parent-child relationship is of crucial importance in early childhood and can be indicative of future cognitive, social, and emotional success. Parents are now spending more time than ever rearing their children and these moments together can be pivotal for teaching, modeling, and shaping children's experiences and behaviors (Dotti Sani & Treas, 2016). The building and maintenance of this prominent relationship early in life is imperative for all children, but can be of particular relevance for children at-risk for future social, emotional, and developmental issues, such as those with autism spectrum disorder. Autism is a neurodevelopmental disorder affecting 1 in 59 children that is characterized by restrictive and repetitive behaviors and interests and deficits in socialization and social communication (Baio et al., 2014). Early in life, children with ASD often demonstrate difficulty communicating and forming appropriate social relationships with others such as peers, teachers, and even parents. These challenges can have great impacts on a child's subsequent development and can lead to developmental issues in other domains of life.

However, by targeting these social deficits specifically and capitalizing on the most prominent relationships in a child's life, broad impacts can occur that may help set a child on course for a more typical trajectory throughout childhood. In fact, investigations of family and language have demonstrated that certain forms of responsive parenting can predict language development in children with or demonstrating early signs of ASD (Baker, Messinger, Lyons, Grantz, 2010). Examining the parent-child relationship and parental responsiveness, particularly, may help shed insight into the unique ways individuals with ASD connect and engage and how these connections are related to other areas of functioning. Additionally, targeting parent responsiveness and engagement may have a profound impact on improving a child’s ability to connect socially with other individuals and improve their overall development and functioning before the most severe symptoms of autism fully manifest. By investigating and focusing on this area, it may be even be possible to mitigate early symptoms of ASD and allow children to experience more typical early social relationships in childhood.

Socialization and Engagement as Areas of Interest

Much of the research on ASD in recent decades has focused on the area of socialization and engagement because improving social skills has been found to have such robust impacts on a child’s overall development. Socialization is a core deficit that impacts individuals with autism spectrum disorder (ASD) of all ages and development levels (American Psychiatric Association, 2013; Seltzer, Shattuck, Abbeduto & Greenberg, 2004). Although many concerns about individuals newly diagnosed with ASD often involve language or communication challenges, social deficits are often prevalent in the earliest years of an ASD diagnosis and can have a profound impact on a child’s developmental trajectory because of the pivotal role socialization can play on influencing a variety of other domains, such as cognitive, language, behavioral, or emotional.

From the earliest years of life, infants who later go on receive an ASD diagnosis demonstrate various red flags in the area of socialization including reduced social orienting, joint attention, imitation, and processing of faces and emotions in others (Dawson & Bernier, 2007). Over the course of development in ASD, these deficits remain throughout childhood and even adulthood, with symptoms manifesting as struggles to form age-appropriate peer relationships, understand others’ perspectives, and interpret social cues (Bauminger-Zviely & Agam-Ben-Artzi, 2014; Orsmond, Shattuck, Cooper, Sterzing, & Anderson, 2013). This deviating trajectory of social cognition and behavior has often been attributed to very early differences in neural and physiological functioning, altered social interactions and experiences, and the interaction of these biological and experiential factors (Dawson, 2008).

According to the transactional model of child development, children, along with members of their social environment (such as parents, family members, teachers, and peers) engage in a series of exchanges that shape the child's behavior, skills, and understanding over time, which ultimately contributes to the development of complex cognitive, language, and social competencies (Sameroff, 2009). Under this model, learning as a whole is conceived as an inherently social endeavor, where the quality and frequency of interpersonal encounters during childhood accumulate and scaffold upon each other to yield a remarkable transformation in human functioning over the span of just a few short years (Rosenthal & Zimmerman, 2014; Sameroff & Fiese, 2000). It seems likely that the transactional model of development can also be applied to the more biological functions of socialization, in that the more a child experiences normal and successful social exchanges with the people close to them, the more their body learns to respond in a more typical way physiologically, which allows for increased future instances of more enjoyable social interactions.

Psychophysiological Synchrony as a Measure of Engagement

Because of the important role that biological and physiological processes play in the social learning process and the development of appropriate socialization and regulation skills in children, there is an increased interest in examining these constructs, especially as they relate to social engagement, in ASD. These physiological indicators of responsiveness to social interaction can possibly serve as a more objective and unbiased measure of joint engagement between two people than the traditional behavioral measurement techniques that have typically been utilized (Feldman, 2012). Findings indicate that physiological activity during an interaction between two or more people can become associated or interdependent over time, which is often referred to as psychophysiological synchrony. Psychophysiological synchrony has been examined across a range of different social relationships and contexts, including with married couples, novel conversation partners, teammates, and parent-child dyads, and it has been found to be correlated with a number of favorable relational and developmental outcomes (Levenson & Gottman, 1983).

To understand this unique biological relationship, it is first important to understand some basic principles behind psychophysiological measurement. The autonomic nervous system is primarily made up of the sympathetic nervous system and the parasympathetic nervous system branches. These systems work together to dynamically regulate internal biological processes including cardiac, respiratory, and glandular systems. In general, the sympathetic nervous system is a catabolic system that is in control of physiological activation (i.e., increased arousal or “fight or flight”). The parasympathetic nervous system is an anabolic system associated with restoration and repair (i.e., decreased arousal or “rest and digest”). These branches of the nervous system work together and fluctuate dynamically to regulate the body to be able to respond either impulsively or carefully in a plethora of environmental conditions, including social interactions with others.

The complex interactions between these two systems can be measured in a variety of ways, each with their own unique characteristics. For example, examining the synchrony of breathing rate and heart rate in conjunction, also known as respiratory sinus arrhythmia (RSA), has been shown to be a measure of the parasympathetic system, specifically (Camm et al., 1996). Conversely, electrodermal activity (EDA), or skin conductance level, has been used as an measure of eccrine sweat glands, which are activated by the sympathetic nervous system (Boucsein, 1992). Looking at the specificity of these measures in regards to the sympathetic and parasympathetic nervous systems can help determine autonomic activity in an individual in a variety of contexts. Typically, an increased RSA is indicative of increased parasympathetic nervous system activity and increased EDA is indicative of increase sympathetic nervous system activity. Because of this, physiological synchrony in these measures is usually indicative of different processes. It has been demonstrated that synchrony in the sympathetic nervous system activity between two individuals occurs more often during negative contexts such as stress, whereas parasympathetic synchrony is more likely in positive contexts, such as empathy (Fox, Schmidt, Henderson, & Marshall, 2007).

Using modern physiological sensors to tap into these physiological constructs offers several advantages over existing observational or standardized assessment measures that are commonly used to quantify engagement and attunement. These specific tools of measurement can provide a constant, objective data stream that is connected to major psychosocial elements present in a complex and consistently changing interaction. Using biological measures also allows researchers to gather information from individuals that may not be responsive to traditional behavior measures, such as those who are nonverbal or have severe cognitive impairments. When physiological data is collected from parent-child dyads engaging in an unfolding interaction, these measures provide information about co-variation in a natural, ecologically valid context that can function as an objective indicator of the quality of sustained attunement and engagement. Further, if parent-child physiological synchrony is measured longitudinally, it could be used to predict child developmental outcomes over time.

Psychophysiological findings have contributed to nearly every aspect of psychology, and physiology plays a known role in critical psychosocial processes including cognition, emotion, and behavior in a wide variety of populations (Cacioppo, Tassinary, & Berntson, 2007). Human physiological regulatory systems strive to operate within an optimal range of sympathetic and parasympathetic nervous system influence, constantly adjusting toward an affective state that balances autonomic function with actual demands (Fox, 1996). Whereas heightened arousal has been shown to associate with enhanced emotion, increased attention, and better memory, over activation can lead to a degradation of these processes (Critchley, 2002). Research has shown that the autonomic nervous system as a whole can be shaped by others and that autonomic processes can be telling of underlying patterns in social interactions (Palumbo et al., 2016).

Because of this, it is of great importance to examine this novel measurement with young children with ASD, due to their inherent psychosocial deficits that may be highlighted differently or more effectively through this innovative technique. Children with ASD exhibit significant social, affective, and behavioral difficulties that may challenge the formation of biological synchrony early in life, but improvement and maintenance of such physiological attunement might promote the development of these children (Feldman, 2012). Evidence from multiple studies also suggests that physiological synchrony increases when mothers are under stress, such that individual physiological profiles moderate the development of this engagement, which may be occurring in parent-child pairs with ASD, as these caregivers tend to be under high levels of stress (Manini et al., 2013; Waters, West, & Mendes, 2014). In addition, children have been found to be more likely to avoid other social partners when mothers undergo a stressful-negative event, suggesting that child behavior is influenced by mothers' psychophysiological state (Waters et al., 2014). In short, using psychophysiological measures to examine synchrony and engagement in children with ASD and their parents is lucrative because of their unique psychosocial challenges that are difficult to detect behaviorally. Additionally, utilizing these more objective measures can allow researchers to use psychophysiological synchrony as a biomarker for detecting ASD, and a tool for predicting treatment success and measuring treatment outcome.

Measurement of Psychophysiological Synchrony

Although synchrony is a quick, reliable, and objective measure of parent-child engagement, it can be complicated and time-consuming to take these measurements repeatedly over the course of treatment, especially if quick treatment decisions based primarily on clinical intuition and judgment need to be made to ensure optimal effectiveness. It may be indicated to examine behavioral, visual indicators of physiological synchrony that can be detected by the naked eye. Feldman et al. (2011) determined that there are observable measures of parent-child heart rate synchrony that can be detected visually, such as parent and child gaze, affect, and vocal synchrony. In a study by McElwain et al. (2008), the research team coined a term called affective mutuality, which they define at "the observable emotional attunement, comfort, intimacy, and positive responsiveness during an interaction." These researchers developed the "Affective Mutuality Scale," where dyads are rated from video on a seven-point scale (1 indicating very low to 7 indicating very high) for behaviors indicative of affective attunement, comfort of emotional exchange, and positive responsiveness to one another. Using this scale, Baker et al., 2015 determined that parent-child electrodermal activity was positively correlated with visually observed parent-child emotional attunement. Additionally, a moderate positive correlation was found between the degree of correlation of parent and child electrodermal activity scores during a free play activity and the observational ratings of the dyads' affective mutuality. The same study also indicated that a dyad's degree of synchrony could also be detected observationally. Although examining psychophysiological synchrony can be undeniably useful in diagnosing ASD, individualizing treatment, or measuring or predicting treatment outcomes, it may also be useful for researchers and clinicians to be able to detect synchrony visually so that they are able to make quick clinical judgements that may help inform assessment and treatment, especially in contexts where advanced physiological measures are not readily available or feasible.

Differences in Synchrony in ASD and TD Populations

Understanding the difference in both individual physiological level and parent-child psychophysiological synchrony between individuals with ASD and their typically developing peers is of paramount importance when attempting to use this construct to characterize, diagnose, or treat these vulnerable individuals. It is noteworthy that there is emerging evidence suggesting an inherent difference in both individual levels of autonomic arousal across a variety of contexts, as well as joint parent-child levels of behavioral synchrony between ASD and typically developing populations. It has been postulated that individuals with ASD have dysregulated or heightened sympathetic nervous responses individually, particularly when they are interacting with others (Prince et al., 2017). In a systematic review by Lydon et al. (2016) on physiological reactivity in autism, it was concluded that individuals with ASD responded differently than their TD peers to a variety of stimuli, including sensory, emotional, stress-inducing, and most importantly, social. In regards to these social differences, individuals with ASD have a greater galvanic skin response when presented with pictures of individuals making direct eye contact than their typically developing peers (Kyllianen et al., 2012). Also of note, Neuhaus, Bernier, and Beauchaine (2010) demonstrated that ASD and typically developing children exhibited differential autonomic reactivity when interacting with a familiar partner, but similar arousal when interacting with a novel partner. Additionally, typically developing children had a more consistent, organized physiological response across social contexts or partners. Toddlers with ASD were found to have greater levels of skin conductance than their typically developing peers in a naturalistic play activity (Prince et al, 2017). However, there was no difference in baseline skin conductance levels between the two groups. These drastic changes in skin conductance level or response have been shown to be related to cognitive demand, anxiety, attention, sensory input, novelty, and affect (Dawson, Schell, & Filion, 2007). This deviation may be one reason individuals with ASD tend to find certain social occurrences to be particularly aversive, leading to avoidance of these situations and the aforementioned vicious cycle of continued lack of opportunities to rectify these inherent deficits.

There appear to be deficiencies in parent-child synchrony among families who have children with ASD compared to those with typically developing children. Infant siblings of autistic children, who are known to be at a higher risk for ASD, exhibited less mother-infant synchrony as early as four months (Yirmiya et al., 2006). Feldman et al. (2012) found lower levels of reciprocal interactions between ASD children and both parents, but differences were mainly related to the child's minimal social engagement, which impaired the dyadic co-regulation. The degree of parent–infant synchrony was linked with more adequate emotion regulation strategies during the elicitation of both positive and negative emotions, indicating that even among children with marked disturbances in social relatedness, synchronous experiences, albeit limited, promote more optimal regulatory skills (Feldman, 2012). Another recent pilot study concluded that a child's autism symptom severity was negatively associated with the strength of measured parent-child bio-behavioral synchrony, indicating that these differences are not only detectable between diagnostic categories, but also within (Baker et al., 2015). Looking forward, it is possible that these determinations can be helpful as a biomarker for ASD or supplemental tool during diagnostic testing. Understanding typical levels of psychophysiological responsiveness or synchrony can also be useful in determining optimal treatment outcomes or predicting what type of patient might be most responsive to certain aspects of treatment.

Examining Synchrony in the Context of Intervention

It is widely accepted that early intervention for ASD can have profound impacts on a child's development and ultimate lifelong outcomes. In terms of primary symptomology, it has been demonstrated that that fewer than 10% of individuals with ASD will remain non-verbal if they receive early intervention (Koegel, 2000). Similar research has also found that non-verbal children who receive early intervention are more likely to gain functional speech than children who begin intervention later in life. Because of this, it is now universally agreed that intervention for ASD should begin as early as possible (Landa, 2007).

Early intervention can also have profound consequences on associated symptomology of autism, including aggression, tantrums, and self-injury, which are not diagnostically relevant to ASD, but may develop if primary symptoms are not addressed. It is hypothesized that these behaviors ultimately stem from difficulties communicating and can be peripherally targeted with early communication interventions (Horner et al., 2002). Similarly, other co-morbid symptoms, such as depression and anxiety have been linked to the difficulties with socialization present in those with ASD; recent research has suggested that these symptoms may be mitigated if the core area of socialization is also targeted (Koegel et al., 2013). Overall, the implementation of early intervention in a child's life can help address the core symptoms of ASD and may even help prevent secondary symptoms, which has the potential to eliminate the need for more intensive interventions throughout life.

Decades of research supports the efficacy of various types of early autism intervention to improve not only language, but also social communication, in young children with ASD. In the beginning stages of this research, success was found using basic behavioral strategies in accordance with applied behavior analysis (ABA) that used repetition and reinforcement to teach children and shape their behavior (Lovaas, 1987). To combat the rigidity and tediousness of ABA, a new generation of early interventions for ASD was introduced called Natural Developmental Behavior Interventions (NDBI; Schreibman et al., 2015). These naturalistic interventions enhanced the components of traditional ABA by altering the treatment to be more motivational, naturalistic, comprehensive, and family-centered. NDBIs have been researched thoroughly and determined to contribute to more positive outcomes across a range of domains, including socialization, language, and behaviors, and have shown to have more consistent generalization to real-world settings than traditional ABA techniques (Schreibman et al., 2015).

Pivotal Response Treatment, one such NDBI, capitalizes on a child's motivation to increase responsivity and engagement (Koegel & Koegel, 2019). The treatment involves modeling appropriate language during play and waiting for the child to attempt communication before providing access to the preferred activity. Additionally, PRT capitalizes on the use of natural reinforcers, in an aim to increase child spontaneous language use and generalization of speech. These reinforcers are logically related to the chain of behaviors. Interventions that utilize these types of natural rewards result strengthen the response-reinforcer relationship, which in turn encourages social communication in young children with autism (Koegel and Koegel, 2018). There has been decades of research supporting the efficacy of PRT, especially as it relates to early language development in ASD (Verschuur et al., 2014). Tests of its effectiveness have concluded that PRT results in increases in self-initiated language, while also demonstrating collateral improvements in communication and responsive language, play skills, affect and reductions in maladaptive behavior.

Importance of Parent Involvement in Intervention

Parents often play a pivotal role in treatment delivery and significantly contribute to their child's skill acquisition and subsequent development (Koegel, Bimbela, & Schreibman, 1996). However, children with autism, by the very diagnostic criteria of their disorder, can be difficult to engage in social interaction (APA, 2013). Parents of children with autism may have more difficulty achieving productive, enjoyable, and interactive play experiences because of the child's limitations in person and object engagement. Children with autism tend to engage in object-focused interactions – their attention is wholly focused on the object without involving another person in their play. Because of this, it can be very difficult for parents to engage the child in reciprocal, symbolic, turn-taking play episodes (Kasari et al., 2010). However, if easy-to-implement, effective intervention strategies can be taught to parents, they are likely to experience increased motivation to engage with their child over time (Schreibman, Kaneko, & Koegel, 1991). Using appropriate strategies, a parent may be able to create the appropriate transactional context to successfully elicit reciprocal social responses. Moreover, teaching parents how to be a sort of “therapist” can have the greatest impacts on the child’s life, as they can receive intensive doses of intervention throughout their normal day. This intensive interaction with parents can also help improve the child’s earliest social relationships, which could have collateral benefits for their overall socialization skills. In this context, parents have the power to model appropriate socialization for the child to imitate, as well as establish shared interests in each other, and other people and objects. These concentrated interactions have the potential to improve the synchrony with their child, leading to gains in language and socialization (Siller & Sigman, 2008).

Although early behavioral interventions are designed to combine clinician-delivered treatment with parent training, in community practice, children often receive primarily clinician-delivered treatment, and providers have limited training in parent-mediated approaches. Importantly, empirical evidence has emerged regarding the efficacy of both clinician-delivered PRT and parent training to effectively administer PRT (Wainer, Pickard, Ingersoll, 2017). A recent RCT revealed that, compared with a psychoeducation control group, children with ASD whose parents participated in a 12-week PRT training group showed improvements in frequency of utterances and adaptive communication skills (Hardan et al., 2015). Similarly, Gengoux et al. (2019) recently supported the efficacy of combining parent training with clinician delivered in-home treatment for improving functional communication skills of young, minimally verbal children with ASD. The PRT “package” of clinician- and parent-delivered treatment resulted in greater improvement in child functional language and social communication behaviors, greater increase in parent-reported number of words, and greater improvement in blindly-rated social communication ability compared to community treatment. Taken together, this research seems to imply that educating parents on the principles of PRT is crucial for optimal child success across of variety of domains and should be considered when implementing PRT packages with young children with ASD.

Pivotal Response Treatment as a Solution

When creating these kinds of parent education programs, the specific type of treatment model to utilize is an important consideration. It has been demonstrated that toddlers who receive PRT often experience a significant reduction in core ASD symptoms, as well as improvements in overall social engagement (Koegel, et al., 2009; Vernon, et al., 2012). As the field of autism research has increasingly recognized the developmental benefits of promoting socialization, and, in particular, parent-child exchanges, steps have been taken to modify existing PRT protocol by purposely embedding social engagement components to further increase its efficacy. Koegel et al. (2009) intentionally embedded a social interaction into activities that were internally motivating to children during PRT sessions and found collateral improvements in various social behaviors, such as engagement, positive affect, dyadic orienting. Creating social learning contexts from pre-existing non-social activities of interest strengthen the association between social interaction and pleasurable experiences for children, improving the motivation for children to engage in social interactions. Enhancing social motivation may allow children with ASD to begin to understand the underlying values of social interactions, causing them to independently seek out these experiences, which may have extensive positive consequences on their overall social-developmental trajectory throughout life. Importantly, involving parents in this type of intervention can magnify these compelling collateral effects because of the intense dose of treatment children receive from engaging with their parents.

Research examining the incorporation of social engagement components into early intervention has demonstrated the importance of increasing social motivation as a primary intervention strategy, which is consistent with the theory that motivation overall is a pivotal area of development that leads to collateral gains in a variety of areas (Koegel, Singh, & Koegel, 2010; Schreibman & Ingersoll, 2005). It has been postulated that the lack of social engagement present in children with ASD may stem from their inability to recognize the rewarding characteristics of social relationships (Dawson et al., 2002). Increasing the social reward of stimuli directly may help elicit more typical social behaviors naturally. By teaching individuals with ASD to derive pleasure from social interactions, they may be more naturally motivated to demonstrate normal levels of eye contact, initiate verbally, and direct positive attention to increase the frequency of these helpful social engagements.

This model of PRT attempts to capitalize on this theory and has demonstrated the hypothesized effects. In an initial investigation, traditional PRT was compared to this modified procedure, which emphasizes utilizing socially engaging activities as reinforcement, rather than traditional natural reinforcers (Koegel, Vernon, Koegel, 2009). Child participants who received this version of PRT demonstrated measurable improvements in social engagement, eye contact, and directed facial expressions. Another investigation examined the effects of this socially-focused version of PRT in the parent-child context and resulted in significant increases in child social responses (eye contact, verbal initiations, directed positive affect) that led to parent social responses (directed positive affect, synchronous engagement) and vice versa (Vernon et al., 2012; Vernon, 2014). In a pilot RCT of feasibility, Vernon et al., (2019) found that toddlers who received the tailored version of PRT experienced changes associated with medium to large effects across a variety of standardized measures, including overall autism symptomology, cognitive abilities, overall language, and receptive language, specifically, and that the treatment was feasible across a range of domains. Because of the specific focus on socialization and also parent involvement, it stands to reason that PRT would be an ideal model to help improve parent-child synchrony and engagement in children with ASD.

In a study by Vernon (2014) examining the use of PRT with embedded social interactions, moment-by-moment associations between parent and child social behaviors were found that were not present during a comparable motivational intervention without the use of socialization enhancements. Parent eye contact, positive affect, and introduction of a motivational social reward was shown to immediately lead to child eye contact and positive affect. Moreover, verbalizations and eye contact by children lead to the immediate onset of parent positive affect, which, together, provide promising evidence that implementing this enhanced version of PRT can have specific impacts on parent-child engagement and synchrony. Because both visual and psychophysiological parent-child synchrony are bidirectional in the ASD population, it is possible that the maintenance of synchrony might contribute to reduced ASD symptom levels over time (Baker et al., 2015). Although PRT has demonstrated feasibility and effectiveness across a range of domains, including preliminary evidence of increasing parent-child synchrony, the intervention has yet to be tested utilizing more objective, unbiased indicators of parent-child engagement or social reactivity. This study aims to examine parent-child psychophysiological synchrony in dyads with both typically developing children and children with ASD and determine the effect of PRT on parent-child psychophysiological synchrony. Additionally, this study examines if parent-child psychophysiology can be predicted via behavioral observation in hopes that, in the future, clinicians can easily engagement as both a predictor of treatment responsiveness and a specific target for behavioral intervention for young children with ASD.

Methods

Research Design

This study utilized a repeated measures experimental design for Research Aim 1. For Research Aim 2, a between-group quantitative descriptive research design was utilized. For Research Aim 3, a single-group quantitative descriptive research design was utilized.

Participants

Participants consisted of 16 parent-child pairs. Of the participants, 9 children had diagnoses of ASD and 7 children were typically developing (TD) with no history of ASD or developmental delay. These participants were included in baseline ASD/TD comparisons. Five children in the ASD group that completed the six-month intervention trial before the COVID-19 shutdown were included in the intervention outcome analysis. See Table 1 for sample information. For the ASD group, inclusion criteria included: (a) an age between 12-59 months, (b) a diagnosis of autism obtained by meeting DSM-5 diagnostic criteria (APA, 2013), (c) meeting autism score cut-offs on the Autism Diagnostic Observation Schedule – Second Edition (ADOS-2; Lord et al., 2000; Luyster et al, 2009), and (d) minimally verbal status (use of fewer than 50 functional words on a regular basis; Koegel et al., 2020). Children with comorbid medical or psychiatric conditions were excluded from participation. For TD participants, children could not have any history of developmental delays or concerns or have an older sibling with autism. One parent per child was recruited to complete parent-child interaction probes for both ASD and TD children and be trained in the intervention model for ASD children. Families in this trial were required to speak English as their primary language at home. Enrollment in this project did not require any payment from families. Participants were recruited through a partnership with a local pediatrician who receives approximately 60-100 new patient referrals in proposed age range per year with concerns of ASD, who they informed about the opportunity to participate. Additionally, participants were recruited through Facebook ads, targeted email campaigns, and the distribution of study flyers to county regional service centers, local daycares, pediatric offices, and community centers.

Procedures

Interested families contacted the Koegel Autism Center if interested and were screened by a graduate student for eligibility. If eligible, participants were invited for an intake assessment.

Data Collection Time-Points

All procedures were approved by the UCSB institutional review board. For both ASD and TD groups, physiological and observational data were collected at intake and 6-month time points. For the ASD group only, standardized assessment data was also collected at intake and 6-month time point.

After obtaining consent from parents and explaining the study procedures, wireless EDA sensors were placed on the non-dominant wrist or ankle of each child and parent. A short baseline period (approximately 2-3 min) then occurred where the child was shown a video of a fish aquarium designed to capture the child’s attention without being overly stimulating. The parent and child were then transitioned to another room with blank walls and three video cameras mounted high on the walls. Toys include a farm house and toy farm animals, blocks, a toy cellphone, a baby doll with food, a spinning toy, three toy vehicles, and a puzzle. The dyads next engaged in a three-phase naturalistic play situation that has been used in several studies of children with ASD and related developmental concerns (e.g., Baker et al. 2007, 2010). For Phase 1, dyads were told, ‘‘We want to see how your child explores the toys on their own. I'm going to ask you to sit against the wall and let them explore the toys on their own. Try not to point out any toys or comment on their actions. However, if they come to you or want to show you something, you can acknowledge them, but then try to send them back to play on their own.” For Phase 2, dyads were told, “I'd like to invite you to play with your child using the toys, trying to elicit as much engagement and communication from them as possible.” For Phase 3, the toys were put away and dyads were told, “For this last video, I'd like see how you and your child play together without using any toys. This might include silly games, songs, or physical play. Again, try to elicit as much engagement and communication from them as possible.” After each phase, the dyad was then left alone and observed through the cameras to ensure they stayed on task. For ASD participants, a series of additional laboratory tasks followed the play situation.

Intervention

For the ASD group only, following completion of the intake assessment, participants participated in six months of the modified PRT intervention. Dyads received 8 hours a week of intervention services, including 2 hours of parent-education and 6 hours of direct clinician-child intervention. Intervention was primarily delivered in families’ homes with sessions also being offered in the UCSB Autism Center or public settings (parks, zoo, museums, etc.) if requested/preferred by the parent.

Intervention Components. The enhanced PRT model uses the foundation of traditional motivational principles (Koegel & Koegel, 2006) to create social communication learning opportunities. These strategies include (a) emphasis on child choice of motivating stimulus, (b) variation of tasks to maximize child motivation, (c) introduction of clear prompt to cue a child to respond, (d) combination of both simple mastered tasks and more challenging tasks to balance engagement with learning, (e) reinforcement of any child language attempts, (f) rapid, contingent access to requested stimuli, and (g) use of motivating and reinforcing stimuli that is naturally related to the words. PRT is generally implemented in natural environments (e.g., child homes, community settings). The clinicians and parents arranged social-communication learning opportunities using the following three-step process: (a) the adult presents an antecedent cue (e.g., the adult provides a verbal prompt or entices the child with a reinforcing object or activity), (b) they wait for the child to make a verbal attempt, and (c) they reinforce the verbal attempt by delivering the motivating stimulus that is socially engaging. As individual sessions progress, new social activities were introduced to maintain the interest and engagement of the child. This model is grounded within PRT with modifications to directly target child social engagement. It includes several components that were added to the fidelity procedures, including high affect bids and social reinforcement strategies.

Training of Clinicians. Clinicians completed a four-hour initial training on how to implement the PRT intervention. After the didactic training, clinicians transitioned to hands-on training and practiced administering the intervention with each other. They were instructed to follow a fidelity checklist that was provided to them, which included six different steps to follow for every PRT probe. Once clinicians were able to administer two practice sessions at 80% fidelity, they could implement the intervention. Ongoing weekly supervision by a doctoral-level student was provided throughout the intervention and fidelity was monitored monthly to ensure proper delivery of the intervention.

Parent Education. Within the parent education sessions, the training clinicians adhered to an established, manualized curriculum. Parent educators initially introduced the primary intervention concepts, provided modeling of the techniques with the child, and then encouraged the parents to practice the techniques and obtain feedback. After the initial month of parent education sessions, the parent educator clinicians adopted a session format that primarily emphasized parent implementation of the procedures with ongoing in-vivo feedback, however, sessions were personalized to meet parent comfort and fidelity. As the parent and child progressed through the intervention, treatment objectives changed to increase overall social engagement, along with the spontaneity and complexity of the child's social-communication bids. To ensure adherence to the project's treatment procedures, fidelity of implementation information was gathered for clinicians every month and parents every week via a five-minute recorded video of the parent or clinician conducting PRT with the child during session.

Fidelity of Implementation

Trained research assistants scored each clinician and parent for fidelity of implementation during 33% of the intervention sessions, a standard that has been found to be representative of fidelity for the entire length of treatment (Caperton et al., 2018). Specifically, these research assistants scored the clinician and parent for correct implementation of the following intervention components for every trial of PRT:

1. The clinician/parent must have the child's attention (focused on the stimulus or the clinician/parent) while presenting the opportunity.

2. The clinician/parent's question/instruction/opportunity for the child to respond must be playful (high vocal register with positive facial expression), clear, and appropriate to the task.
3. The clinician/parent followed the child's choices and/or interests with tasks and activities.
4. Reinforcement must be contingent upon the desired language attempt (a goal-directed vocalization or word). The clinician/parent's delivered consequence (e.g., giving the child a toy) must be dependent upon the child's response (e.g., saying toy).
5. Reinforcement should be natural, or directly/logically related to the child verbalization.
6. The reinforcement should be in the form of an interactive activity that requires the presence of another person and enhance solitary play.

A trial was defined as one antecedent-behavior-consequence (ABC) sequence, in which a clinician entices a child with a preferred object or activity, the child makes a verbal attempt, and the clinician reinforces the child's language by delivering the preferred stimulus. Scores of 80% or above were considered effective implementation of the intervention procedures (Borrelli et al., 2005). All clinicians (mean = 96.1%, SD = 4.5%) and parents (mean = 92.8%, SD = 6.5%) in the study met fidelity of implementation.

Research assistants were trained in scoring procedures during a half-day didactic with the study investigators. They were given a checklist to use to code intervention videos and practiced scoring on sample videos until they were able to correctly identify and score all intervention components correctly in three sample videos.

Measures

Physiological Data

Physiological data was collected from parent-child dyads during the interaction videos using non-invasive wristband biosensors. Specifically, wireless Empatica E4 Wristband sensors were used to gather physiological data. Data on heart rate (HR) and electrodermal activity (EDA) were collected from both parent and child during all interaction phases and downloaded to a computer for data analysis. In addition to logging EDA and HR, the sensors also recorded movement across three dimensions using a triaxis accelerometer. Movement data was converted into an acceleration magnitude, then transformed into a measure of relative activity by subtracting the baseline static acceleration of gravity. This measure was then averaged over a two second window for each measurement frame and was used as a covariate to control for excessive movement impacting biobehavioral data.

Electrodermal Activity (EDA). EDA was recorded in microsiemens at 8 Hz using the E4 sensors worn by each parent and child. The sensors utilized wire leads and sticky electrodes and data were recorded and stored within the wrist sensor itself, and downloaded for later analysis. Although measurement from the wrist is less standard and may result in decreased sensitivity to small changes in EDA as compared to certain other locations (Van Dooren et al., 2012), evidence suggests reliability of wrist data with traditional measurement locations, and that wrist measurement may actually be more sensitive to EDA under certain circumstances (Poh et al., 2010; Van Dooren et al., 2012). EDA scores during the free play were collapsed from 8 Hz (1920 frames per dyad) to 2 s (120 frames), to better approximate the temporal window for the processes of interest (Boucsein, 2012; Skowron and Hastings, 2014).

Heart Rate (HR). Similar to EDA, HR was also recorded using the E4 Wristband sensors worn by each parent and child. HR values were computed in spans of 10 seconds. These values were not derived from a real-time reading, but are created after the session was completed, as the values were derived directly from the Blood Volume Pulse analysis of the session. Sample rate of HR was 1Hz. Data were recorded and stored within the wrist sensor itself, and downloaded for later analysis. HR during the free play was collapsed from 1 Hz (420 frames per dyad) to 2 s (120 frames), to better approximate the temporal window for the processes of interest (Boucsein, 2012; Skowron and Hastings, 2014).

Observational Data

Parent-child interaction videos were coded by two trained research assistants using Noldus Observer software for a number of key social measures, including child and parent word use, parent and child affect (positive emotion), synchronous engagement, and eye contact (using or adapting operational behavioral definitions described in Vernon et al., 2012). During the videos, dyads were presented with a standardized set of toys and asked to engage in three different play scenarios (Scenario 1: Child playing alone with toys; Scenario 2: Parent and child playing together with toys; and Scenario 3: Parent and child playing together without toys). Frequency and duration data for various parent and child behaviors were collected for each video at each time point in this investigation. Observational social measures were analyzed jointly, as a summed score of overall visual attunement, and for each individual parent and child. Interobserver agreement was calculated using built-in Observer analyses and was sufficient (M = 81%, SD = 5.1%).

Child Word Use. As a measure of social engagement, children's verbal initiations towards their parents were recorded. A child verbal initiation was defined as any unprompted, functional verbal utterance towards a parent. Because of the interest in assessing spontaneous language production, verbal responses to a parent's initial word prompt (i.e., repeating a word modeled by a parent) were *not* included. Additionally, self-stimulatory and other nonfunctional vocalizations were not counted. Child initiations were recorded with a time-stamped frequency count.

Child Positive Affect. In order to ascertain a measure of overall social enjoyment, probes were scored on a continuous basis for the occurrence versus non-occurrence of directed positive child affect. Positive affect was defined as visible and/or audible indications of happiness and enjoyment, including smiling, laughing, and physical affection (hugging and kissing). The total number of seconds with positive affect were calculated for each video probe.

Parent Positive Affect. Similar to the corresponding child measure, parent positive affect was coded for total duration as a measure of parent social enjoyment. Parent positive affect was defined as visible and/or audible indicators of happiness and enjoyment, including smiling, laughing, using an elevated and playful vocal tone, clapping, and physical affection (i.e. hugging, kissing). This variable was scored on a continuous basis following the same procedure as child positive affect.

Synchronous Engagement. In order to ascertain data related to the extent that mutually reinforcing interactions occurred during the session probes, synchronous engagement was coded. Synchronous engagement was defined as time intervals in which both parent and child are simultaneously directing positive affect at one another while engaged in the same activity. This variable was scored on a continuous basis.

Child Eye Contact. As a measure of a child's level of social engagement with their parent, videos were coded on a continuous basis for the occurrence versus non-occurrence of eye contact. Child eye contact was defined as the child looking at the facial region of their parent's face. For each probe, the number of seconds with child eye contact was counted.

Parent Eye Contact. As a measure of a parent's level of social engagement with their child, videos were coded on a continuous basis for the occurrence versus non-occurrence of eye contact. Parent eye contact was defined as the parent looking at the facial region of their child's face. For each probe, the total number of seconds with parent eye contact was counted.

Child Assessment Measures

All participants received a thorough characterization battery that included diagnostic, developmental, adaptive functioning, verbal/nonverbal social-communication, and vocabulary assessments. The specific assessments that were included in the present study are described. All assessments were administered by advanced graduate students in clinical psychology.

Report of Current and Past Services. To control for the effects of outside factors on outcome, parents were asked to report any past and current behavioral, psychological, psychosocial, or academic services their child has received at each 3-month assessment.

The Autism Diagnostic Observation Schedule-Second Edition (ADOS-2; Lord et al., 2000; Luyster et al., 2009). The ADOS-2 was utilized to assess for autism symptom severity across treatment. The ADOS-2 is a semi-structured, standardized observational assessment of social communication and behavioral symptoms associated with ASD in individuals aged 12 months through adulthood. One of two modules (Toddler Module;

Module 1) were administered as appropriate. The total Calibrated Severity Score (CSS; Esler et al., 2015; Gotham, Pickles, & Lord, 2009) was used as a common metric for comparing ASD symptom severity across modules.

Mullen Scales of Early Learning (MSEL; Mullen, 1995). To control for overall developmental level, the MSEL was administered. The MSEL is an individually administered comprehensive measure of developmental abilities in infants and preschool children (Mullen, 1995). The Early Learning Composite (ELC) Standard Score was used as a global composite of developmental functioning with a mean of 100 and standard deviation of 15. Additionally, four scales (Visual Reception [VR], Fine Motor Skills [FM], Receptive Language [RL], and Expressive Language [EL]) were examined for more specific information on multiple developmental domains. Each scale is represented with t-scores with a mean of 50 and a standard deviation of 10.

Social Responsiveness Scale, Second Edition (SRS-2; Constantino & Gruber, 2012). The SRS-2 is a 65-item rating scale that covers various dimensions of interpersonal behavior, communication, and stereotypic behavior associated with ASD. Internal consistency alpha reliability coefficients for the parent forms were reported to be above 0.90 and strong correlations ($r=0.52$-0.74) with subscales of the ADI-R. This measure was used as an indicator of ASD symptom severity for both ASD and TD groups.

MacArthur-Bates Communicative Development Inventories (MB-CDI; Fenson et al., 2007). The MB-CDI is a standardized parent-completed measure that helps assess children's emerging language and communication skills between the ages of 8 and 37 months, though the measure has been found to be reliable for older children with developmental delays. The MB-CDI assesses both early verbal and nonverbal language ability (Fenson et al., 2007). The inventory provides a measure of vocabulary comprehension, vocabulary production, and use of gestures at 12 months and a measure of vocabulary and sentence production from 16 months onward. Norms have been developed on a representative sample of children and the MB-CDI has demonstrated excellent validity and reliability for both typically developing and ASD child populations (Charman et al., 2003).

Case Analysis of Individual Synchrony and Behavioral Profiles

Rather than primarily using group analyses on our sample of 5 ASD participants that would have resulted in a loss of important individual data, a case series design was used to inspect the individual participant outcomes of each parent-child dyad. Due to significant differences in baseline developmental profiles and subsequent treatment response, a case-by-case inspection of individual profiles of synchrony and behavioral outcomes was indicated for this pilot investigation to examine the feasibility of using psychophysiological measures as an intervention outcome measure. Examining these cases individually also helped better shed light on the various behavioral and physiological profiles and trajectories present in this heterogenous sample. Each case that completed six months of PRT intervention is presented to highlight these findings (Table 3).

Data Analysis Plan

Analyses examining overall EDA and HR pattern covariation (mean and variability) between parents and their children were examined through basic correlation, as was our analysis of biological covariation and observed social interactions. Regarding the latter, more complex modeling was not used due to sample size considerations.

Our investigation of synchrony in relation to ASD diagnosis (Aim 1) was tested using hierarchical linear models (HLM; Raudenbush et al., 2011). HLMs can simultaneously model the effects of time-varying (EDA, HR, and in-time covariates) and non-time-varying (ASD symptoms) factors. HLMs allow for using a within-person, repeated measures design, and are currently recommended for the analysis of biological covariation between individuals (Skowron and Hastings, 2014). These models are used to provide descriptive characterizations of average trajectories of change over time and the heterogeneity in these trajectories across participants (in terms of the mean and variance of the change over time). Analyses for EDA and HR were done separately. Level 1 of the model involved the regression of child EDA and HR scores (per 2-second interval) on to parent EDA and HR scores (per 2-second interval), controlling for child movement (per 2-second interval) and time. The control for time prevented against inflated covariation estimates due to any growth in mean EDA levels across the task (i.e., the dyads tending to end higher in EDA than they began; Curran and Bauer, 2011; Skowron and Hastings, 2014). Level 2 included the main effect of ASD diagnostic group.

For Aim 2, the examination of changes in parent-child psychophysiological synchrony in dyads of children with ASD and their parents as a result of participation in six months of PRT, HLM modeling was also used. Level 1 of the model involved the regression of child EDA and HR scores (per 2-second interval) on to parent EDA and HR scores (per 2-second interval), controlling for child movement (per 2-second interval) and time. Level 2 included the main effect of study timepoint. Analyses for EDA and HR were done separately.

To examine the correlation between parent-child psychophysiological synchrony and behaviorally coded indicators of engagement, bivariate correlations were conducted between each measure of psychophysiological synchrony (EDA and HR) and each behavioral code of engagement (observed synchrony, parent eye contact, child eye contact, parent positive affect, and child positive affect) during each time point for participants in the ASD treatment group. Parent-child coded behaviors were summed across Scenarios 1-3 and reported as a proportion of seconds engaged in each social behavior divided by the total time (720 seconds). Synchrony was calculated across Scenarios 1-3 and was examined separately for EDA and HR.

Because our sample was small and underpowered due to challenges collecting endpoint data due to COVID-19, a Case Series design was utilized posteriori to examine the feasibility of utilizing psychophysiological data with children with ASD and their families, the preliminary effectiveness of PRT intervention on parent-child psychophysiological synchrony, and any patterns in outcome differences between physiological measures and more standardized behavioral and observational measures.

Sample Characteristics and Missing Data

All 19 participants (parents and children) tolerated the application of the EDA sensors for the entirety of the free play. The child sensors malfunctioned for one child in the ASD group for a portion of Scenario 3 of the free play task at post-intervention. For this case, only 2 minutes and 40 seconds of data was captured and analyzed, instead of the expected 4 minutes. For a second case in the ASD group, the child was crying for Scenario 1 and 2 at post-intervention. For both situations, research assistants attempted to troubleshoot for over an hour, but families had to leave the evaluation due to time constraints. MSEL Composite Standard scores for ASD children ranged from 49 to 95, indicating a wide range of estimated developmental functioning for this group. SRS Total T-Scores ranged from 60 to 90 for ASD children and 41 to 51 for TD children.

Results

All case series data is summarized in Table 2.

Case 1: Treatment Responder, Increasing Psychophysiological Synchrony. Case 1 was a 31-month-old Multiracial (Caucasian, Black, Asian, Middle Eastern) male. He lived with his mother, father, and infant sister within 10 miles of the clinic. His mother cared for him full-time and was recruited to receive parent training in PRT and complete all standardized, behavioral, and physiological assessments. Case 1's study sessions were conducted in two-hour blocks, four days a week. All of his study sessions were conducted at his home or in community settings (i.e., parks, museums, library, zoo). He demonstrated substantial increases in parent-reported words said (Baseline CDI = 250 words, Endpoint CDI = 375 words) and expressive and receptive language as measured by a standardized assessment (Baseline Mullen Receptive T-Score = 43, Endpoint Mullen Receptive T-Score = 70; Baseline Mullen Expressive T-Score = 43, Endpoint Mullen Expressive T-Score = 53) after participation in PRT intervention. He exhibited a substantial decrease in autism symptoms on the ADOS (Baseline ADOS Total = 17, Endpoint ADOS Total = 12).

At Baseline, Case 1 and his mother demonstrated low levels of psychophysiological synchrony (Baseline EDA Synchrony: r = -.26, Baseline HR Synchrony: r = .11). At Endpoint, the dyad demonstrated more synchrony (Endpoint EDA Synchrony: r = .12, Endpoint HR Synchrony: r = .56). Similarly, he and his mother showed increased levels of most behaviorally coded measures of social engagement, including behaviorally coded synchrony (Baseline = 42.8%, Endpoint = 58.6%), parent eye contact (Baseline = 50.3%, Endpoint = 57.7%), and parent positive affect (Baseline = 19.3%, Endpoint = 55.4%) across all play scenarios in the Standard Laboratory Observation. Upon review, we classified Case 1 as a treatment responder, who showed gains across standardized assessments, behavioral observations, and physiological synchrony measures.

Case 2: Minimal Treatment Responder, Maintained Low Psychophysiological Synchrony. Case 2 was a 41-month-old Caucasian male. He lived with his mother, father, and older brother over 50 miles from the clinic. His mother and aunt cared for him full-time and were both recruited to receive parent training in PRT. His mother was recruited to complete all standardized, behavioral, and physiological assessments. Because of the family's distance from the clinic, his study sessions were conducted in two two-hour blocks, two days a week. All of his study sessions were conducted at the university clinic or in community settings. He demonstrated a minimal increase in parent-reported words said (Baseline CDI = 0 words, Endpoint CDI = 4 words) and expressive language as measured by a standardized assessment (Baseline Mullen Expressive T-Score = 20, Endpoint Mullen Expressive T-Score = 23) after participation in PRT. He did not demonstrate an increase in receptive language (Baseline Mullen Receptive T-Score = 20, Endpoint Mullen Receptive T-Score = 20). Finally, he showed a small decrease autism symptoms on the ADOS (Baseline ADOS Total = 24, Endpoint ADOS Total = 21).

At Baseline, Case 2 and his mother demonstrated low levels of psychophysiological synchrony (Baseline EDA Synchrony: $r = -.22$, Baseline HR Synchrony: $r = -.23$). At Endpoint, the dyad continued to show low levels (Endpoint EDA Synchrony: $r = -.12$, Endpoint HR Synchrony: $r = -.25$). They did, however, show moderately increased levels of some measures of behaviorally coded social engagement, including behaviorally coded synchrony (Baseline = 17.9%, Endpoint = 34.8%), parent positive affect (Baseline = 14.9%, Endpoint = 26.6%), and child positive affect (Baseline = 4.0%, Endpoint = 12.9%) across all play scenarios in the Standard Laboratory Observation. Upon review, we classified Case 2 as a minimal treatment responder, who did not demonstrate gains in standardized assessments, behavioral observations, or physiological synchrony measures.

Case 3: Treatment Responder; Invalid Psychophysiological Data

Case 3 was a 28-month-old Asian male. He lived with his mother, father, and older brother (who also had an ASD diagnosis) within 10 miles from the clinic. His mother cared for him full-time and was recruited to receive parent training in PRT and complete all standardized, behavioral, and physiological assessments. His study sessions were conducted in two-hour blocks, four days a week. All of his study sessions were conducted at his home. He demonstrated a substantial increase in parent-reported words said (Baseline CDI = 46 words, Endpoint CDI = 130 words) and expressive and receptive language as measured by a standardized assessment (Baseline Mullen Receptive T-Score = 20, Endpoint Mullen Receptive T-Score = 30; Baseline Mullen Expressive T-Score = 23, Endpoint Mullen Expressive T-Score = 33) after participation in the PRT intervention. Finally, he showed a substantial decrease in autism symptoms on the ADOS (Baseline ADOS Total = 23, Endpoint ADOS Total = 9).

At Baseline, Case 3 and his mother demonstrated low levels of psychophysiological synchrony (Baseline EDA Synchrony: $r = -.38$, Baseline HR Synchrony: $r = .14$). Case 3 and his mother continued to show low levels of psychophysiological synchrony at endpoint, although the child's negative mood during the parent-child interaction compromised the validity of the data (Endpoint EDA Synchrony: $r = .06$, Endpoint HR Synchrony: $r = -.40$). They also showed decreased levels of behaviorally coded social engagement during this interaction, including behaviorally coded synchrony (Baseline = 59.3%, Endpoint = 25.5%), parent eye contact (Baseline = 69.1%, Endpoint = 48.0%), parent positive affect (Baseline = 73.2%, Endpoint = 48.5%), and child positive affect (Baseline = 28.6%, Endpoint = 22.9%) across all play scenarios in the Standard Laboratory Observation. Upon review, we classified Case 3 as a treatment responder who demonstrated gains in standardized assessments, but not on behavioral observations and physiological synchrony measures. Of note, Case 3 was crying throughout Phases 2 and 3 of the Standard Laboratory Observation at Endpoint and was inconsolable by his mother, which may have contributed to the lack of progress captured by the psychophysiological and behaviorally observed data.

Case 4: Treatment Responder; Maintained High Psychophysiological Synchrony. Case 4 was a 34-month-old Hispanic male. He lived with his mother, father, grandmother and older sister within 10 miles from the clinic. His mother, father, and grandmother split time caring for him. His mother was recruited to receive parent training in PRT and complete all standardized, behavioral, and physiological assessments. His study sessions were conducted in two-hour blocks, four days a week. All of his study sessions were conducted at his home, in the clinic, or in the community (i.e., parks, museums, libraries). He demonstrated a moderate increase in parent-reported words said (Baseline CDI = 45 words, Endpoint CDI = 99 words) and expressive language as measured by a standardized assessment (Baseline Mullen Expressive T-Score = 21, Endpoint Mullen Expressive T-Score = 25) after participation in the PRT intervention. He showed significant gains in receptive language as measured by the Mullen (Baseline Mullen Receptive T-Score = 20, Endpoint Mullen Receptive T-Score = 35). He also showed a moderate decrease in autism symptoms on the ADOS (Baseline ADOS Total = 12, Endpoint ADOS Total = 8).

At Baseline, Case 4 and his mother demonstrated high levels of psychophysiological synchrony (Baseline EDA Synchrony: $r = .72$, Baseline HR Synchrony: $r = .26$). He and his mother continued to show high levels of psychophysiological synchrony at endpoint (Endpoint EDA Synchrony: $r = .41$, Endpoint HR Synchrony: $r = .30$). They demonstrated increased levels of behaviorally coded social engagement, including behaviorally coded synchrony (Baseline =38.2%, Endpoint = 47.5%), parent eye contact (Baseline = 47.4%, Endpoint = 75.0%), child eye contact (Baseline = 5.3%, Endpoint = 13.1%), and child positive affect (Baseline = 22.2%, Endpoint = 40.9%) across all play scenarios in the Standard Laboratory Observation. Upon review, we classified Case 4 as a treatment responder, who demonstrated moderate to high gains in standardized assessments and behavioral observations, and maintained high levels of physiological synchrony.

Case 5: Partial Treatment Responder, Maintained Low Psychophysiological Synchrony. Case 5 was a 41-month old Caucasian male. He lived with his mother, father, and younger brother within 10 miles from the clinic. His mother cared for him full time and was recruited to receive parent training in PRT and complete all standardized, behavioral, and physiological assessments. His study sessions were conducted in two-hour blocks, four days a week. All of his study sessions were conducted at his home or in the community (i.e., parks, museums, libraries). Case 5 demonstrated a substantial improvement in his language skills, including parent-reported words said (Baseline CDI = 90 words, Endpoint CDI = 375 words), receptive language (Baseline Mullen Receptive T-Score = 29, Endpoint Mullen Receptive T-Score = 57), and expressive language as measured by a standardized assessment (Baseline Mullen Expressive T-Score = 20, Endpoint Mullen Expressive T-Score = 43) after participation in the PRT intervention. He showed a moderate decrease in autism symptoms on the ADOS (Baseline ADOS Total = 10, Endpoint ADOS Total = 7).

At Baseline, Case 5 and his mother demonstrated low levels of psychophysiological synchrony (Baseline EDA Synchrony: $r = -.38$, Baseline HR Synchrony: $r = -.23$). At Endpoint, he and his mother continued to show low levels of psychophysiological synchrony (Endpoint EDA Synchrony: $r = -.38$, Endpoint HR Synchrony: $r = -.71$). They also showed mixed results in regards to behaviorally coded social engagement, in that they either slightly increased or decreased on all observable measures. Upon review, we classified Case 5 as a partial treatment responder, who demonstrated gains in standardized assessments (specifically those measuring language), but not behavioral observations and physiological synchrony measures.

Group Analysis of Outcome Measures

Standardized Assessments

Dependent samples t-tests were conducted to determine the differences in standardized assessment data from baseline to post-intervention (6-months) for the ASD treatment group ($N = 5$). Child decreases in overall total scores on the ADOS-2 from pre- (M = 16.4, SD = 6.2) to post-intervention ($M = 12.4$, $SD = 6.2$) approached significance, $t(4) = 1.5$, $p =.19$. Scores on the Mullen Scales of Early Learning Receptive Subscale ($M = 26.4$, $SD = 10.1$) increased significantly after participation in the intervention ($M = 42.4$, $SD = 20.5$, $t(4) = -3.0$, $p = .04$). Total Mullen Composite score increases also approached significance (Baseline: $M = 65.4$, $SD = 18.5$; Endpoint: $M = 74.8$, $SD = 21.3$, $t(4) = -1.6$, $p = .19$). Score increases from pre- ($M = 25.4$, $SD = 9.9$) to post-intervention ($M = 32.6$, $SD = 12.6$) on the MSEL Expressive Language Subscale approached significance, $t(4) = -1.6$, $p =$

.17) . Score increases on the MacArthur-Bates Communicative Development Inventories (words said) approached significance post-intervention (Baseline: *M* = 93.8 *SD* = 113.1; Endpoint: *M* = 196.2, *SD* = 168.8), *t*(4) = -2.2, *p* = .09).

Observational Data

Dependent samples t-tests were conducted to determine the differences in behaviorally coded observational data during a parent-child play interaction from baseline to post-intervention for the ASD treatment group (*N* = 5). For this analysis, each observational code was summed for seconds of occurrence during Scenarios 2 and 3 of the Standard Laboratory Observation (Parent and Child Playing Together with Toys and Parent and Child Playing Together without toys) to give a composite score of each social measure across the two interactive scenarios. The total possible length of time that each behavior could have been observed was 480 seconds. Of all observable measures, only improvements in Synchronous Engagement approached significance from baseline (*M* = 48.4%, *SD* = 19.1%) to post-intervention (*M*= 63.7%, *SD* = 18.4), *t*(4) = -2.5, *p* = .07). Changes across intervention for Parent Positive Affect, Child Positive Affect, Parent Eye Contact, Child Eye Contact, and Child Spontaneous Word Use were not significant.

Parent–Child Psychophysiological Synchrony

Descriptive Data

For the ASD group, observed synchrony scores ranged from 0% of time synchronously engaged to 100% of time synchronously engaged across each phase of the play situation, with the mean of 43% time spent synchronously engaged during each 4-minute phase. In terms of physiological covariation, correlations of parent-child EDA ranged from -.94 to .92 across all phases of the play situation and correlations of parent-child HR ranged from -.64 to .88 across all phases of the play situation. For the TD group, correlations of parent-child EDA ranged from -.82 to .27 across all phases of the play situation and correlations of parent-child HR ranged from -.98 to .85 across all phases of the play situation. Due to the combination of both negative and positive correlations of synchrony present in the data, a mean calculation of synchrony for these groups is misleading.

Difference in ASD and TD Psychophysiological Synchrony

Group differences were examined at Baseline only and were examined separately for EDA and HR during the interactive phases of the behavioral observation (Phases 2 and 3), where we would expect most synchrony to occur. The interaction between ASD diagnostic category

and parent EDA in predicting child EDA was not significant at any time point or phase (Table 4).

Correlation Between Psychophysiological Synchrony and Behaviorally Coded Synchrony Measures

Of importance, psychophysiological synchrony as measured by both EDA and HR were highly correlated at both baseline (r = .59) and endpoint (r = .53). EDA Synchrony was moderately correlated with child eye contact (r = -.46) and highly correlated with parent eye contact (r =-.65) at baseline. EDA Synchrony was also moderately correlated with parent positive affect (r = -.39) at baseline. At endpoint, EDA Synchrony was moderately correlated with child eye contact (r =.44) and highly correlated with child positive affect (r = .61). Behaviorally coded synchrony was moderately correlated with HR synchrony at baseline (r = .41) and highly correlated (r = .81) at endpoint. HR Synchrony was highly correlated with parent eye contact at baseline (r = -.89) and endpoint (r = .72). Child positive affect was highly correlated with HR synchrony at baseline (*r* = .77) and parent positive affect was strongly negatively correlated with HR synchrony at endpoint (*r* = .68). Tables 6 and 7 provide data of all correlations at both timepoints.

Change in Parent-Child Psychophysiological Synchrony Over Six-Month Intervention Period

Changes in psychophysiological synchrony over the course of intervention were examined separately for EDA and HR during the interactive phases of the behavioral observation (Phases 2 and 3), where we would expect most synchrony to occur. The interaction between time point and parent EDA in predicting child EDA was not significant at any time point or phase (Table 5).

Discussion

This is the first study to compare psychophysiological synchrony to children in ASD and TD children and to examine the theory of psychophysiological synchrony in the context of a behavioral intervention. Our study had three aims:

1. *To determine if parent-child psychophysiological synchrony will increase in children with ASD and their parent over the course of six months of Pivotal Response Treatment:* Results suggested that children with ASD who participated in six months of the PRT intervention demonstrated significant or approaching significant desirable changes in a variety of standardized behavioral measures, as well as significant increases in some measures of behaviorally observed parent-child synchronous engagement. However, these improvements were not similarly captured by psychophysiological measures, which is unsurprising when examining the heterogeneity in our sample. It may suggest that there are certain profiles of children and families that demonstrate physiological changes in

response to small doses of early intervention that that aggregating this data does not fully capture these trends. Additionally, it may stand to reason that six months of PRT, focused on language development and social engagement, is not a long enough time period to yield expected outcomes for all participants. A longer duration of intervention may be needed to facilitate these outcomes.

Notably, this study is one of the first to examine multiple physiological measures of synchrony simultaneously. The majority of research on parent–child psychophysiological synchrony has focused on a single physiological measure (Lunkenheimer et al., 2015) and studies that have included multiple indicators have usually used measures that are closely related to one another, such as RSA and HR (Creaven et al., 2014). Results from this pilot study suggest that there is a moderately high correlation between two less related measures of synchrony (EDA and HR) in the ASD population both at baseline and after participation in intervention, which provides important information on the relationship between multiple biological processes and how synchrony operates across these various systems.

2. *To examine potential differences in parent-child psychophysiological synchrony between toddlers with ASD and their TD peers:* Our results indicate that diagnostic status was not a significant predictor of either EDA or HR synchrony during parent-child play interactions. However, it should be noted that this study is significantly underpowered to detect group differences in our sample. The lack of a statistically significant difference between groups is a potentially important finding if replicated in a larger and more matched sample. It suggests that at least some children with ASD may be responding physiologically to changes in their parents' affect and physiology to the same extent as

their TD peers. This may indicate that observed social impairments in ASD might stem from difficulty interpreting experienced physiological changes, rather than from dysfunction in the core biological systems underlying interpersonal physiological response. It may be that some individuals with social-emotional impairment may experience underlying physiological reactions to others' affect but exhibit impaired ability to identify or attribute the source of physiological changes.

3. *To determine if levels of parent-child psychophysiological synchrony are correlated with visual observation of video recorded parent-child social behaviors:* We found that parent-child psychophysiological synchrony was moderately to highly correlated with some observable, parent-child behaviors, and that correlations were both positive and negative. Behaviorally coded synchrony was moderately to highly positively correlated with both EDA and HR synchrony at both time points. However, regarding the more nuanced behavioral observations (parent and child eye contact and positive affect) correlations tended in the negative direction at baseline and the positive direction at endpoint. These results could indicate that before intervention, parents and children that displayed more outward signs of engagement actually demonstrated lower levels of physiological synchrony, which grew to become more consistent either with intervention or over the course of time. This may be due to adverse child psychophysiological reactions in response to increased positive socialization prior to intervention, which was remediated as a result of the PRT targets on increasing social motivation via pairing reinforcing stimuli with social interactions. Replication and further analyses are needed to determine the stability and validity of these findings, however, they may suggest a preliminary theoretical foundation for service providers to make observational judgments

about levels of parent-child attunement to be able to quickly make judgments regarding treatment as well as assess for improvements over time.

Case examination of each participant suggests that certain participant and family characteristics may differentially contribute to robust increases in synchrony and ultimately how children respond behaviorally and physiologically to early intervention. Our inspection suggests that individuals that experienced significant gains in (or maintained high levels) of psychophysiological attunement also experienced corresponding gains in behavioral outcomes and standardized assessments (receptive language, expressive language, social communication, cognitive ability), whereas those who had lower levels and/or non-improving psychophysiological synchrony generally had less pronounced behavioral and developmental assessment gains. It may also be possible that individuals with less impairment in baseline language, social communication, and cognition show exponentially more growth in physiological synchrony as a result of intervention compared to those with higher impairment. Additionally, some individuals may be responding well to the language-focused portions of PRT, but may need additional intervention to improve social engagement. Individual exploration of treatment cases may be indicated in further intervention research using psychophysiological measures to better understand the various profiles of treatment response and possibly tailor treatment to reflect these characteristics.

Limitations and Future Directions

There were several limitations to the current study. Due to the COVID-19 pandemic, our sample size was smaller and less diverse than anticipated than the originally recruited cohort for both ASD and TD groups. Although HLM has been used effectively with smaller samples in prior ASD research (Lerner et al., 2011), future studies should aim to have a larger, more diverse sample (i.e., more female representation) of ASD participants. Additionally, our TD control group was not demographically matched to the ASD group in terms of gender and age (i.e., there were more females and young children in the TD group). Targeted recruitment of matched TD participants was discontinued due to COVID-19 restrictions. Because of this, we cannot fully attribute group analysis findings to ASD diagnostic group classification. Future directions in this area include a demographically-matched sample of ASD and TD participants.

A further limitation of this study was the single-day assessment format to collect psychophysiological data. At several assessment time points, complications arose during the standard play observation, including negative child affect during observations (e.g., crying, tantrumming), child fatigue during observations, and E4 sensor malfunctions. Due to family time-constraints, additional data was not able to be collected to address these incidents. Future research on parent-child physiological synchrony could serve to build in multiple standard play observation visits at each time point into the study design to account for any missing or confounding physiological or observable behavioral data. Additionally, previous research on this model of PRT has postulated that six months of intervention may not be sufficient to see robust treatment effects measured via standard behavioral measures or behavioral observation measures. It is possible that this same trend may extend to psychophysiological measures and that a longer intervention period may be necessary to make a meaningful change in parent-child psychophysiological synchrony. Future research could serve to examine trends in psychophysiological synchrony over a longer period of intervention.

To date, most research that captures how parent–child physiological synchrony unfolds across time has done so within a short time frame, such as during a single lab visit or over the span of a few days (Sethre-Hofstad et al., 2002; Williams et al., 2013). Although research examined parent-child psychophysiological synchrony across a longer period than previous studies (6 months), this is a relatively short window in an individual's overall development throughout childhood, which is characterized by large changes in other related developmental variables. Limited research has directly addressed questions of continuity and change in parent–child physiological synchrony across developmental periods. More research is needed to better understand the developmental trajectories of physiological synchrony, especially beyond early childhood. Future research could serve to examine trends in psychophysiological synchrony in individuals with ASD and their parents over the course of development, as well as with other important people in their life such as siblings, friends, and clinicians to determine how this important aspect of develop changes across time and contexts.

This study did not explicitly examine baseline parent-child synchrony as a predictor of treatment outcome. Preliminary exploration of different profiles of synchrony across ASD participants suggested that certain baseline levels of synchrony may have been predictive of both outcome in terms of post-intervention synchrony and outcome based on standardized assessment report and behavioral observation. Future studies could serve to examine the mediating and moderating effects of synchrony on treatment outcome, or overall lifelong ASD symptoms trajectory. Having a better understanding of this unique variable in ASD research could be a pivotal step in evaluating strategies to promote optimal levels of parent-child synchrony, which is theorized to be a gateway towards accelerated developmental progress.

Collectively, our findings suggest that psychosocial processes influence and can be measured at a physiological level, however, more systematic work is needed to determine the variables and conditions that contribute to these interactions. The existing literature suggests that physiological synchrony is transient. Studies showing differences in synchrony across contexts and conditions indicate that physiological relationships change over time and require meaningful benchmarks to anchor developmental expectations. This is evident in studies such as Müller and Lindenberger (2011) and Ghafar-Tabrizi et al. (2008), which show that during a given time period, measures of synchrony are not static. This is an important consideration, as attempts to apply statistical models that assume a constant state may be problematic. For example, if a dyad shifts between periods of positive and negative physiological synchrony during a trial or one party's physiological responses to a partner are slightly delayed instead of immediate (as we saw in our study), but the entire interaction is assessed using a single linear model, then results will be an aggregate of two heterogeneous processes and will misrepresent the patterns of both.

Future directions could serve to employ more complex analyses, such as dynamical systems modeling, which may pick up on and account for these patterns. Additionally, it may be beneficial to re-examine how psychophysiological synchrony is conceptualized in research. It is expected that dyads will have desirable periods of synchronous and non-synchronous engagement during an interaction, however, in our study, we examined synchrony across an interaction and consolidated data from the entirety of the exchange into one composite measure of synchrony. Future research may serve to examine if psychophysiological synchrony is better characterized by examining only instances of high behavioral engagement, joint attention, or attunement. Further work must be done to explore moment by moment changes in physiology across an interaction to determine if there are more accurate representations of synchrony than a single composite and static score.

Given the highly heterogeneous presentation of autism, it is unsurprising that physiological response varies widely and shows different levels of growth across time across individuals who share the same diagnosis. A potential explanation for the high degree of variability in physiological response observed in our study is the possible existence of subtypes of ASD characterized by different physiological profiles. The presumed existence of subtypes within ASD is not a new phenomenon and may account for the high degree of variability in physiological response observed among participants with autism in our study. Previous research has characterized distinct subtypes of physiological responders in their samples (i.e. hypo-aroused, normally aroused, and hyper-aroused), while exposed to the same within-study stimuli sets (Hirstein et al., 2001; Schoen et al., 2008). Future research is needed to further examine the prevalence of physiological responder and synchrony subtypes among individuals with ASD to determine whether such patterns of responding are stable over time, constitute meaningful differences, and have predictive validity. This research could possibly incorporate adaptive treatment designs aimed at carefully selecting a series of treatment components that reflect the unique needs of each child and eventually culminating in a package of individually tailored intervention components that may lead to more robust gains across multiple domains of functioning.

While our findings provide support for the potential validity of measures of physiological synchrony, additional work is needed to further establish the validity and reliability of these measures. Future analysis could further assess validity by comparing moment-by-moment behavioral coding of social behaviors during periods of high and low physiological synchrony, leveraging the continuously-sampled interpersonal physiology data. Likewise, future studies should seek to better understand the reliability of physiological synchrony, which may be dependent on context, individual affective state, and the medium of interaction. For example, one could collect longitudinal physiology data on multiple dyads, in conjunction with repeated measurement of real time behaviors and experiences in individuals' natural environments, to track affective and contextual states. Future research may also include measures of interoceptive awareness, emotional regulation, and emotional diversity to allow for investigation into how individual characteristics may influence physiological synchrony. Ultimately, the present findings support the need for more basic and applied investigation of interpersonal physiology in ASD, and the potential value of utilizing flexible and interpretable interpersonal physiology analyses to support such work.

Conclusion

Although behavioral manifestations of interpersonal attunement in ASD is well documented, there is considerably less research investigating its underlying psychophysiological mechanisms at play. Through this pilot study, we were able to examine the feasibility of measuring psychophysiological synchrony in dyads of children with ASD and their parents. Though data collection was curtailed due to the COVID-19 pandemic, the use of this more objective measure in ASD research is extremely promising with adaptations to study design, measure conceptualization, and data analysis. With the continued examination of psychophysiological data, we hope to be able to further refine the use of this more objective measure of parent-child engagement and attunement, that can be utilized to understand mechanisms of treatment effectiveness and inform future intervention efforts to strengthen this crucial area of development. In the future, we hope that measuring parent-child psychophysiological synchrony can serve both as a predictor of treatment outcome and a construct through which to tailor interventions based on baseline levels. Intervening at this critical time in development and targeting this historically untapped area could have lasting consequences in terms of improving the long-term outcomes for children with ASD.

References

Abidin, R. R. (1990). *Parenting stress index-short form* (p. 118). Charlottesville, VA: Pediatric Psychology Press.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub.

Baio, J., Wiggins, L., Christensen, D. L., Maenner, M. J., Daniels, J., Warren, Z., ... & Durkin, M. S. (2018). Prevalence of autism spectrum disorder among children aged 8 years—autism and developmental disabilities monitoring network, 11 sites, United States, 2014. *MMWR Surveillance Summaries*, 67(6), 1.

Baker, J. K., Fenning, R. M., Crnic, K. A., Baker, B. L., & Blacher, J. (2007). Prediction of social skills in 6-year-old children with and without developmental delays: Contributions of early regulation and maternal scaffolding. *American Journal on Mental Retardation*, 112, 375–391.

Baker, J. K., Fenning, R. M., Howland, M. A., Baucom, B. R., Moffitt, J., & Erath, S. A. (2015). Brief report: A pilot study of parent–child biobehavioral synchrony in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *45*(12), 4140-4146.

Baker, J. K., Messinger, D. S., Lyons, K. K., & Grantz, C. J. (2010). A pilot study of maternal sensitivity in the context of emergent autism. *Journal of Autism and Developmental Disorders*, 40(8), 988-999.

Bauminger-Zviely, N., & Agam-Ben-Artzi, G. (2014). Young friendship in HFASD and typical development: Friend versus non-friend comparisons. *Journal of Autism and Developmental Disorders, 44*(7), 1733-1748.

Borrelli, B., Sepinwall, D., Ernst, D., Bellg, A. J., Czajkowski, S., Breger, R., ... & Orwig, D. (2005). A new tool to assess treatment fidelity and evaluation of treatment fidelity across 10 years of health behavior research. *Journal of Consulting and Clinical Psychology*, *73*(5), 852.

Boucsein, W. (2012). Electrodermal activity. Springer Science & Business Media.

Cacioppo, J. T., Tassinary, L. G., & Berntson, G. (Eds.). (2007). *Handbook of psychophysiology*. Cambridge University Press.

Camm, A. J., Malik, M., Bigger, J. T., Breithardt, G., Cerutti, S., Cohen, R. J., ... & Lombardi, F. (1996). Heart rate variability: Standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology.

Caperton, D. D., Atkins, D. C., & Imel, Z. E. (2018). Rating motivational interviewing fidelity from thin slices. *Psychology of Addictive Behaviors*, *32*(4), 434.

Charman, T., Drew, A., Baird, C., & Baird, G. (2003). Measuring early language development in preschool children with autism spectrum disorder using the MacArthur Communicative Development Inventory (Infant Form). *Journal of Child Language*, *30*(1), 213.

Creaven, A. M., Skowron, E. A., Hughes, B. M., Howard, S., & Loken, E. (2014). Dyadic concordance in mother and preschooler resting cardiovascular function varies by risk status. *Developmental Psychobiology*, *56*(1), 142-152.

Critchley, H. D. (2002). Electrodermal responses: what happens in the brain. *The Neuroscientist*, *8*(2), 132-142.

Constantino, J. N., & Gruber, C. P. (2012). *Social responsiveness scale: SRS-2*. Torrance, CA: Western Psychological Services.

Curran, P. J., & Bauer, D. J. (2011). The disaggregation of within-person and between-person effects in longitudinal models of change. *Annual Review of Psychology*, *62*, 583-619.

Dawson, G. (2008). Early behavioral intervention, brain plasticity, and the prevention of autism spectrum disorder. *Development and Psychopathology*, *20*(3), 775-803.

Dawson, G., & Bernier, R. (2007). Development of social brain circuitry in autism. *Human Behavior, Learning, and the Developing Brain: Atypical Development*, 28-56.

Dawson, G., Carver, L., Meltzoff, A. N., Panagiotides, H., McPartland, J., & Webb, S. J. (2002). Neural correlates of face and object recognition in young children with autism spectrum disorder, developmental delay and typical development. *Child Development*, 73(3), 700–717.

Dawson, M. E., Schell, A. M., & Filion, D. L. (2007). The electrodermal system. *Handbook of Psychophysiology*, *2*, 200-223.

Dotti Sani, G. M., & Treas, J. (2016). Educational gradients in parents' child-care time across countries, 1965–2012. *Journal of Marriage and Family*, *78*(4), 1083-1096.

Esler, A. N., Bal, V. H., Guthrie, W., Wetherby, A., Weismer, S. E., & Lord, C. (2015). The autism diagnostic observation schedule, toddler module: standardized severity scores. *Journal of Autism and Developmental Disorders*, 45(9), 2704-2720.

Feldman, R. (2012). Bio-behavioral synchrony: A model for integrating biological and microsocial behavioral processes in the study of parenting. *Parenting*, *12*(2-3), 154-164.

Feldman, R., Magori-Cohen, R., Galili, G., Singer, M., & Louzoun, Y. (2011). Mother and infant coordinate heart rhythms through episodes of interaction synchrony. *Infant Behavior and Development*, *34*(4), 569-577.

Fenson, L. (2007). *MacArthur-Bates communicative development inventories*. Baltimore, MD: Paul H. Brookes Publishing Company.

Ferrer, E., & Helm, J. L. (2013). Dynamical systems modeling of physiological coregulation in dyadic interactions. *International Journal of Psychophysiology*, *88*(3), 296-308.

Fox, S. I. (1996). Human physiology (5th ed.). Dubuque, IA: W. C. Brown.

Fox, N. A., Schmidt, L. A., Henderson, H. A., & Marshall, P. J. (2007). Developmental psychophysiology: Conceptual and methodological issues. *Handbook of Psychophysiology*, *3*, 453-481.

Gengoux, G. W., Abrams, D. A., Schuck, R., Millan, M. E., Libove, R., Ardel, C. M., ... & Hardan, A. Y. (2019). A Pivotal Response Treatment package for children with autism spectrum disorder: An RCT. *Pediatrics*, *144*(3), e20190178.

Ghafar-Tabrizi, R. (2008). Reversal theory and physiological linkage in the low-conflict and high-conflict mother-daughter dyadic interactions. *Contemporary Psychology*, *3*(1), 62-75.

Gotham, K., Pickles, A., & Lord, C. (2009). Standardizing ADOS scores for a measure of severity in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 39(5), 693-705.

Guimond, A. B., Wilcox, M. J., & Lamorey, S. G. (2008). The early intervention parenting self-efficacy scale (EIPSES) scale construction and initial psychometric evidence. *Journal of Early Intervention*, 30(4), 295-320.

Hardan, A. Y., Gengoux, G. W., Berquist, K. L., Libove, R. A., Ardel, C. M., Phillips, J., ...

& Minjarez, M. B. (2015). A randomized controlled trial of Pivotal Response Treatment Group for parents of children with autism. *Journal of Child Psychology and Psychiatry*, *56*(8), 884-892.

Hirstein, W., Iversen, P., & Ramachandran, V. S. (2001). Autonomic responses of autistic children to people and objects. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *268*(1479), 1883-1888.

Horner, R. H., Carr, E. G., Strain, P. S., Todd, A. W., & Reed, H. K. (2002). Problem behavior interventions for young children with autism: A research synthesis. *Journal of Autism and Developmental Disorders*, *32*(5), 423-446.

Kasari, C., Gulsrud, A., Paparella, T., Hellemann, G., & Berry, K. (2015). Randomized comparative efficacy study of parent-mediated interventions for toddlers with autism. *Journal of Consulting and Clinical Psychology*, *83*(3), 554.

Koegel, L. K. (2000). Interventions to facilitate communication in autism. *Journal of Autism and Developmental Disorders*, *30*(5), 383-391.

Koegel, L. K., Ashbaugh, K., Koegel, R. L., Detar, W. J., & Regester, A. (2013). Increasing socialization in adults with Asperger's syndrome. *Psychology in the Schools*, *50*(9), 899-909.

Koegel, R. L., Bimbela, A., & Schreibman, L. (1996). Collateral effects of parent training on family interactions. *Journal of Autism and Developmental Disorders*, *26*(3), 347-359.

Koegel, L. K., Bryan, K. M., Su, P. L., Vaidya, M., & Camarata, S. (2020). Definitions of nonverbal and minimally verbal in research for autism: A systematic review of the literature. *Journal of Autism and Developmental Disorders*, 1-16.

Koegel, R. L., & Koegel, L. K. (2006). *Pivotal response treatments for autism:*

Communication, social, & academic development. Paul H Brookes Publishing.

Kim, S., Bradshaw, J., Gengoux, G. W., Vismara, L. A., Tagavi, D., Oliver, K., ... & Koegel, B. L. (2019). *Pivotal response treatment for autism spectrum disorders*. R. L. Koegel, & L. K. Koegel (Eds.). Paul H. Brookes Publishing Company.

Koegel, L. K., Singh, A. K., & Koegel, R. L. (2010). Improving motivation for academics in children with autism. *Journal of Autism and Developmental Disorders*, *40*(9), 1057-1066.

Koegel, R. L., Vernon, T. W., & Koegel, L. K. (2009). Improving social initiations in young children with autism using reinforcers with embedded social interactions. *Journal of Autism and Developmental Disorders*, *39*(9), 1240-1251.

Kylliäinen, A., Wallace, S., Coutanche, M. N., Leppänen, J. M., Cusack, J., Bailey, A. J., & Hietanen, J. K. (2012). Affective–motivational brain responses to direct gaze in children with autism spectrum disorder. *Journal of Child Psychology and Psychiatry*, *53*(7), 790-797.

Landa, R. (2007). Early communication development and intervention for children with autism. *Mental Retardation and Developmental Disabilities Research Reviews*, *13*(1), 16-25.

Lerner, M. D., Mikami, A. Y., & Levine, K. (2011). Socio-dramatic affective-relational intervention for adolescents with Asperger syndrome & high functioning autism: Pilot study. *Autism*, 15, 21–42.

Levenson, R. W., & Gottman, J. M. (1983). Marital interaction: physiological linkage and affective exchange. *Journal of Personality and Social Psychology*, *45*(3), 587.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., ... & Rutter,

M. (2000). The Autism Diagnostic Observation Schedule—Generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders*, 30(3), 205-223.

Lovaas, O. I. (1987). Behavioral treatment and normal educational and intellectual functioning in young autistic children. *Journal of Consulting and Clinical Psychology*, *55*(1), 3.

Lunkenheimer, E., Tiberio, S. S., Buss, K. A., Lucas-Thompson, R. G., Boker, S. M., & Timpe, Z. C. (2015). Coregulation of respiratory sinus arrhythmia between parents and preschoolers: Differences by children's externalizing problems. *Developmental Psychobiology*, *57*(8), 994-1003.

Luyster, R., Gotham, K., Guthrie, W., Coffing, M., Petrak, R., Pierce, K., ... & Richler, J. (2009). The Autism Diagnostic Observation Schedule—Toddler Module: A new module of a standardized diagnostic measure for autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 39(9), 1305-1320.

Lydon, S., Healy, O., Reed, P., Mulhern, T., Hughes, B. M., & Goodwin, M. S. (2016). A systematic review of physiological reactivity to stimuli in autism. *Developmental Neurorehabilitation*, *19*(6), 335-355.

Manini, B., Cardone, D., Ebisch, S., Bafunno, D., Aureli, T., & Merla, A. (2013). Mom feels what her child feels: thermal signatures of vicarious autonomic response while watching children in a stressful situation. *Frontiers in Human Neuroscience*, *7*, 299.

McElwain, N. L., Booth-LaForce, C., Lansford, J. E., Wu, X., & Justin Dyer, W. (2008). A process model of attachment–friend linkages: Hostile attribution biases, language ability, and mother–child affective mutuality as intervening mechanisms. *Child Development*, *79*(6), 1891-1906.

Mullen, E. M. (1995). Mullen scales of early learning (pp. 58-64). Circle Pines, MN: AGS.

Müller, V., & Lindenberger, U. (2011). Cardiac and respiratory patterns synchronize between persons during choir singing. *PloS One*, *6*(9), e24893.

Neuhaus, E., Beauchaine, T. P., & Bernier, R. (2010). Neurobiological correlates of social functioning in autism. *Clinical Psychology Review*, *30*(6), 733-748.

Orsmond, G. I., Shattuck, P. T., Cooper, B. P., Sterzing, P. R., & Anderson, K. A. (2013). Social participation among young adults with an autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *43*(11), 2710-2719.

Palumbo, R. V., Marraccini, M. E., Weyandt, L. L., Wilder-Smith, O., McGee, H. A., Liu, S., & Goodwin, M. S. (2017). Interpersonal autonomic physiology: A systematic review of the literature. *Personality and Social Psychology Review*, *21*(2), 99-141.

Poh, M. Z., Swenson, N. C., & Picard, R. W. (2010). A wearable sensor for unobtrusive, long-term assessment of electrodermal activity. *IEEE Transactions on Biomedical Engineering*, *57*(5), 1243-1252.

Prince, E. B., Kim, E. S., Wall, C. A., Gisin, E., Goodwin, M. S., Simmons, E. S., ... & Shic, F. (2017). The relationship between autism symptoms and arousal level in toddlers with autism spectrum disorder, as measured by electrodermal activity. *Autism*, *21*(4), 504-508.

Raudenbush, S. W., Bryk, A. S., Cheong, A. S., Fai, Y. F., Congdon, R. T., & du Toit, M.

(2011). HLM 7: Hierarchical linear and nonlinear modeling. Lincolnwood, IL: Scientific Software International.

Rosenthal, T. L., & Zimmerman, B. J. (2014). *Social learning and cognition*. Academic Press.

Sameroff, A. (2009). *The Transactional Model*. American Psychological Association.

Sameroff, A. J., & Fiese, B. H. (2000). Transactional regulation: The developmental ecology of early intervention. *Handbook of Early Childhood Intervention*, *2*, 135-159.

Seltzer, M. M., Shattuck, P., Abbeduto, L., & Greenberg, J. S. (2004). Trajectory of development in adolescents and adults with autism. *Mental Retardation and Developmental Disabilities Research Reviews*, *10*(4), 234-247.

Schoen, S. A., Miller, L. J., Brett-Green, B., & Hepburn, S. L. (2008). Psychophysiology of children with autism spectrum disorder. *Research in Autism Spectrum Disorders*, *2*(3), 417-429.

Schreibman, L., & Ingersoll, B. (2005). Behavioral Interventions to Promote Learning in Individuals with Autism. In F. R. Volkmar, R. Paul, A. Klin, & D. Cohen (Eds.), *Handbook of autism and pervasive developmental disorders: Assessment, interventions, and policy* (pp. 882-896). Hoboken, NJ, US: John Wiley & Sons Inc.

Schreibman, L., Kaneko, W. M., & Koegel, R. L. (1991). Positive affect of parents of autistic children: A comparison across two teaching techniques. *Behavior Therapy*, *22*(4), 479-490.

Sethre-Hofstad, L., Stansbury, K., & Rice, M. A. (2002). Attunement of maternal and child adrenocortical response to child challenge. *Psychoneuroendocrinology*, *27*(6), 731-747.

Schreibman, L., Dawson, G., Stahmer, A. C., Landa, R., Rogers, S. J., McGee, G. G., ... & McNerney, E. (2015). Naturalistic developmental behavioral interventions: Empirically validated treatments for autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *45*(8), 2411-2428.

Siller, M., & Sigman, M. (2008). Modeling longitudinal change in the language abilities of children with autism: Parent behaviors and child characteristics as predictors of change. *Developmental Psychology*, *44*(6), 1691.

van Dooren, M., & Janssen, J. H. (2012). Emotional sweating across the body: Comparing 16 different skin conductance measurement locations. *Physiology & Behavior*, *106*(2), 298-304.

Skowron, E. & Hastings, P. (2014). Examining the importance of physiological self-regulation for parenting across the spectrum of risk. Symposium presented at the Society for Research in Child Development Special Topic Meeting on New Conceptualizations in the Study of Parenting-At-Risk. San Diego, CA.

Verschuur, R., Didden, R., Lang, R., Sigafoos, J., & Huskens, B. (2014). Pivotal response treatment for children with autism spectrum disorders: A systematic review. Review *Journal of Autism and Developmental Disorders*, 1(1), 34-61.

Vernon, T. W. (2014). Fostering a social child with autism: A moment-by-moment sequential analysis of an early social engagement intervention. *Journal of Autism and Developmental Disorders*, *44*(12), 3072-3082.

Vernon, T. W., Holden, A. N., Barrett, A. C., Bradshaw, J., Ko, J. A., McGarry, E. S., ... &

German, T. C. (2019). A pilot randomized clinical trial of an enhanced pivotal response treatment approach for young children with autism: The PRISM model. *Journal of Autism and Developmental Disorders*, *49*(6), 2358-2373.

Vernon, T. W., Koegel, R. L., Dauterman, H., & Stolen, K. (2012). An early social engagement intervention for young children with autism and their parents. *Journal of Autism and Developmental Disorders*, *42*(12), 2702-2717.

Wainer, A. L., Pickard, K., & Ingersoll, B. R. (2017). Using web-based instruction, brief workshops, and remote consultation to teach community-based providers a parent-mediated intervention. *Journal of Child and Family Studies*, *26*(6), 1592-1602.

Waters, S. F., West, T. V., & Mendes, W. B. (2014). Stress contagion: Physiological covariation between mothers and infants. *Psychological Science*, *25*(4), 934-942.

Williams, S. R., Cash, E., Daup, M., Geronimi, E. M., Sephton, S. E., & Woodruff-Borden, J. (2013). Exploring patterns in cortisol synchrony among anxious and nonanxious mother and child dyads: A preliminary study. *Biological Psychology*, *93*(2), 287-295.

Yirmiya, N., Gamliel, I., Pilowsky, T., Feldman, R., Baron-Cohen, S., & Sigman, M. (2006). The development of siblings of children with autism at 4 and 14 months: Social engagement, communication, and cognition. *Journal of Child Psychology and Psychiatry*, *47*(5), 511-523.

Table 1

Pre-Trial Between Group Demographic and Measure Comparisons

Variable	ASD Group (n=9)	TD Group (n=10)
Mean child age in years (SD)	38 (9.34)	29.56 (7.13)
Child is male (%)	100	50
Primary caregiver is female (%)	88.9	100
Mean annual family income		
Less than $25,000 (%)	11.1	10.0
$25,000-$74,999 (%)	0	0
$75,000-$99,999 (%)	11.1	10.0
$100,000-$149,999 (%)	11.1	40.0
$150,000+ (%)	66.7	10.0
Not reported (%)	0	30.0
Race/ethnicity (child/parent)		
Caucasian, non-Hispanic (%)	44.4/44.4	50.0/40.0
Hispanic (%)	0/0	20.0/20.0
Asian (%)	22.2/22.2	10.0/20.0
Black (%)	0/0	0/0
Multiracial (%)	22.2/22.2	20.0/20.0
Other (%)	11.1/11.1	0/0
Mullen Cognitive T-Score (SD)	122 (44.5)	Not Administered
SRS Total T-Score (SD)	75.4 (16.9)	46.3 (4.1)
Range of correlations between parent and child EDA	-.94-.92	-.82-.27
Range of correlation between parent and child HR	-.64-.88	-.98-.85
Proportion of behaviorally coded synchronous engagement	.41 (.15)	.44 (.13)

Table 2

Pre-Post Case Analysis Data for ASD Group

	MB-CDI (Words Said)		Mullen Receptive (T-Score)		Mullen Expressive (T-Score)		ADOS Total Score		EDA Synchrony		HR Synchrony	
	BL	EP	BL	EP	BL	EP	BL	EP	BL	EP	BL	EP
Case 1	90	373	29	57	20	43	14	13	-.26	.12	.11	.56
Case 2	0	4	20	23	20	20	24	21	-.22	-.12	-.23	-.25
Case 3	46	130	20	30	23	33	23	9	-.38	.14	.06	-.40
Case 4	45	99	20	35	21	25	12	8	.72	.41	.26	.30
Case 5	90	373	29	57	20	43	10	7	-.38	-.38	-.23	-.71

Table 3

Pre and Post Trial Assessment Data for ASD Group

Measure	Pre		Post		*t*	*p*	95% CI for d	
	M	*SD*	*M*	*SD*			Low	High
ADOS-2	16.4	6.2	12.4	6.2	1.54	.19	-3.2	11.2
Mullen Receptive Language	26.4	10.1	42.4	20.5	-3.02	.04	-30.7	-1.3
Mullen Expressive Language	25.4	9.9	32.6	12.6	-1.63	.17	-19.4	5.0
Mullen Overall	65.4	18.5	74.8	21.2	-1.57	.19	-26.0	7.2
PLS-5 Auditory Comprehension	79.6	30.6	77.2	19.2	.38	.72	-15.0	19.8
PLS-Expressive Communication	73.2	14.4	75.8	13.4	-.72	.51	-12.6	7.4
PPVT-4 (SS)	80.2	35.5	83.2	30.4	-.80	.47	-13.4	7.4
EVT-3 (SS)	79.2	27.9	77.0	26.2	.28	.72	-18.8	18.2
MB-CDI Words Said	93.8	113.1	196.2	168.8	-2.15	.09	-234.4	29.6

Table 4

Hierarchical Linear Model Predicting Parent-Child EDA and HR Synchrony from ASD Diagnostic Status

	Fixed effect	Coefficient	SE	t ratio	p value
1. Phase 2	Phase 2 EDA Synchrony intercept, β_0				
EDA	Intercept, γ_{00}	-.26	.14	-1.92	.08
	ASD Group, γ_{01}	.28	.21	1.34	.21
2. Phase 2	Phase 2 HR Synchrony intercept, β_0				
HR	Intercept, γ_{00}	-.18	.21	-.85	.41
	ASD Group, γ_{01}	.22	.25	.88	.40
3. Phase 3	Phase 3 EDA Synchrony intercept, β_0				
EDA	Intercept, γ_{00}	-.03	.07	-.45	.66
	ASD Group, γ_{01}	.05	.16	.33	.75
4. Phase 3	Phase 3 HR Synchrony intercept, β_0				
HR	Intercept, γ_{00}	.23	.22	1.05	.31
	ASD Group, γ_{01}	-.25	.26	-.97	.35

Table 5

Hierarchical linear model predicting parent-child EDA and HR synchrony from time point

	Fixed effect	Coefficient	SE	t ratio	p value
1. Phase 2	Phase 2 EDA Synchrony intercept, β_0				
EDA	Intercept, γ_{00}	-.52	.56	-.94	.38
	Time, γ_{01}	.43	.35	1.24	.25
2. Phase 2	Phase 2 HR Synchrony intercept, β_0				
HR	Intercept, γ_{00}	-.22	.46	-.48	.65
	Time, γ_{01}	.28	.29	.98	.36
3. Phase 3	Phase 3 EDA Synchrony intercept, β_0				
EDA	Intercept, γ_{00}	.50	.40	1.27	.24
	Time, γ_{01}	-.38	.22	-1.68	.13
4. Phase 3	Phase 3 HR Synchrony intercept, β_0				
HR	Intercept, γ_{00}	.34	.44	.77	.47
	Time, γ_{01}	-.15	.28	-.54	.61

Table 6

Descriptive Statistics and Correlations for Baseline Variables

Variable	*n*	*M*	*SD*	1	2	3	4	5	6	7
1. EDA Synchrony	5	-.10	-.46	-						
2. HR Synchrony	5	.01	.20	.59	-					
3. Behaviorally Coded Synchrony	5	.41	.15	.25	.41	-				
4. Parent Eye Contact	5	.66	.16	-.65	-.89*	-.16	-			
5. Child Eye Contact	5	.09	.04	-.46	.26	.31	.02	-		
6. Parent Positive Affect	5	.35	.24	-.39	.14	.84	.27	.49	-	
7. Child Positive Affect	5	.17	.09	.18	.77	.87	-.48	.35	.71	-

*Significant correlation at the .05 level

Table 7

Descriptive Statistics and Correlations for Endpoint Variables

Variable	*n*	*M*	*SD*	1	2	3	4	5	6	7
1. EDA Synchrony	5	.02	.29	-						
2. HR Synchrony	5	-.09	.50	.53	-					
3. Behaviorally Coded Synchrony	5	.44	.13	.45	.81	-				
4. Parent Eye Contact	5	.64	.11	-.05	.72	.91*	-			
5. Child Eye Contact	5	.11	.03	.44	.17	-.31	-.04	-		
6. Parent Positive Affect	5	.24	.15	.22	.69	.90*	-.87	.31	-	
7. Child Positive Affect	5	.22	.12	.61	.29	.13	.44	.83	-.14	-

*Significant correlation at the .05 level