Journal of Developmental and Physical Disabilities
https://doi.org/10.1007/s10882-023-09940-6

ORIGINAL ARTICLE

The Relationship Between Parent-Child Movement Synchrony and Social Behavior of Children Diagnosed with Autism Spectrum Disorder and Children Diagnosed with Down Syndrome

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Accepted: 20 October 2023

Abstract

Purpose: Dyadic synchrony is positively associated with social competence. Although children diagnosed with Autism Spectrum Disorder (ASD) and children diagnosed with Down Syndrome (DS) both have trouble with dyadic synchrony, the origin of their difficulties is fundamentally different. In this mixed method study, we investigated differences in dyadic synchrony and social behavior between children diagnosed with ASD and DS. **Methods:** Twenty-seven children diagnosed with ASD (10 cisgender females; *M*age = 10.98 years; *SD* = 2.21) and twenty-five children diagnosed with DS (11 cisgender females; *M*age = 11.91 years; *SD* = 2.27) performed a collaborative drawing task with a parent in which they had to synchronize their drawing movements. We continuously tracked their dominant hand movements using wearable accelerometers, and performed Cross-Recurrence Quantification Analysis to extract synchrony measures. Additionally, we compared the social behaviors (interpersonal synchrony, emotion regulation, and social cognition, motivation, and confidence) of these children using quantitative parental questionnaires. **Results:** Parent-child synchrony measures were significantly higher for children diagnosed with ASD. Yet, parents were significantly more positive about the social behaviors of children diagnosed with DS. No significant correlation between the synchrony and questionnaire measures was found. **Conclusion:** While children diagnosed with ASD synchronize better during a collaborative task, the social behavior of the children diagnosed with DS (including social synchrony) is more positively evaluated by their parents. Possible reasons for this discrepancy are discussed.

Keywords Recurrence · Attunement · Collaboration · Interpersonal Synchrony · Social Difficulties

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Published online: 31 October 2023

Interpersonal synchrony is a co-regulated and reciprocal rhythmic pattern of two individuals interacting (Feldman et al., 2014; Golds et al., 2022; Harrist & Waugh, 2002; Leclère et al., 2014). This mutual pattern, in which one interaction partner reacts, adds to, and anticipates on the actions and verbalizations of the other interaction partner occurs naturally, in the same or in different modalities. The earliest manifestation of interpersonal synchrony can be found in caregiver-child interactions, starting in infancy and occurring on a day-to-day basis throughout childhood and beyond (Feldman, 2007). In the most optimal situation, caregivers respond to infants' movements and sounds by providing the care or attention the child 'asks for' (Stern et al., 1987). The same reciprocal temporal structure can be seen in playful interactions between parents and their children—and later in caregiver-child conversations—increasingly initiated by the children themselves as they age (Harrist & Waugh, 2002).

Although interpersonal synchrony has been studied on neural and physiological levels (Birk et al., 2022), many studies focus on behavioral and affective accounts of synchrony in parent-child dyads (Rennung & Göritz, 2016). Frequently experiencing caregiver-child synchrony during infancy and early childhood is associated with better outcomes at a later age. Most of these positive outcomes are defined in the social domain, such as social competence and confidence (Harrist & Waugh, 2002), prosocial behavior (Rabinowitch & Meltzoff, 2017; Trainor & Cirelli, 2015), and emotion regulation (Hu et al., 2022; Leclère et al., 2014). On the other hand, a lack of affective or behavioral synchrony in caregiver-child interactions is associated with later maladaptive social behavior (Harrist & Waugh, 2002; Leclère et al., 2014). Since both caregiver and child shape their interpersonal synchrony together, previous research has shown that synchrony can be compromised when the responsivity of one interaction partner is limited, for example in the case of parental depression or stress (Golds et al., 2022) or when children are diagnosed with a neurodevelopmental disorder, such as Down Syndrome (DS; Sigman & Ruskin, 1999; Van Gameren-Oosterom et al., 2011) or Autism Spectrum Disorder (ASD; Lense et al., 2021; Saint-Georges et al., 2011).

Although the social difficulties of both children diagnosed with ASD and children diagnosed with DS limit their ability to engage in synchronous interactions (Lense et al., 2021; Sigman & Ruskin, 1999; Udhnani et al., 2020), it is important to recognize that the nature of their social difficulties seems fundamentally different. While children diagnosed with DS are often seen as highly social (Næss et al., 2016), they experience motor abnormalities, a cognitive delay, and attention and language difficulties (Udhnani et al., 2020). Difficulties with language acquisition (Adamson et al., 2009) and rhythm and timing impairments (Lense et al., 2021) limit children diagnosed with DS in establishing synchrony with others. The communicative difficulties of children diagnosed with DS have been associated with emotional and behavioral problems, such as social withdrawal, oppositional behavior, or ADHD (Van Gameren-Oosterom et al., 2011). Indeed, a large cohort study ($n=320$) found that children diagnosed with DS scored significantly higher on the social difficulties subscale of the Child Behavior Checklist (CBCL; Achenbach & Ruffle, 2000) compared to a normative sample ($d=1.55$; Van Gameren-Oosterom et al., 2011). In another study on children diagnosed with DS, Næss et al. (2016) used the Strengths and Difficulties

Questionnaire (SDQ, Goodman, 1997) and concluded that the social functioning of children with DS was weaker compared to typically developing children.

Children diagnosed with ASD, on the other hand, show more apparent difficulties in achieving reciprocity with others, the use of nonverbal communication, and understanding and engaging in relationships (American Psychiatric Association, 2013; Lord & Bishop, 2021). Given the inherently social nature of these difficulties, and the notable lack of reciprocity as one of the diagnostic criteria (American Psychiatric Association, 2013), the number of studies focusing on the impaired synchrony between children diagnosed with ASD and their caregivers is greater. These studies mostly show that children diagnosed with ASD attend less to their caregiver's communicative attempts, such as seeking eye contact, their gaze directions and gestures, as well as their verbalizations, and also initiate less contact themselves (e.g., Maestro et al., 2005; Saint-Georges et al., 2011; Wan et al., 2012; Zampella et al., 2020). Importantly, successful synchronization between caregivers and children diagnosed with ASD is positively associated with higher levels of adaptive social behavior (Crowell et al., 2019; Patterson et al., 2014).

Only a few studies compare the synchronous caregiver-child interactions of children diagnosed with DS and ASD. Saint-Georges and colleagues (2011), for instance, found that children with an intellectual disability display an early delay in synchronous behavior with their caregiver, but catch up with typically developing infants during the first year of life. Children diagnosed with ASD, on the other hand, display a different pattern of orienting less to their caregivers. These children also seem to catch up—to a smaller extent— after their first year, but their increase is mostly receptive, that is, they are mostly responding to others instead of initiating contact. This receptive behavior then also declines after one year of age. In another study, Adamson and colleagues (2009) investigated caregiver-child joint engagement of toddlers diagnosed with ASD or DS. Their results indicate that children diagnosed with ASD engaged less in joint attention periods compared to typically developing toddlers. The children diagnosed with DS focused more on their caregivers, but rarely on the symbols or objects used during their interaction needed for joint attention, and hence, to establish synchrony.

Notably, the small number of studies that compare synchrony in dyads with children diagnosed with ASD and DS focus on early childhood. Yet, as Harrist and Waugh (2002) postulated two decades ago, establishing synchrony with others is important *beyond* infancy. Synchrony at a later age likely serves the purpose of relation building or maintenance, but also becomes more complex to measure, which could be a reason why the majority of the research on parent-child synchrony is conducted during infancy and early childhood (Birk et al., 2022). Yet, research has indicated that interpersonal synchrony at older ages positively contributes to reasoning about other people's point of view (i.e., theory of mind), thereby fostering social cooperation (Baimel et al., 2015). A systematic review on behavioral synchrony in later childhood (5–18 years of age) showed that higher levels of parent-child synchrony are related to better social outcomes in typically developing children (Birk et al., 2022). Specifically, better social skills and fewer antisocial behaviors were mentioned (Criss et al., 2003), as well as more advanced moral reasoning (Hinnant et al., 2013). These posi-

tive social outcomes are similar to what has been found in early childhood studies (Leclère et al., 2014).

Whereas synchrony in dyads with infants and toddlers is often measured by systematically observing interactions during free play or in collaborative tasks (Adamson et al., 2009; Endedijk et al., 2015; Leclère et al., 2014; Rabinowitch & Meltzoff, 2017), studies with older children often measure synchrony during parent-child discussions (Birk et al., 2022), or by measuring the movements of interaction partners (Bernieri & Rosenthal, 1991; Fitzpatrick et al., 2018; Gueugnon et al., 2016; Harrist & Waugh, 2002). A systematic review found three studies on interpersonal movement synchrony with children diagnosed with ASD, one conducted in middle childhood, and one in early adolescence (Baldwin et al., 2022). In both studies, children diagnosed with ASD showed less synchronization with typical developing peers while performing a pendulum coordination task during which their movements were continuously measured (Fitzpatrick et al., 2016, 2017). Another recent study in which raters observed mother-child interactions of adolescents showed a significant difference in the way adolescents with ASD moved their bodies during mother-child conversations, as opposed to typically developing children (Zampella et al., 2020). These findings seem to be in line with a study by Marsh et al. (2013) in which 4- to 9-year old children diagnosed with ASD showed less in-phase rocking behavior with their parents while seated in rocking chairs, compared to typically developing peers. Research on interpersonal movement synchrony in (caregiver-child) dyads with older children or adolescents with DS seems absent in the literature. Moreover, no study to date compares the interpersonal movement synchrony of children diagnosed with DS and ASD beyond infancy.

The lack of studies that compare caregiver-child synchrony of older children diagnosed with DS and children with ASD is striking. Comparing and contrasting the way these children's social difficulties manifest, and how this could both cause and be caused by problems with interpersonal synchrony, can be key to the adjustment or design of different aid programs specifically targeting these groups. Studying synchrony is especially relevant beyond infancy, given its importance for relationship-building, whereby the interaction between caregiver and child serves as a model for interactions with others. In the current study, we therefore investigate differences in parent-child movement synchrony between pre- and early-adolescent children diagnosed with ASD and children diagnosed with DS. We also compare the social behaviors of these two groups, and examine whether the synchrony measures relate to children's social behavior. The following three questions guide this study: (1) Are there any differences in social behavioral difficulties between children diagnosed with ASD and DS, as reported by their parents? (2) How can we characterize the parent-child movement synchrony of children diagnosed with ASD and DS during a collaborative task? (3) Are parent-child movement synchrony measures associated with children's social behavioral difficulties?

Method

This study used quantitative parental questionnaire data about their children's social behavior, as well as quantitative movement synchrony measures of parent-child interactions. In accordance with studies that measure interpersonal synchrony in populations beyond infancy (Fitzpatrick et al., 2018), we measure the movements of parents and children while they engage in a collaborative task. This study is part of larger study approved by the ethical review board of the host university and preregistered at the Open Science Framework (doi: https://doi.org/10.17605/OSF.IO/6AJF7).

Participants

A total of 52 participants (8–15 years of age) took part in this study (M_{age} = 11.43 years; SD=2.27 years). Most children lived with two (biological) parents, seven children had one parent at home, and two children lived in a long-term foster care placement. Parents reported no severe visual-, hearing-, or motor- impairments that would prevent their children from participating in the study. According to the parents, all children were able to understand simple verbal instructions, were able to perform this study's tasks, and could express themselves verbally.

Twenty-five children were diagnosed with DS (14 cisgender males, 11 cisgender females; M_{age} = 11.91 years; SD=2.27 years). Parents reported the following co-occurring conditions: Low-impact hemiplegia (n=1) and hyperthyroidism (n=1). According to the parents, most children were diagnosed with a mild intellectual disability (IQ range 50–69; n=11), three children were diagnosed with a moderate intellectual disability (IQ range 25–49), and three were diagnosed at borderline intellectual disability (IQ range 70–79). The IQ scores of 8 children were unknown. Twenty-seven children were diagnosed with ASD (17 cisgender males, 10 cisgender females; M_{age} = 10.98 years; SD=2.21 years). According to their parents the children were diagnosed with: ASD "requiring support" (n=7), ASD "requiring substantial support" (n=4), Asperger syndrome (n=3), Pervasive Developmental Disorder not otherwise specified (n=3), 16p13.11 micro duplication with autistic features (n=1), and ASD diagnosis without any further specification (n=9). Parents reported the following co-occurring conditions: ADHD (n=7), anxiety (n=4), genetic obesity (n=1), attachment difficulties (n=1), and tics (n=1). According to the parents, the intellectual functioning of the children diagnosed with ASD was assessed as mild intellectual disability (IQ range 50–69; n=2), borderline intellectual disability (IQ range 70–79, n=4), below average (IQ range 80–89, n=5), average (IQ range 90–109; n=7), high average (IQ range 110–119, n=5), and well-above average (IQ range 120–129, n=2). For two children the IQ scores were unknown.

There was no significant age difference between the children diagnosed with ASD and DS, $t(50)=1.50$, $p=.14$. The difference in the division of (cisgender) males and females between the two diagnosis groups was also not statistically significant $\chi^2(1, N=52)=0.261$, $p=.61$. There was, however, a significant association between the participants' diagnosis and IQ. The children diagnosed with DS had lower IQ scores, $\chi^2(7, N=52)=31.94$, $p<.001$, Cramer's $V=0.78$, which seems to be in line with population estimates (Sigman & Ruskin, 1999).

Procedure

Parents were recruited via social media and parent organizations for children diagnosed with ASD or DS in the Netherlands. After signing up on the research website, parents received an information package about the study, including icon images to explain the study to their child. All parents signed a consent form, were free to withdraw from the study at any moment without any consequences, and were encouraged to ask any questions they might have.

After giving consent, parents received a link to an online questionnaire about their child's social behavior, designed with the program Qualtrics (https://www.qualtrics.com). The questionnaire (see below) contained open- and close-ended questions and could be completed in 10 min at the parent's own convenience. The data were stored on a secure drive.

After the questionnaire was completed, a researcher visited each parent-child pair at their home to explain the study and to administer the collaborative task during which their movement synchrony was measured. We administered a task similar to tasks that have been used before to study interpersonal movement coordination. Examples are a joint tower building task (Abney et al., 2015), simultaneous finger tapping (Kodoma et al., 2015), jointly navigating a ball through a labyrinth (Lang et al., 2016), pendulum coordination tasks (e.g., Fitzpatrick et al., 2016;, 2017; Varlet et al., 2014), and a task in which participants are asked to coordinate their movements while sliding a handle along a string (Gueugnon et al., 2016). Importantly, we wanted our task to be (a) a task in which interpersonal coordination of (fine motor) movements was required, (b) meaningful for children, (c) understandable for children diagnosed with an intellectual disability, and (d) easy to set up at the children's home environment. We considered the drawing task described below as fulfilling all four requirements, as well as sufficiently similar to tasks used in earlier research.

A protocol was followed to make sure all drawing tasks were conducted in a similar way. The parent and child were asked to take a seat at a table, facing each other with a transparent screen (297×420 mm) in between. Using a dry erase marker, the parent and child were asked to draw a house on their own side of the screen, at the same time (see Fig. 1). They were instructed to draw the exact same house by following the other person's movements. The participants were allowed to verbalize their intentions and to discuss their next steps to make the drawings match, if they considered this helpful. Participants could draw matching elements such as windows or a chimney, as long as they kept following each other's movements. All dyads decided to do this, without any exceptions. On average, it took participants with DS 2.10 min ($SD = 1.01$) and participants with ASD 2.70 min (SD = 1.82) to complete this task together.

The online questionnaire was specifically designed for this study. Parents were asked to indicate how often their child showed the (social) behaviors mentioned in the items during the last month using a five-point Likert scale with the options never, seldom, sometimes, often, and very often (Table 1). The 66 items were based on five relevant constructs in the literature about social functioning: Interpersonal synchrony and social attunement (Harrist & Waugh, 2002; Leclère et al., 2014), social cognition and understanding social information (Gallese et al., 2004; Hartman et al., 2006),

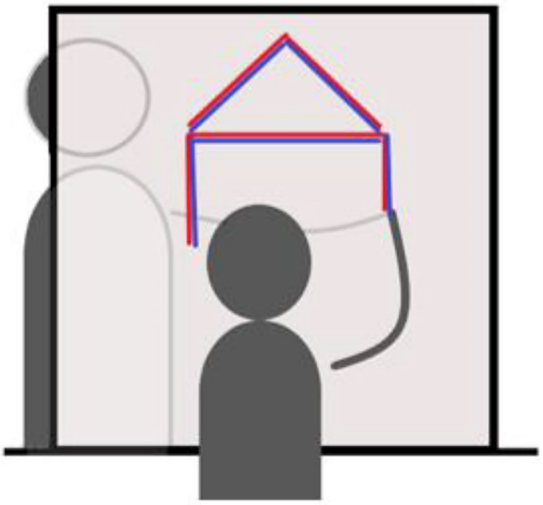

Fig. 1 Setup of the collaborative drawing task

Table 1 Example items and internal consistency of questionnaire scales

Scale	Number of items (*n*)	Example items *In the last month, my child…*	Cronbach's alpha (α)	McDonald's omega (ω)
Interpersonal synchrony	14	• Seemed to live in their own world • Seemed to be on another wavelength	0.81	0.80
Social cognition	10	• Did not understand the core of a conversation • Did not understand others' actions	0.82	0.82
Emotion regulation	17	• Got upset easily • Had a hard time to be in control of emotions	0.88	0.88
Social motivation	10	• Sought contact with other children • Responded to other children's requests	0.80	0.76
Social confidence	9	• Was confident in contact with others • Stood up for him/herself	0.84	0.84

Note. Example items are translated from Dutch. McDonald's omega (ω) was calculated using the Hayes macro for SPSS (Hayes & Coutts, 2020)

emotion regulation and impulse control (Mazefsky & White, 2014), social motivation and interest in others (Hartman et al., 2006), and social anxiety/confidence (Connor et al., 2020). Items were both positively and negatively phrased. Prior to the study, six experts from the network of the authors, who work with the target groups in clinical practice or research, confirmed they considered the questionnaire suitable to measure children's social strengths and problems.

A factor analysis on the items with oblique rotation confirmed the existence of the five constructs mentioned above. These five factors accounted for 53.87% of the variance and had items that matched the five constructs. Based on the scale-if-item-deleted analysis, six items were removed from the questionnaire (two items within the social motivation scale, one item in each of the other scales), resulting in a total of 60 items. The resulting scales were computed by adding all scores on the items

belonging to that scale. Negatively phrased items were converted so that a higher scale score represented a more positive view of the child's behaviors. Table 1 presents the final five scales with an example item and two measures of internal consistency, reflecting a good average degree of interrelatedness among the items within each scale (Sijtsma, 2009; Taber, 2018).

Parent-Child Synchrony

During the collaborative drawing task, we continuously measured the X, Y, and Z coordinates of the position of the parent's and child's dominant hand using wearable sensors (Mbientlab, 2017) containing a three-axis accelerometer. The sensors were attached on top of a wristband, measuring the hand's position. The sensors were connected to a smartphone app (Mbientlab, 2017) of the researcher by means of Bluetooth. The smartphone app first synchronized the two sensors before data collection started. When the parent and/or the child indicated the drawing was ready, the researcher used the app to switch the sensors off and downloaded CSV files with the position data, i.e., coordinates for each data point and a timestamp. Hand movements were sampled by the devices with an average sample rate of either 12.5 or 25.0 Hz (12.5 or 25.0 data points per second). Due to this difference, the timeseries sampled at 25 Hz were down sampled with a factor 2. Furthermore, timeseries were low-pass filtered using a low-pass Butterworth filter with a cut-off frequency of 6 Hz before being processed further.

In the data preparation, we focused on the child's and parent's acceleration profiles, that is, changes in the absolute velocity of their movements. These profiles are closely related to processes of movement initiation and reaction (Elliott et al., 1991; Jeannerod, 1984), and hence, reflect parent-child synchrony during the task. We analyzed these acceleration profiles with cross-recurrence quantification analyses (CRQA) using the CRP tool (Marwan et al., 2007). Specifically, CRQA captures recurring patterns between two coupled systems (see for elaborate discussion on the mathematical underpinnings, Riley & Van Orden, 2005; Shockley et al., 2002; Webber & Zbilut, 2005; Cox et al., 2016). In the current study, these two coupled systems are represented by the time series of the acceleration produced by the parent and the time series of the acceleration produced by the child. Measures derived from CRQA (see below) indicate how often movement patterns recur between child and parent, for how long these recurring patterns persists, and whether the coupling is more rigid or flexible. Given that the CRQA for continuous data requires a reconstruction of the timeseries in a multidimensional phase space, three key parameters need to be defined. First, using the Average Mutual Information (Fraser & Swinney, 1986), we established the time delay ($tau = 1$) at which the coupled timeseries are compared. Next, the necessary number of dimensions ($m = 4$) was determined. Adding more dimensions can help to identify which movements are recurring and which ones are not. That is, a lower number of dimensions can lead to falsely identifying patterns that could be more accurately distinguished when more dimensions are available. To give an example, a cube may appear as a square when it is viewed only from the front. Once the cube is turned and the third dimension becomes visible, the distance between the points on the z-axis can be determined. To identify how many of such

dimensions are required to avoid incorrect inferences for recurrence, the False Nearest Neighbors (Kennel et al., 1992) analysis was conducted. The threshold ($\epsilon = 0.50$) was established, which represents the maximum distance between two points in order to labeled 'recurrent'. Finally, the minimum length of a deterministic pattern was set to 12 recurrent points, which represents a duration of about one second. To optimize comparisons between all dyads, we tailored one parameter setting to all analyses (i.e., *tau* = 1, $m = 4$, □ = 0.50). The analyses were double-checked with slight variations of these parameters (see Supplementary files).

CRQA yields several measures (Marwan et al., 2007). First, the overall *Recurrence Rate* is the proportion of all points that were identified as recurrent. This means that the higher the recurrence rate is, the more synchronous the time series of the child and caregiver are. *Laminarity* reflects synchrony in periods in which the shared state of the two time series in the phase space does not change at all (or very little). This means that the caregiver-child dyad moves in the same way for a while, or rests at the same time. *Determinism*, on the other hand, reflects synchrony during changing states. For example, when child and parent guide each other through changing movement patterns over some period of time, the degree of determinism increases. The *Mean Diagonal Line* represents the average length of all deterministic patterns in the dyadic movements, of at least 12 recurrent points. Finally, *Entropy* relates to the amount of repetitive information in the deterministic structure of the movements, based on Shannon's (1948) entropy of the distribution of lengths of the recurrent patterns. If this value is low, the dyadic system has a relatively simple dynamic. High values show that the synchronous movements of the two interaction partners are changing continuously, and, hence, are likely to be more adaptive to each other. Taken together, the results of the CRQA demonstrate how synchronized and persistent the movement patterns of the child-parent dyad are.

Analysis

A power analysis was conducted using G*Power 3.1 (Faul et al., 2009) to test the difference between the two groups in a Multivariate Analysis of Variance (MANOVA), using an effect size of $F^2(V) = 0.49$, and an alpha of 0.05. Results showed that our total sample of 52 participants divided in two groups yields a power of 0.97. We then examined if the data did not violate assumptions of normality, homoscedasticity, and no multicollinearity. For the first and third research question, we analyzed the data of 51 dyads, as the questionnaire data of one participant diagnosed with ASD was missing. For the second research question, we used the data of 52 dyads.

To answer the first question about differences in social behavioral difficulties and strengths between children diagnosed with ASD and DS, we performed a MANOVA. Children's diagnosis (ASD or DS) was added as the independent variable, and children's age and sex were added as covariates, since synchrony seems to become more complex with age (Harrist & Waugh, 2002) and since earlier research has documented a difference between same-gender and other-gender parent-child dyads, albeit in infancy (Feldman, 2003). The scores on the five subscales of the questionnaire served as dependent variables. The MANOVA was followed up by a discriminant function analysis to further interpret differences in subscale scores.

To answer the second research question about the difference in parent-child movement synchrony of children diagnosed with ASD and DS during the collaborative task, we performed a similar MANOVA, with the CRQA measures Recurrence Rate (RR), Laminarity (LAM), Determinism (DET), Mean Diagonal Line (MDL), and Entropy (ENT) as dependent variables (see above for an explanation of these measures). This MANOVA was also followed up by a discriminant function analysis to further interpret differences in synchrony measures.

To answer the third research question about the relationship between the questionnaire scores and parent-child synchrony measures, we visually inspected scatter plots of combinations of questionnaire scale scores and synchrony measures and calculated Pearson correlation coefficients for the total group of participants and for the two diagnosis groups separately.

Results

RQ1: Differences in Social Behavior

Table 2 shows the means and standard deviations of the questionnaire scale scores for the group children diagnosed with ASD and DS. The mean scores of children diagnosed with DS are higher on all questionnaire scales, apart from Social cognition (see Fig. 2). The standard deviations are similar in both groups, apart from the Interpersonal synchrony scale.

MANOVA indicated a significant effect of diagnosis on the combination of questionnaire scales, Philai's $V=0.33$, $F(5,43)=4.22$, $p=.003$. The multivariate effect size $f^2(V)$ was 0.49, which can be considered large (Cohen, 1988). Discriminant analyses were used to further interpret the differences in questionnaire scale scores between the two groups. There was a significant difference between the two diagnosis groups ($\Lambda=0.67$, χ^2 $(5)=18.92$, $p=.002$), with an R^2 canonical of 0.33 and an 82.4% correct re-classification. The group centroids of the discriminant function were 0.71 for the DS group and −0.68 for the ASD group. Table 3 shows the standardized canonical correlation coefficients and structure weights. The structure weights show that Emotion Regulation ($r=.77$), Social Confidence ($r=.70$) and Social Motivation ($r=.60$) particularly correlated to the discriminant function (i.e., the difference between the

Table 2 Means and standard deviations of questionnaire data by diagnosis

	Diagnosis	Mean	Std. Deviation
Interpersonal synchrony	DS	40.12	5.93
	ASD	38.62	8.54
Social confidence	DS	29.84	5.75
	ASD	24.42	5.48
Emotion regulation	DS	54.52	7.88
	ASD	45.69	8.58
Social motivation	DS	33.60	5.29
	ASD	29.08	5.59
Social cognition	DS	27.16	5.86
	ASD	27.54	5.91

Note. ASD: $n=26$; DS: $n=25$

Table 3 Standardized Canonical Discriminant Function Coefficients and Structure Weights of questionnaire scale scores

Variable	Standardized Coefficients	Structure Weights
Interpersonal synchrony	−0.10	0.15
Social confidence	0.56	0.70
Emotion regulation	0.71	0.77
Social motivation	0.11	0.60
Social cognition	−0.39	−0.05

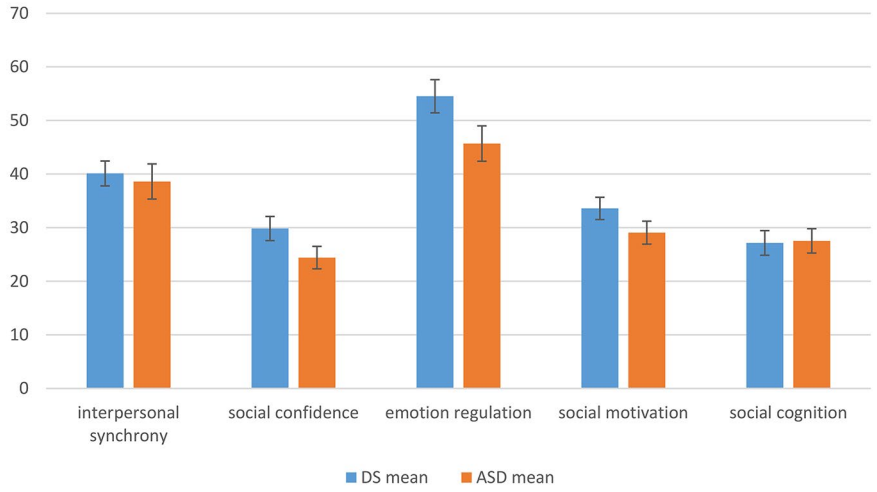

Fig. 2 Mean questionnaire scale scores by diagnosis
Note: Error bars represent 95% confidence intervals

two groups), but not Interpersonal synchrony ($r = .15$) and Social cognition ($r = -.05$). A graphical display of the results (Fig. 2) also shows that children diagnosed with DS scored higher on Emotion regulation, Social Confidence and Social Motivation.

In addition, a significant effect for the covariate Age was found, Philai's $V = 0.35$, $F(5,43) = 4.66$, $p = .002$, but not for the covariate Sex. Bivariate correlations between age and the questionnaire scale scores were low, but positive, for Emotion regulation ($r = .34$, $p = .02$), Social cognition ($r = .27$, $p = .05$), and Interpersonal synchrony ($r = .27$, $p = .06$), indicating that children's scores tended to be higher with age. Correlations were close to zero for Social confidence ($r = .003$, $p = .99$) and Social motivation ($r = -.09$, $p = .55$).

In sum, parents of children diagnosed with DS were significantly more positive about their child's social behavior than the parents of children diagnosed with ASD. The scales Emotion Regulation, Social Confidence and Social Motivation mostly contributed to this difference. Parents also tended to be more positive about their child's behavior with increasing age.

Table 4 Means and standard deviations of synchrony measures by diagnosis

	Diagnosis	Mean	Std. Deviation
Recurrence Rate	DS	0.26	0.13
	ASD	0.27	0.07
Laminarity	DS	0.60	0.20
	ASD	0.64	0.15
Determinism	DS	0.48	0.22
	ASD	0.55	0.14
Mean diagonal line	DS	22.15	7.08
	ASD	22.08	3.53
Entropy	DS	3.13	0.57
	ASD	3.27	0.34

Note. ASD diagnosis: $n=27$; DS diagnosis: $n=25$

Table 5 Standardized Canonical Discriminant Function Coefficients and Structure Weights of synchrony measures

Variable	Standardized Coefficients	Structure Weights
Recurrence Rate (RR)	1.88	−0.08
Laminarity (LAM)	1.44	−0.16
Determinism (DET)	-5.44	−0.28
Mean diagonal line (MDL)	1.35	0.01
Entropy (ENT)	0.83	−0.20

RQ2: Parent-Child Synchrony Measures During Collaborative Drawing Task

Table 4 shows the means and standard deviations of the CRQA synchrony measures for the group children diagnosed with ASD and DS. In contrast to the questionnaire scores, the means of children diagnosed with ASD are higher on all synchrony measures, apart from MDL (see Fig. 3). The standard deviations are higher for the children diagnosed with DS.

MANOVA indicated a significant effect of diagnosis on the combination of synchrony measures (RR, DET, ENT, LAM and MDL), Philai's $V=0.39$, $F(5,44)=5.58$, $p<.001$. The multivariate effect size $f^2(V)$ was 0.64, which again, can be considered large (Cohen, 1988). Discriminant analyses were used to further interpret the differences in synchrony scores between the two groups. There was a significant difference between the two diagnosis groups ($\Lambda=0.65$, χ^2 $(5)=20.18$, $p=.001$), with an R^2 canonical of 0.35 and an 80.8% correct re-classification. The group centroids of the discriminant function were 0.74 for the DS group and −0.69 for the ASD group. Table 5 shows the standardized canonical correlation coefficients, revealing that all variables uniquely contributed to the multivariate effect. The structure weights show that DET ($r=-.28$), ENT ($r=-.20$) and LAM ($r=-.16$) particularly correlated to the discriminant function (i.e., the difference between the two groups), but not MDL ($r=.01$) and RR ($r=-.08$), which had lower structure weights. A graphical display of the results (Fig. 3) reveals the same, and also shows that children diagnosed with ASD scored higher on all synchrony measures, apart from MDL. No significant differences were found for the covariates Age and Sex.

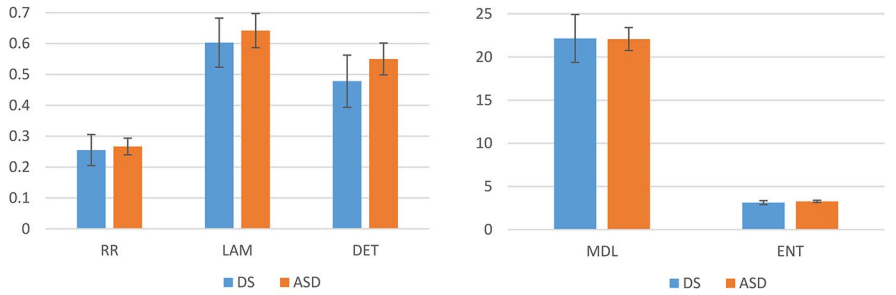

Fig. 3 Means of synchrony measures by diagnosis
Note: The measures RR, LAM and DET represent proportions and are therefore grouped in the same graph. Error bars represent 95% confidence intervals

Table 6 Pearson correlations between questionnaire scores and synchrony measures

		Interpersonal synchrony	Social confidence	Emotion regulation	Social motivation	Social cognition
Total (n=51)	Recurrence Rate	0.08 (0.58)	0.08 (0.58)	−0.07 (0.65)	0.10 (0.48)	−0.06 (0.66)
	Laminarity	0.07 (0.64)	−0.04 (0.77)	−0.10 (0.47)	0.01 (0.93)	−0.12 (0.42)
	Determinism	0.02 (0.88)	−0.01 (0.93)	−0.13 (0.37)	0.01 (0.95)	−0.10 (0.50)
	Mean diagonal line	0.06 (0.66)	0.15 (0.28)	0.07 (0.62)	0.18 (0.20)	−0.10 (0.49)
	Entropy	0.02 (0.87)	0.06 (0.66)	−0.07 (0.61)	0.05 (0.73)	−0.11 (0.44)
ASD (n=26)	Recurrence Rate	0.14 (0.49)	0.01 (0.96)	0.01 (0.97)	−0.08 (0.70)	0.08 (0.70)
	Laminarity	0.24 (0.25)	−0.05 (0.83)	0.06 (0.77)	−0.02 (0.91)	0.14 (0.50)
	Determinism	0.15 (0.48)	−0.06 (0.76)	−0.01 (0.97)	−0.08 (0.68)	0.10 (0.64)
	Mean diagonal line	0.19 (0.36)	0.11 (0.59)	0.12 (0.55)	0.04 (0.86)	0.07 (0.75)
	Entropy	0.15 (0.47)	0.05 (0.81)	0.05 (0.83)	−0.05 (0.83)	0.07 (0.72)
DS (n=25)	Recurrence Rate	0.06 (0.79)	0.19 (0.37)	−0.07 (0.73)	0.28 (0.17)	−0.16 (0.46)
	Laminarity	−0.08 (0.70)	0.05 (0.81)	−0.16 (0.45)	0.13 (0.53)	−0.32 (0.11)
	Determinism	−0.05 (0.81)	0.18 (0.39)	−0.07 (0.75)	0.23 (0.28)	−0.25 (0.23)
	Mean diagonal line	−0.02 (0.93)	-21 (0.33)	0.06 (0.78)	0.30 (0.15)	−0.20 (0.35)
	Entropy	−0.05 (0.80)	0.20 (0.33)	−0.04 (0.84)	0.23 (0.27)	−0.24 (0.24)

Note. p-values within brackets

In sum, caregiver-child dyads with children diagnosed with ASD established more synchrony compared to dyads with children diagnosed with DS. This was particularly visible in the measures Determinism (synchrony during changing movements), Entropy (adapting to each other's movements) and Laminarity (synchrony during rigid movements or rest).

RQ3 Relationship Between Questionnaire Scores and Synchrony Measures

Table 6 shows the Pearson correlations between the questionnaire scale scores and synchrony measures for the total group of participants, and for the children diagnosed

with ASD and the children diagnosed with DS separately. In general, the correlations were weak and not significant, indicating that there were no meaningful linear relationships between the measures of parent-child synchrony and the questionnaire scale scores. A visual inspection of the scatter plots also showed no indications of quadratic, cubic or logarithmic relationships.

Discussion

In this study we compared the social behavior and parent-child movement synchrony of pre- and early-adolescent children diagnosed with ASD or DS, two neurodevelopmental disorders with phenotypic overlap (Morris-Rosendahl & Crocq, 2022). We measured synchrony in the movements of parents and their children during a collaborative drawing task, and related this to parental scores of children's social behavior. The results show that although parents rated the social behavior of children diagnosed with DS as significantly more positive (particularly with regard to emotion regulation, social confidence and social motivation), the synchrony measures of the parent-child dyads were significantly higher for children diagnosed with ASD (particularly the Determinism and Laminarity measures). No significant relationships between synchrony measures and questionnaire data were found. These seemingly conflicting results are puzzling. Although the more positive social behavior of children diagnosed with DS could have been suspected based on previous studies comparing the social strengths and difficulties of these groups (Fisher et al., 2013; Griffith et al., 2010; Sigman & Ruskin, 1999), it is generally accepted that higher levels of parent-child (movement) synchrony are associated with more positive social behavior (Hu et al., 2022; Leclère et al., 2014). Moreover, fine motor skills, such as the skills needed for the drawing task in this study, have also been associated with social communication skills, mostly in children diagnosed with ASD (e.g., Taverna et al., 2021), but also in children diagnosed with Down Syndrome (Volman et al., 2007). Yet, across our sample no relationship between synchrony measures and social behavior scores could be found.

Interestingly, Mayo and Gordon (2020) postulate that—despite the positive associations of interpersonal synchrony in the literature—higher levels of synchrony are not always a good predictor of social functioning. Similar to our study, they found that the scores on the Social Responsiveness Scale of 18 children diagnosed with ASD were unrelated to parent-child synchrony in gaze direction during a face-to-face discussion. In similar vein, Fitzpatrick et al. (2013) found that parental scores of 6-year-old children's social-emotional and adaptive behavior were not associated with interpersonal movement synchrony with an experimenter during a drumming task. Hence, a possible reason for the lack of association between our synchrony scores and questionnaire measures of social behavior might be due to a misinterpretation of the unambiguous positive nature of higher levels of synchrony. Instead, Mayo and Gordon (2020) propose that flexibly moving in and out of synchrony is more adaptive for adequate social functioning than the presence of overall high synchrony levels. Note, however, that Zampella and colleagues (2020) did find a positive association between interpersonal movement synchrony and social and communication

questionnaire scores of adolescents diagnosed with ASD. Yet, an important difference with our study is that Zampella et al. (2020) used rating scales of movement synchrony rather than the continuous movement data that we used in this study. Altogether, combined with earlier findings, our results suggest that we should not only reconsider the dominant view that higher synchrony levels are always associated with more positive social outcomes, but also that different measurements of interpersonal movement synchrony can result in different associations with social and behavioral questionnaire data, at least for children with ASD. Moreover, our study suggests this also applies to children with DS.

Although the collaborative drawing task we used in this study has not been used before, it is comparable to other tasks during which synchrony has been measured, such as the mirror game in which participants are asked to coordinate their movements while sliding a handle along a string (Gueugnon et al., 2016), or joint drumming tasks (Endedijk et al., 2015). Moreover, while synchrony in younger populations is often measured by rating daily interactions in naturalistic settings (Leclère et al., 2014), movement synchrony during tasks has been measured before, also within populations diagnosed with ASD (Isenhower et al., 2012). Yet, what does make our task different compared to observations in daily life, is that parental directiveness could *potentially* contribute to a synchronous movement pattern in this task. For instance, if the parent takes the lead by verbally instructing the child to move the marker, or by always being the first to move the marker when changing directions, the measures Recurrence Rate, Determinism, Laminarity, and Mean Diagonal line would still indicate high levels of synchrony. In contrast, parent directiveness in daily interactions is often designated as a characteristic of low synchrony (Patterson et al., 2014). Moreover, earlier studies found that a considerable number of parents of children with ASD show directiveness in their behavior to their children (Crowell et al., 2019). This could explain their higher levels of synchrony in this study's task compared to children with DS. Note, however, that we did not analyze the spatial position data of the markers on the screen, but instead acceleration profiles—changes in the absolute velocity of the parent's and child's movements—which are harder to consciously direct. In other words, parents can direct their child to go to a particular position on the screen with their marker, but it is harder to influence the child's changes in velocity from one position to the next. Parental directiveness can, therefore, not be the sole explanation for the more positive synchrony outcomes of the children with ASD.

A second possible explanation for the discrepancy in our results is that parents may have different expectations and perceptions of their child's social behavior, which would be reflected in the questionnaire scores, but not in the synchrony measures, thereby creating the discrepancy in our findings. A DS diagnosis is immediately apparent after birth, and might lead parents to adjust their expectations about their child's social skills (Sigman & Ruskin, 1999). Children diagnosed with ASD in contrast, appear like typical developing children at birth. There may be some difficulties in interacting or rigid movements early in life (Osterling et al., 2002), but generally children are not diagnosed before 38 months of age (Canu et al., 2021). This might lead to parents being more vigilant about their child's social difficulties, rating the child's social skills more negatively compared to parents of children with DS, who may have expected social difficulties from the beginning. The fact that 70% of the

children diagnosed with ASD in our sample went to mainstream education, compared to 16% of the children diagnosed with DS, may contribute to parents' perception of their child's social behavior as deviating from the norm. Of course, a combination of both explanations, as well as a possible selection bias—in the sense that parents of more "socially adept" children with DS and less "socially adept" children with ASD signed up for the study— may have contributed to our inconsistent results.

No significant difference in age or gender distribution was found between the two groups. Yet, children diagnosed with DS had significantly lower intelligence levels. Whereas it is unlikely that intelligence affects children's movement and ability to synchronize in a *direct* way, it is possible that children with lower intelligence levels had trouble to understand the task instructions, resulting in lower synchrony scores. Due to the high association between IQ category and diagnosis (multicollinearity), we could not add intelligence level as a covariate to our analysis. For the purpose of this discussion, however, we analyzed the association between IQ and the synchrony measures post hoc. No significant association was found, overall and within each diagnosis group (see supplementary files). This suggests that intelligence level may not contribute as much to the difference in synchrony as other characteristics of the children in our sample.

Limitations and Future Directions

This study used a specific task to measure parent-child synchrony, whereas previous studies with younger children diagnosed with ASD and DS mostly used observational methods (Leclère et al., 2014). While the choice for this task was deliberate, in line with other studies (e.g., Gueugnon et al., 2016), it would be worthwhile to replicate this study in a more naturalistic setting, especially given the absence of an association between the questionnaire and synchrony measures, and to associate our CRQA measures with qualitative rating scales of caregiver-child synchrony, such as the scale used by Zampella et al. (2020). Future studies could also test if the hypothesis of Mayo and Gordon (2020)—flexibly moving in and out of synchrony is more adaptive than high levels of interpersonal synchrony—also applies to dyads with children with ASD or DS.

The questionnaire we used was specifically designed for this study, as existing, validated questionnaires seemed more applicable for screening and diagnosis, and focus less on the relevant aspects of social (synchronous) behavior for this study. Yet, although our questionnaire was first subjected to a factor analysis and validated by asking expert opinions, it could be further validated to assess its usefulness in measuring social difficulties. Moreover, although the groups were comparable in age and gender, both children diagnosed with DS and ASD can display a wide range of social difficulties and strengths, motor impairments, attention problems, and language and communication skills (Sigman & Ruskin, 1999). It is, therefore, important that future studies go beyond simply categorizing children by diagnosis and take other differences between children into account (Griffith et al., 2010). In light of the task we used, this is particularly valuable when it comes to children's visual-perceptual and fine motor skills. Although we asked parents as part of the inclusion criteria if their children had any visual or motor problems, we did not specifically measure children's visual-perceptual and fine motor skills as part of this study. Lastly, in future research the Diagonal Recurrence Profiles (Paxton & Dale, 2017)

could be analyzed to see whether the children diagnosed with DS and ASD differed in taking the lead during the task, or letting their parent take the lead. This could be supplemented by measures of parental and child directiveness or responsiveness to paint a more complete picture of the interactions during the task.

Conclusion

In this study, parents rated the social behavior of their pre- and early-adolescent children diagnosed with DS as significantly more positive compared to children diagnosed with ASD. Yet, higher levels of parent-child synchrony were found for children diagnosed with ASD during a collaborative task in which we examined the attunement of the child's and parent's acceleration profiles. The absence of a relationship between synchrony measures and social behavior warrants further research to investigate the relevance of synchronous parent-child interactions for the social difficulties and strengths of children diagnosed with ASD and DS beyond early childhood.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10882-023-09940-6.

Acknowledgements This research was supported by a grant from the Dutch Research Council (NWO), grant number 016.Veni.195.247 6821.

Compliance with Ethical Standards

Research Involving Human Participants and/or Animals All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 2013 version of the Helsinki Declaration of Research.

Informed Consent Informed parental consent was obtained for all participants included in the study. All parents were provided with an information sheet which explained that the authors intended to submit this study for journal publication. All parents signed consents forms stating that they understood this fact and consented to this. The research was explained to the children using words and pictograms.

Conflict of Interest The authors have no conflicts of interest to declare.

Ethical Approval This study was approved by the Ethical Review Board of the host institution.

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