Journal of Autism and Developmental Disorders
https://doi.org/10.1007/s10803-021-05307-y

ORIGINAL PAPER

Shifts in Behavioral Synchrony in Response to an Interaction Partner's Distress in Adolescents With and Without ASD

Ester Zadok[1] · Ilanit Gordon[1,2] · Roni Navon[1] · Shai Joseph Rabin[1] · Ofer Golan[1,3]

Accepted: 24 September 2021

Abstract
Individuals with Autism spectrum disorder (ASD) show altered behavioral synchrony and empathic behavior. Yet, an ecologically valid examination of these in adolescents is still required. We employed a social interaction sequence comprising a friendly conversation with a confederate, an expression of distress by her, and a return to friendly conversation. 44 male adolescents (22 with ASD) participated. Socio-emotional behaviors, coded by blind raters and through automated analyses of motion, were analyzed. Results indicated reduced synchrony in the ASD group. Moreover, whereas controls displayed a decrease in synchrony when facing another's distress, adolescents with ASD showed no such change. No group differences were found on empathic behavior. Findings imply gaps between verbal and non-verbal responses of adolescents with ASD to a distressed interaction partner.

Keywords Autism spectrum disorder · Behavioral synchrony · Motion energy analysis · Prosocial behavior · Adolescence

Behavioral synchrony, the spontaneous coordination and congruence of behaviors between interacting partners in both form and timing, is an important component of successful social interaction (Delaherche et al., 2012). During social interactions, individuals automatically synchronize their tones of voice (Neumann & Strack, 2000), eye movements (Richardson et al., 2007), facial expressions (Hess & Blairy, 2001), and their postures and gestures (Lakin & Chartrand, 2003; Lakin et al., 2003). In addition, coordination of motion, irrespective of the specific movements, has been found in between unacquainted individuals, while conversing (Tschacher et al., 2014) and during shared drumming activities (Gordon et al., 2020).

Developing and implementing an automated computer method to quantify motion, called Motion Energy Analysis (MEA; Ramseyer, 2020), Ramseyer and colleges have presented extensive work that addressed synchrony of body movement. They demonstrated negative relationships between motion synchrony and core deficits and difficulties in clinical populations, including individuals with borderline personality disorder (Ramseyer et al., 2020) and schizophrenia (Kupper et al., 2015). Further studies established the importance of motion synchrony to relationship quality and positive affect, in psychotherapy (Ramseyer & Tschacher, 2011) and between unacquainted individuals (Tschacher et al., 2014).

Indeed, through its different modalities, behavioral synchrony has been associated with individual satisfaction from conversation (Cappella, 1997), and smoothness of the interaction (Chartrand, & Bargh, 1999), and has been shown to enhance rapport (Chartrand et al., 2005). Moreover, it has been linked to perspective taking (Chartrand & Bargh, 1999), mentalizing (Baimel et al., 2018) and expression of empathy (Valdesolo & DeSteno, 2011). Although the relationship is more bidirectional in nature (Shamay-Tsoory et al., 2019) such that behavioral synchrony both reflects and supports these psychological and cognitive capabilities, findings from experimental studies that manipulated synchrony in dyads showed a causal role of behavioral synchrony in mentalizing and in emotional responding during interaction (Baimel et al, 2018; Valdesolo & DeSteno, 2011). These findings highlight the important role of behavioral synchrony, and of motion synchrony in particular, in social

✉ Ofer Golan
ofer.golan@biu.ac.il

1 Department of Psychology, Bar-Ilan University, Ramat Gan, Israel

2 Gonda Multidisciplinary Brain Research Center, Bar-Ilan University, Ramat Gan, Israel

3 Autism Treatment and Research Center - Association for Children at Risk, Givat Shmuel, Israel

Published online: 05 October 2021

interactions, thus calling for examination among individuals with Autism spectrum disorder (ASD), who are known to have difficulties in the social realm.

Behavioral Synchrony in ASD

Research has shown that individuals with ASD, a neurodevelopmental condition marked by atypical socio-emotional reciprocity (American Psychiatric Association, 2013), show reduced behavioral synchrony compared to Typically developing (TD) individuals, across various behavioral domains. A meta-analysis by Trevisan et al. (2018) established less facial expression synchrony in ASD, in both spontaneous and intentional mimicry. Moreover, computer vision analysis revealed less facial expression coordination among youth with ASD during positive and cooperative conversations (Zampella et al., 2020). In addition, less synchronization of speech features, including volume, pitch, and speech rate, was demonstrated among adults with ASD (Ochi et al., 2019).

Alternations in body movement synchrony were also demonstrated in ASD, indicating less synchronization of upper and lower limbs with a partner during rhythmic actions (Kaur et al., 2018), while swinging a pendulum (Fitzpatrick et al., 2016) and during a rocking chair paradigm (Marsh et al., 2013). Quantifying synchronization by automated measures, movement coordination was found related to higher competence during the ADOS-2 (Autism diagnostic observation schedule–2nd edition; Lord et al., 2012) assessment (Romero et al., 2018). Moreover, reduced motion synchrony, i.e., decreased amount of overall body movement coordination, was found during conversation among individuals with ASD compared to TD controls (Georgescu et al., 2020; Noel et al., 2017), thus demonstrating difficulties in this implicit, yet crucial, aspect of social communication.

Several possible mechanisms have been suggested to underlie the deficits in behavioral synchrony that individuals with ASD exhibit (McNaughton & Redcay, 2020). First, alternations in intra-individual coordination may explain difficulties in coordinating with others (Bloch et al., 2019). Indeed, individuals with ASD have been found to have difficulties in motor coordination and postural control (Bhat et al., 2011; Fournier et al., 2010), in synchronizing their verbal and non-verbal responses (de Marchena & Eigsti, 2010) and in integrating multisensory information, i.e., auditory and visual cues (Ben-Yosef et al., 2017; Noel et al., 2017). Secondly, reduced attention to social information, often seen in individuals with ASD and widely demonstrated through eye tracking studies (Frazier et al., 2017), can impede synchronization with social partners, as relevant social cues (e.g., a partner's facial expression) might be overlooked and not aligned with. Thirdly, alternations in brain circuits relevant to synchrony with others have been demonstrated in ASD, including the oxytocin system (Green et al., 2001) and the mirror neuron system (Hamilton, 2013). Finally, differences between interactional styles of individuals with ASD and TD partners, i.e., in their manners of communicating and sharing information, may hamper rapport and harmonious interaction (Crompton et al., 2019), which corresponds with behavioral synchrony (Chartrand et al., 2005).

Therefore, poor behavioral synchrony may play a central role in the social difficulties that individuals with ASD display (Koehne et al., 2016).

Dynamics of Synchrony

Despite the established prosocial consequences of behavioral synchrony or its dynamics (Baimel et al., 2018; Chartrand et al., 2005; Valdesolo & DeSteno, 2011), there is also accumulating evidence demonstrating that more behavior synchrony is not necessarily always better (Abney et al., 2015; Butler, 2015, 2017; Dahan et al., 2016; Feniger-Schaal et al., 2016; Randall et al., 2011; Wass et al., 2019). Instead, it has been suggested that flexibly going in and out of synchrony should be measured and examined as an adaptive indicator of social reciprocity (Mayo & Gordon, 2020).

Specifically, being continually in synchrony with another may come at a price of hampering self-regulation (Butler, 2015). This trade-off might be especially relevant in emotionally charged social interactions (Levenson & Gottman, 1983; Parkinson & Simons, 2012). Furthermore, shifts from synchrony to asynchrony or no synchrony may foster empathy, as they strengthen a sense of connectedness with others, while also refining self-other differentiation (Behrends et al., 2012). Supporting this claim, Dimitroff and colleagues (2017) have shown that while viewing others in a stressful situation, some observers displayed cardiac deceleration, an autonomic response opposite to that of the stressed individual. Further, examining motion synchrony via MEA, Galbusera et al. (2019) have found that high interpersonal synchrony was related to greater difficulties in self-regulation of affect. Emphasizing the notion of an adaptive interpersonal synchrony as a flexible one, Mayo and Gordon (2020) have shown that the flexibility in eye gaze synchronization between children with ASD and their parents, measured from entries and withdrawals from synchrony, was related to the child's social functioning, whereas the total duration of synchrony was not. As such, the current study examined behavioral synchrony dynamics during social interaction in two contexts – friendly conversation, and empathic concern. We suggest that adaptive behavior, which would be linked to intact social skills and effective interaction, would also be characterized by altering levels of behavioral synchrony.

Synchrony and Empathic Behavior

Examining synchrony in an empathy-related context (i.e., in an interaction that involves the expression of distress by the interaction partner) appears highly relevant when considering the manners in which behavioral synchrony and empathic behavior intertwine. Co-variation between interaction partners, which corresponds with behavioral synchrony and includes matching facial expressions, motion and emotional reactions, is suggested to be the basis for the development of shared emotional experience and emotional understanding, and eventually, the facilitation of empathic response towards the other (Decety, 2010; Shamay-Tsoory, 2011). Indeed, research has shown that interpersonal synchrony is associated with stronger rapport (Chartrand et al., 2005) and more prosocial behavior (Kirschner & Tomasello, 2010). Therefore, behavioral synchrony is particularly relevant in emotionally charged situations, such as those that call for an empathic response.

Empathic Behavior in ASD

Altered empathic behavior and difficulties in recognition of emotions and mental states have been demonstrated in individuals with ASD extensively, in childhood (e.g., Capps et al., 1993; Golan et al., 2015) and adulthood (e.g., Baron-Cohen & Wheelwright, 2004; Golan et al., 2006; Minio-Paluello et al., 2009). However, these findings are mostly based on questionnaires and computerized tasks, which do not fully encompass the social world and its demands. Therefore, a characterization of empathic behavior in actual social situations among individuals with ASD is required. Indeed, studies that employ naturalistic examinations of empathy are scarce, and have mainly focused on infants and young children, who were found to show fewer pro-social behaviors towards an adult in pain (Charman et al., 1997; Sigman et al., 1992; Travis et al., 2001).

The Current Study

The current study employed a social interaction sequence that included a friendly conversation with a confederate, a response to her sudden distress, and a return to a friendly conversation after the cause for distress has been resolved. This sequence may allow us to investigate shifts in empathic and synchronized behavior of individuals with ASD. Considering previous studies, we hypothesized that adolescents with ASD would display less empathic behavior in response to the conversation partner's distress, as well as reduced behavioral synchrony throughout the interaction, compared to controls. With regards to the behavioral synchrony dynamics throughout the social interaction sequence, we expected TD adolescents to display shifts in behavioral synchrony, specifically, a reduction in synchrony when facing the social partner's distress. Adolescents with ASD were expected to display no change in their behavioral synchrony between friendly and distress contexts. These hypotheses were tested using behavioral coding, as well as motion video analysis.

Methods

Participants

Two groups of participants took part in the study. The ASD group comprised 24 male adolescents, aged 11–17 years, who took part in a clinical trial of a social skills intervention (Rabin et al., 2018, 2020). The data used in the current study was collected before the intervention. Due to the small number of female adolescents who took part in the clinical trial, and in order to avoid power problems, we chose to focus on male adolescents only. ASD diagnosis was confirmed using module 3 or 4 of the Autism Diagnostic Observation Scale, 2nd edition (ADOS-2; Lord et al., 2012), according to participant age. The Typically developing (TD) group comprised 23 male adolescents, aged 12–16, who were recruited through ads in the community and in social networks. The Social Responsiveness Scale (SRS-2; Constantino & Gruber, 2012) was used to screen-out TD participants who exceed the cutoff for suspected ASD. One participant was excluded for this reason. All the participants completed the vocabulary subtest from the Hebrew versions of the WISC-IV (Wechsler, 2014) or the WAIS-III (Wechsler, 2008), according to the participant's age. Participants who scored less than one standard deviation from the mean (a standard score lower than 7) were excluded from the study (two participants from the ASD group). The final sample comprised 22 participants in each group. Table 1 presents averages and standard deviations of participant demographics. The study was ethically approved by the Institutional Review Board of Bar-Ilan University.

Measures

Pro-Social and Empathic Behavioral Assessment (PEBA; Golan, Navon, Zadok, and Rabin, Unpublished Manual)

This behavioral measure included an interaction sequence and a corresponding global behavioral coding system

Table 1 Means (standard deviations), ranges and t tests for background variables in the ASD and TD groups

	ASD n = 22		TD n = 22			
	M (SD)	Range	M (SD)	Range	t	df
Age	14.19 (1.69)	11.83–17.42	14.53 (1.35)	12–16.41	−.73	42
Wechsler vocabulary	11.09 (2.38)	7–15	12.13 (1.42)	9–14	−1.76~	34.25
SRS-2	75.32 (12.93)	57–105	43.68 (4.83)	36–52	−10.74***	26.75
SSIS-SS	82.95 (14.80)	50–106	106.64 (9.81)	92–128	6.25***	42
EQ	38.32 (11.41)	22–66	45.64 (10.83)	26–61	2.18*	42
ADOS-2-CSS	7.05 (2.17)	4–10				

SRS-2 Social responsiveness scale, 2nd edition; *SSIS-SS* Social skills improvement system – Social skills scale; *EQ* Empathy quotient; *ADOS-2-CSS* Autism diagnostic observation schedule, 2nd edition, calibrated severity scores

~p < .1, *p < .05, ***p < .001

(detailed below), which examined the participant's empathic and pro-social behavior in response to a friendly stranger's distress. The participant met a confederate, introduced as "someone who takes part in the study" and the two were asked to talk for a few minutes and to get to know each other. After 3 min of friendly conversation, the confederate received a disturbing text message (e.g., "you just failed your math test"), following which she demonstrated distress verbally (e.g., "I can't believe this is happening to me again") and nonverbally (slowing of nonverbal communication. expressing mild distress). A minute later, after receiving another, reassuring, text message (e.g., "you can retake the test"), the confederate regained her friendly disposition and continued the interaction for another minute, after which the examiner terminated it.

The confederates were six female undergraduate psychology students, trained according to the PEBA administration protocol (see supplementary material) by the first and third authors. They were provided with corrective feedback routinely throughout the trial, based on administration videos, to maintain fidelity. Participants were matched with confederates based on confederate availability. The confederates, as well as the raters, were naïve to the participants' diagnoses and to the research hypotheses. The interaction was videotaped and its last 3 min (i.e., friendly, distress, return to friendly stages) were analyzed in two ways:

Global Behavioral Coding

Each of the three interaction stages was globally coded on 5-point Likert scales (higher scores indicated a greater level of the behavior) by trained naïve raters: two undergraduate psychology students were trained according to the PEBA coding protocol (see supplementary material) by the first and third authors. Following the training, and before proceeding to rating study videos, interrater reliability was calculated, based on the coding of five training videos. Average intraclass correlation coefficient (ICC) between the coders and the third author was 0.88.

The following coded behaviors were averaged and grouped into two domains: (1) *Behavioral Synchrony*—synchronization of nonverbal characteristics of behavior to those of the social partner. These included facial expression, eye gaze, vocalization (i.e., volume, tempo and intonation of speech, disregarding the content of verbalizations, in line with Gordon & Feldman, 2015; Gordon et al., 2017), body language, and affect. The coordination of behaviors was examined both in form (e.g., the valence of a facial expression) and in time (e.g., the coupling of facial expression change to that of the confederate); (2) *Empathic Behavior*: comments, interest, prosocial behavior, and social understanding. Empathic behaviors were coded only for the distress and return to friendly stages, due to the change of the interaction context. For sample prompts of the nine coded items, see Table 2.

For each of the nine items scored, interrater reliability between the two raters was assessed based on 20% of the coded interactions, reaching an average ICC of 0.82. Internal consistency coefficients for total PEBA scores were 0.83 for the friendly stage, 0.88 for the distress stage, and 0.85 for the return to friendly stage; internal consistency coefficients for the *Behavioral synchrony* domain were 0.85, 0.82, and 0.84 for the three stages respectively, and for the *Empathic Behavior* domain were 0.80 for the distress stage and 0.62 for the return to friendly stage.

The PEBA was validated through correlation analyses between its measures in the three stages and total scores derived from the SSIS-SS, SRS-2 and EQ. As shown in Table 3, total PEBA scores and behavioral synchrony scores correlated with the SSIS-SS and the SRS-2 in all stages, and with the EQ in the distress and return to friendly stages. Empathic behavior scores correlated with the EQ, in the distress stage.

Table 2 Sample coding prompts of the nine Pro-social and empathic behavioral assessment (PEBA) items

Domain	Item	Sample coding prompts
Behavioral synchrony	Vocal synchrony	Does the participant synchronize his volume, tempo, and intonation of speech?
	Facial expression synchrony	Does the participant synchronize his facial expressions in valence, timing, and intensity?
	Eye gaze synchrony	Does the participant modulate his eye gaze in a flexible manner (as opposed to avoidance or staring)?
	Body language synchrony	Does the participant synchronize his bodily movements, gestures, and posture?
	Affect synchrony	Does the participant demonstrate overall affect that is appropriate to the immediate social context?
Empathic behavior	Comments	Does the participant engage in the conversation by commenting and sharing information?
	Interest	Does the participant express interest by asking appropriate questions?
	Prosocial behavior	Does the participant verbally express empathic concern by offering comfort or assistance?
	Social understanding	Does the participant's reaction reflect an understanding of the socio-emotional context?

Table 3 Pearson correlations of PEBA empathic behavior, behavioral synchrony, and total scores with questionnaire scores

	Total PEBA score			Empathic behavior		Behavioral synchrony		
	Friendly	Distress	Return to friendly	Distress	Return to friendly	Friendly	Distress	Return to friendly
SSIS-SS	.48**	.35*	.50**	.24	.27	.52***	.40**	.56***
SRS-2	−.47**	−.34*	−.51***	−.24	−.26	−.55***	−.39*	−.59***
EQ	.24	.40**	.34*	.36*	.22	.27~	.38*	.36*

PEBA Pro-social and empathic behavioral assessment; *SSIS-SS* The social skills improvement system – Social skills scale; *SRS-2* Social responsivenes scale, 2nd edition; *EQ* Empathy quotient

~p < .1, *p < .05, **p < .01, ***p < .001

Motion Energy Analysis (MEA; Ramseyer, 2020)

MEA is an automated method calculating motion synchrony in a dyad. In each dyad, the participant and confederate were seated facing one another, with the camera set up in front of them, capturing their full bodies. Each filmed interaction was trimmed to three videos, according to the three stages of the PEBA paradigm, and each video was analyzed separately. The videos had a resolution of 1080p and a frame rate of 30fps. The MEA software computed the interactive partners' motion by monitoring continuous changes in pixels from frame to frame in pre-defined Regions of interest (ROI). Two ROI's were defined: full bodies of the participant and the confederate. For illustration, see Fig. 1. To quantify motion synchrony, the rMEA R package (Kleinbub & Ramseyer, 2018) was used. Following Tschacher et al. (2014), and considering the dynamic nature of our conversational setting, the analysis was done within 30 s window segments overlapping by 15 s. Within each segment, cross-correlation functions were performed for positive and negative time-lags in a time window of 5 s, by shifting the data in steps of 0.03 s (i.e., a shift of one frame at a time). Then, results were standardized (Fisher's Z) and their absolute values in each 30 s segment were averaged. Thus, the MEA yielded one value, which represents motion synchrony, for each participant at each of the paradigm's three stages (i.e., friendly, distress and return to friendly).

Social Responsiveness Scale, 2nd Edition (SRS-2; Constantino & Gruber, 2012)

The SRS-2 is a 65-item rating scale measuring the severity of autism spectrum symptoms as they occur in natural social settings. Completed by parents, the SRS-2 is appropriate for use with children from 4 years of age to adulthood. Subscales include social awareness, social cognition, social communication, social motivation and mannerisms. Internal consistency for SRS-2 subscales was reported as 0.91–0.97, with test–retest reliability of 0.84–0.97 and interrater reliability of 0.74–0.95 (Bölte et al., 2008).

The Social Skills Improvement System (SSIS; Gresham & Elliott, 2008)

The SSIS is a standardized rating scale that assesses global social competence for children aged 3 to 18 years. This instrument evaluates target social behaviors including communication, cooperation, assertion, responsibility, empathy,

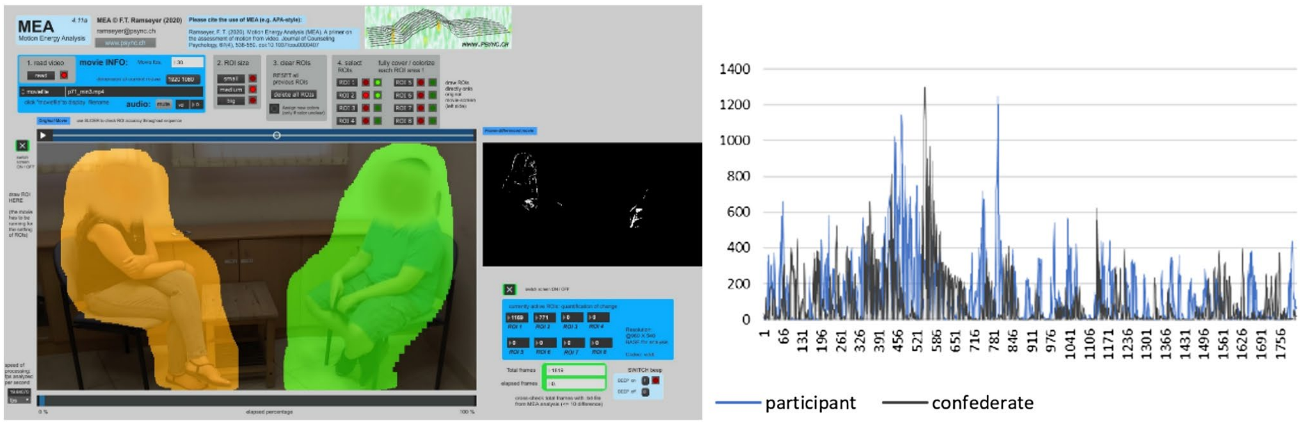

Fig. 1 On the left, an example of the MEA software at work, quantifying change in pixels from frame to frame in predefined regions in the video; On the right, an example of results outputted by the rMEA analysis package for a pair of participants during a face-to-face interaction: Y-axis = raw amount of movement (frame-to-frame difference), X-axis = frames

engagement, and self-control. The instrument includes a social skills scale, and a behavior problems scale, which was not used in the current study. Internal consistency for the SSIS ranges from 0.92 to 0.97, test–retest reliability from 0.77 to 0.87, inter-rater reliability from 0.50 to 0.68 (Gresham et al., 2011).

Empathy Quotient (EQ; Baron-Cohen & Wheelwright, 2004*)*

The EQ is a 40-item, self-report questionnaire measuring empathy levels in individuals with normal intelligence. Items are rated on 1–4 scale (example item: "I am quick to spot when someone in a group is feeling awkward or uncomfortable"). This instrument is widely used in ASD studies, including studies involving adolescents (e.g., Rabin et al., 2018). The EQ has been reported to have high internal consistency (0.99; Allison et al., 2011) and high test–retest reliability (0.83), as well as good construct validity (Lawrence et al., 2004).

Procedure

Participants arrived at the lab for a one-hour session. Following assent and parent consent, participants completed the Wechsler vocabulary test, followed by the PEBA, and filling out of questionnaires. Participants in the ASD group arrived to a preliminary meeting with clinicians who were not involved in the PEBA, in which the ADOS-2 and the Wechsler assessment were administered. They were given the PEBA on a separate session, followed by questionnaire completion.

Statistical Analyses

Statistical Analyses were performed in IBM's SPSS 25. Since the PEBA items were coded on a 5-point Likert scale, we treated them as interval measures in the following analyses. To examine group differences in the PEBA total scores and the domains scores (i.e., empathic behavior and behavioral synchrony) during the interaction stages, i.e., the friendly, distress and return to friendly stages, three ANOVA's were performed, with group and stage as factors (a 2×3 design for total scores and behavioral synchrony, and a 2×2 design for empathic behavior).

To validate the motion synchrony measure as representing meaningful coordinated motion, we compared our data with shuffled data generated by the rMEA package, which reflects coincidental synchrony between conversational partners who did not actually interact with each other. To that end, for each participant we calculated a mean of 21 correlations of himself with a confederate in 21 pseudo interactions of his study group. By that we created pseudo correlations, which were compared to the actual correlations, using two paired sample t-tests. Finally, to examine group differences in motion synchrony, each participant pseudo score (mean correlation from the shuffled data) was subtracted from his actual motion synchrony score. This subtraction was done to remove systematic differences from the participants' scores, due to using different filming equipment and room settings for the ASD and TD groups. The pseudo scores described above were assumed to reflect the "noise" such initial differences between the groups might have created. Thus, by subtracting them from the actual scores, we created delta scores, reflecting standardized motion synchrony scores equivalent across different rooms and cameras. These deltas were entered as a dependent variable in a mixed design two-way ANOVA (2 × 3), with group and stage as factors.

Results

Score means and S.D.s in the three stages for the two groups appear in Table 4.

Group Differences in Coded Behavior

To examine behavioral group differences during the three interaction stages, three mixed design two-way analyses of variance were conducted, using Holm's sequential rejective Bonferroni procedure (Holm, 1979) as correction for familywise type I error rates. Next, pairwise comparisons were completed with Bonferroni correction. The first ANOVA included total PEBA scores as the dependent variable, and revealed a significant effect for group, $F(1,42) = 13.60$, $p < 0.01$, $\eta_p^2 = 0.24$, as on average, the ASD group had lower scores than the TD group, as well as a significant effect for stage, $F_{wilks}(2,41) = 13.30$, $p < 0.001$, $\eta_p^2 = 0.39$. Pairwise comparisons showed that over and above group, scores were lower in the distress stage compared to the friendly (mean difference = − 0.38, s.e. = 0.11, $p < 0.01$) and return to friendly (mean difference = − 0.42, s.e. = 0.08, $p < 0.001$) stages. Group by stage interaction was not significant. A similar ANOVA for the behavioral synchrony domain scores revealed a significant effect for group, $F(1,42) = 21.40$, $p < 0.001$, $\eta_p^2 = 0.34$, with lower scores in the ASD group, and a significant effect for stage, $F_{wilks}(2,41) = 28.71$, $p < 0.001$, $\eta_p^2 = 0.58$. Over and above group, in the distress stage adolescents were less coordinated with the social partner in comparison to the friendly stage (mean difference = − 0.37, s.e. = 0.09, $p < 0.01$) and the return to friendly stage (mean difference = − 0.41, s.e. = 0.06, $p < 0.001$). In addition, a group by stage interaction was found, $F_{wilks}(2,41) = 10.74$, $p < 0.001$, $\eta_p^2 = 0.34$. Pairwise comparisons showed that while TD adolescents were less synchronized with the social partner in the distress stage compared to the friendly (mean difference = − 0.52, s.e. = 0.13, $p < 0.01$) and the return to friendly (mean difference = − 0.64, s.e. = 0.09, $p < 0.001$) stages, no such differences were found for the ASD group. This means that the ASD group did not demonstrate significant differences from stage to stage but rather maintained an overall lower, and less varying level of synchrony (see Fig. 2). A third ANOVA conducted for empathic behavior domain scores yielded a significant effect for stage, $F_{wilks}(1,42) = 9.54$, $p < 0.01$, $\eta_p^2 = 0.18$, indicating that adolescents responded less empathically in the distress stage (M = 2.81, SD = 1.07) compared to the return to friendly stage (M = 3.22, SD = 0.80). No significant effects were found for group or for the group by stage interaction.

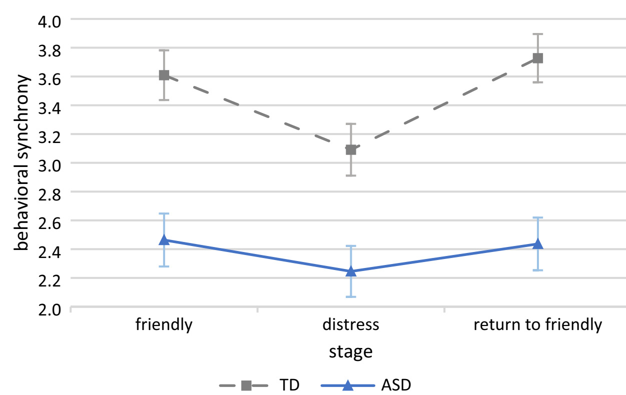

Fig. 2 Mean scores of the behavioral synchrony domain (with standard error bars) of the ASD and the TD groups

Table 4 Means (standard deviations) and ranges for PEBA empathic behavior, behavioral synchrony and total scores and for standardized motion synchrony scores in the ASD and TD groups

	Friendly		Distress		Return to friendly		Overall	
	ASD	TD	ASD	TD	ASD	TD	ASD	TD
Total PEBA scores[a]	2.63 (.84) 1.00 – 4.00	3.58 (.75) 1.71 – 4.71	2.40 (.85) 1.22 – 4.00	3.06 (.89) 1.11 – 4.22	2.73 (.80) 1.00 – 4.00	3.56 (.69) 1.55 – 4.44	2.59 (.76) 1.22 – 3.81	3.40 (.70) 1.76 – 4.39
Empathic Behavior[a]	–	–	2.59 (.99) 1.00 – 4.25	3.02 (1.12) 1.00 – 4.75	3.10 (.86) 1.00 – 4.50	3.35 (.73) 1.50 – 4.50	2.85 (.83) 1.50 – 4.37	3.19 (.82) 1.37 – 4.25
Behavioral Synchrony[a]	2.46 (.86) 1.00 – 3.80	3.61 (.81) 1.40 – 4.80	2.24 (.83) 1.40 – 3.80	3.09 (.84) 1.20 – 4.20	2.44 (.86) 1.00 – 3.80	3.73 (.79) 1.40 – 4.60	2.38 (.81) 1.13 – 3.37	3.48 (.76) 1.47 – 4.40
Motion synchrony (standardized)[b]	−.014 (.026) −.051 – .048	.014 (.038) −.045 – −.095	−.006 (.022) −.038 – .064	−.008 (.035) −.062 – .078	.008 (.039) −.057 – .114	.022 (.029) −.043 – .076	−.004 (.016) −.032 – .038	.009 (.021) −.022 – .076

PEBA Pro-social and empathic behavioral assessment

[a]Mean Likert scores (score range 1 to 5)

[b]Motion synchrony standardized scores represent the difference between actual motion synchrony scores and individualized pseudo scores

Motion Synchrony Group Differences

Preliminary t-tests comparing our data with shuffled data revealed that for the TD group, the real data set comprised significantly higher correlations compared to the shuffled data ($t(21) = 2.09$, $p < 0.05$), which indicates meaningful motion synchrony resulting from the actual interactions, rather than chance or the conversation setting. Interestingly, for the ASD group, the real and shuffled data did not differ significantly ($t(21) = -1.13$, p = n.s.).

Next, an ANOVA examining these group differences throughout the interaction stages, revealed a significant main effect for group, $F(1,42) = 5.51$, $p < 0.05$, $\eta_p^2 = 0.12$, indicating more motion synchrony in the TD group than in the ASD group. In addition, a significant main effect for stage was found, $F_{wilks}(2,41) = 5.15$, $p < 0.05$, $\eta_p^2 = 0.20$. Pairwise comparisons with Bonferroni correction showed that this effect stemmed from less motion synchrony in the distress stage compared to the return to friendly stage (mean difference = − 0.02, SE = 0.01, $p < 0.01$). Finally, a significant group by stage interaction effect was found, $F_{wilks}(2,41) = 3.55$, $p < 0.05$, $\eta_p^2 = 0.15$. Pairwise comparisons with Bonferroni correction showed that whereas in the TD group motion synchrony in the distress stage was significantly lower compared to the friendly (mean difference = − 0.02, SE = 0.01, $p < 0.05$) and return to friendly (mean difference = − 0.03, SE = 0.01, $p < 0.05$) stages, in the ASD group synchrony did not differ significantly across stages. Notably, a marginally significant trend was observed in the ASD group, depicting greater motion synchrony in the return to friendly stage compared to the friendly stage (mean difference = 0.02, SE = 0.01, $p = 0.09$). As illustrated in Fig. 3, whereas the TD group showed a decrease in motion synchrony is the distress stage, followed by an increase in the return to friendly stage, the ASD group showed a steady increase in motion synchrony over time.

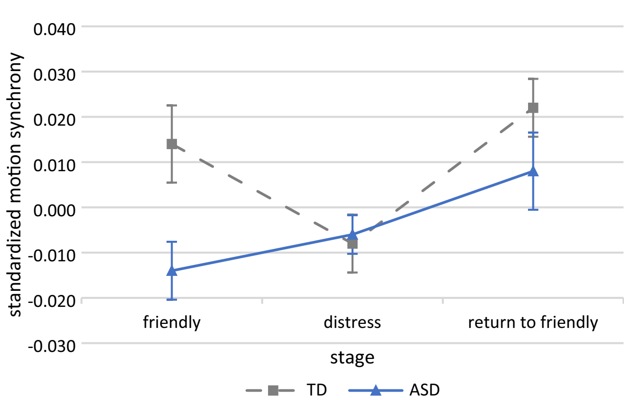

Fig. 3 Mean scores of participants' standardized motion synchrony (with standard error bars) in the ASD and the TD groups

Discussion

The current study examined empathic behavior and behavioral synchrony in adolescents with ASD during social interaction that involved changing emotional contexts. Our findings indicate that throughout the interaction, adolescents with ASD displayed lower levels of behavioral synchrony with the social partner, as indicated by naïve raters' assessments of behavior. In addition, whereas TD adolescents displayed shifts in behavioral synchrony when facing the social partner's distress, among adolescents with ASD such shifts were not observed. Motion Energy analysis revealed significant motion synchrony only in the TD group. Moreover, it revealed similar patterns of shifts throughout the paradigm stages among TD adolescents, compared to constant and lower levels of motion synchrony among adolescents with ASD. Contrary to our hypothesis, empathic behavior did not differ between groups.

In line with our hypothesis, adolescents in the ASD group displayed lower levels of behavioral synchrony throughout the interaction, i.e., they were less synchronized with the partner with regards to facial expression, eye gaze, body language and overall affect. Motion synchrony was also lower in the ASD group. Moreover, this behavior seemed less flexible compared to TD adolescents, who shifted in and out of synchrony when the interaction context changed. Specifically, TD adolescents were less synchronized when the social partner shared her distress compared to the other interaction stages. Similar patterns were found regarding their motion synchrony. In line with the notion of a trade-off between continual synchrony and affect regulation, this apparent disengagement may be driven by a need to down-regulate one's own affect, by distancing oneself from the other and from the stressful situation. This kind of differentiation is thought to moderate one's own distress and enable a prosocial response towards the other who is in need (Decety & Lamm, 2006).

Noteworthy, among adolescents with ASD, patterns of synchrony as assessed by raters were different than the patterns of motion synchrony measured by MEA. Regarding the latter, adolescents with ASD demonstrated a trend of increase in motion synchrony through time. It can be assumed that some adolescents with ASD began the interaction feeling tense or anxious (van Steensel & Heeman, 2017). Hence, the increase in synchrony observed may reflect unwinding as the interaction continues, that enabled the adolescents to soften a tense static posture or rather to relax anxious hyperkynesic movement, and by that to achieve more motion synchrony with the social partner. Such changes may have been expressed through diminished motion due to fidgeting or other restless movements (such as touching one's face or agitatedly moving hands or legs). The MEA, which measured movement generally across the entire body, may have captured such changes, whereas the PEBA coding, which assessed distinct movements chosen a-priori (such as leaning forwards, crossing one's arms, smiling, etc.) and its congruency with the social partner's behavior, may have not. This notion needs to be further examined and calls for a consideration of the role of anxiety in interactional synchrony.

Contrary to our hypothesis, empathic behavior did not differ between groups. Adolescents in both groups responded with similar levels of expressed empathy when the social partner shared her distress and when she returned to a friendly conversation. This indicates adequate capability to recognize and attend to the partner's sudden distress, and challenges previous reports of poorer empathic and pro-social behaviors among younger children with ASD (Charman et al., 1997; Sigman et al., 1992; Travis et al., 2001). We tested our hypotheses in adolescents with no comorbid intellectual impairment, who, through maturation and experience, may have developed compensatory mechanisms (Livingston et al., 2019), which could explain their intact patterns of response. Such compensatory mechanisms are more likely to be found in adolescents than in younger children. Notably, our paradigm included a salient operationalization of distress which may have allowed for the recruitment of compensatory mechanisms. It requires further investigation to discern if more subtle manipulations of distress would reveal differences in empathic behavior in adolescents with ASD.

Despite their intact empathic responses, alterations in nonverbal aspects of communication were observed, as indicated by lower levels of synchrony with the social partner. This supports previous findings demonstrating less synchrony in ASD, through different modalities, by using observational (Trevisan et al., 2018) and automated (Georgescu et al., 2020; Zampella et al., 2020) measurements. The current study adds to the existing literature by employing a naturalistic interaction that involved changing socio-emotional contexts, and particularly, an expression of distress by the social partner. Considering our findings, it can be argued that adolescents with ASD relied adequately on social knowledge regarding *what* to say to the distressed other, but struggled with *how* to say it. That is, they found it difficult to time and to coordinate their verbal response with non-verbal aspects of communication, and to flexibly synchronize their non-verbal behavior with that of the social partner. Indeed, discrepancies between verbal and nonverbal communication abilities have been evident among individuals with ASD (Grossman et al., 2013; de Marchena & Eigsti, 2010). It has been suggested that some individuals with ASD use conscious strategies to achieve intact verbal social skills, despite deficits in core socio-cognitive abilities. Such strategies, however, may be less effective regarding more implicit aspects of social behavior (Livingston & Happé, 2017).

The paradigm employed in our study enabled real-time examination of synchronous and empathic behaviors in a naturalistic social setting. To assess synchrony, two different measures were used. The first, an observational coding system that addressed different modalities of synchrony (i.e., facial expression, eye gaze, speech features and body language). The coding process considered the content of the response, meaning, its valence and intensity and assessed its appropriateness to the immediate socio-emotional context. Still, building on human raters' impressions, it is prone to possible cognitive biases (Bellé et al., 2017). The second measure of synchrony used, the MEA, is automatic and objective, and enables quantification of motion and precise analysis of temporal synchrony. Yet, it is limited to crude measuring of movement overall, disregarding its context. In an exploratory manner, we examined correlations between these two measures during the friendly stage of the interaction (since this stage represents a natural social exchange prior to the distress manipulation), over and above group. A significant and moderate correlation was found ($r = 0.36$ $p < 0.05$), implying a complementary role of the two measures of synchrony, as they seem to capture two different aspects of interpersonal coordination.

Additional correlation analyses were also performed exploratorily, to examine associations between the MEA measure and questionnaire scores. Results showed that for the friendly stage alone, motion energy scores correlated positively with adolescent self-reports of empathy on the EQ ($r = 0.26$ $p < 0.05$), marginally positively correlated with parent-reports of social skills on the SSIS ($r = 0.25$ $p = 0.05$) and negatively correlated with parent-reported autistic symptoms on the SRS-2 ($r = -0.34$ $p < 0.05$). These encouraging preliminary findings require further consolidation with a larger sample.

Our findings are limited by the small sample size of adolescents, who had relatively good cognitive skills. Future research should employ a larger and more varying sample, which would better represent the diversity of skills and difficulties in the Autism Spectrum. A larger sample may enable us to validate the PEBA through correlation analyses with questionnaires' scores for the ASD and the TD groups separately, rather than for the combined sample, allowing for the examination of potential group differences in these correlations. Moreover, the relationship between motion synchrony and broader social skills as reported by parents is a worthy objective for future investigation. A larger sample may also enable to examine the ability of the observational and motion energy measures combined to discriminate between TD and ASD adolescents. Another limitation of this study lies in our examination of male adolescents conversing with female confederates. In view of recent findings on gender differences in social communication of individuals with ASD (Dean et al., 2017; Lai et al., 2017), a complete examination of male and female adolescents conversing with male and female confederates in warranted. In addition, the ASD and TD groups were filmed using different equipment and room settings (due to location constraints). Although a standardization procedure was conducted to minimize those initial differences in the motion synchrony analyses, the potential effect of these differences should be considered when interpreting our results. Finally, further research should extend our behavioral findings by including physiological measurements which may shed light on the affective aspects of empathy, and thus achieve a fine-grained examination of empathic and synchronous behavior and the mechanisms underlying it in adolescents with and without ASD.

We conclude that adolescents with ASD show difficulties moving in and out of synchrony in social interactions that involve another person's expressed distress. Recent advances in clinical interventions, such as music and movement therapy treatments, suggest that targeting synchrony and its dynamics in individuals with ASD have shown promising results. Through shared musical and bodily improvisation and rhythmic patterns, these interventions aim to facilitate attunement, mirroring, and alignment with an interactive partner. (Dvir et al., 2020; Koehne et al., 2016; Srinivasan et al., 2016; Venuti et al., 2017). Such therapies, which were found beneficial for children and adults with ASD, may also be harnessed to promote behavioral coordination and social responsiveness in adolescents.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10803-021-05307-y.

Acknowledgments We are grateful to the adolescents who took part in the study, to Prof. Michal Lavidor for her advice, to Dr. Irit Mor-Snir for her support, and to Tomer Kleinfeld, Rolli Azenkot-Levi, Maayan Berkovitch, Anat Chomsky, Heli Cohen, Shulamit Deitch, Bat-Sheva Gans, Roni Golan, Noa Reinhardt and Lior Weil, for assisting with data collection and coding. This study was supported by grants from the Israel Science Foundation (ISF) to Ofer Golan (#1009/15) and to Ilanit Gordon (#2096/15 and #1726/15).

Author Contributions EZ, IG, SJR and OG designed the study, collected the data and analyzed it, and wrote the manuscript. OG and RN composed the behavioral coding protocol. All authors approved the final manuscript.

Declarations

Conflict of interest All authors declare they have no conflict of interests.

Ethical Approval The study was ethically approved by the Institutional Review Board of Bar-Ilan University.

Informed Consent Participants' parents provided written informed consent, and participants provided verbal ascent.

References

Abney, D. H., Paxton, A., Dale, R., & Kello, C. T. (2015). Movement dynamics reflect a functional role for weak coupling and role structure in dyadic problem solving. *Cognitive Processing, 16*(4), 325–332.

Allison, C., Baron-Cohen, S., Wheelwright, S. J., Stone, M. H., & Muncer, S. J. (2011). Psychometric analysis of the Empathy Quotient (EQ). *Personality and Individual Differences*, *51*(7), 829–835.

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

Baimel, A., Birch, S. A., & Norenzayan, A. (2018). Coordinating bodies and minds: Behavioral synchrony fosters mentalizing. *Journal of Experimental Social Psychology, 74*, 281–290.

Baron-Cohen, S., & Wheelwright, S. (2004). The empathy quotient: An investigation of adults with Asperger syndrome or high functioning autism, and normal sex differences. *Journal of Autism and Developmental Disorders, 34*(2), 163–175.

Behrends, A., Müller, S., & Dziobek, I. (2012). Moving in and out of synchrony: A concept for a new intervention fostering empathy through interactional movement and dance. *The Arts in Psychotherapy, 39*(2), 107–116.

Bellé, N., Cantarelli, P., & Belardinelli, P. (2017). Cognitive biases in performance appraisal: Experimental evidence on anchoring and halo effects with public sector managers and employees. *Review of Public Personnel Administration, 37*(3), 275–294.

Ben-Yosef, D., Anaki, D., & Golan, O. (2017). Context processing in adolescents with autism spectrum disorder: How complex could it be? *Autism Research, 10*(3), 520–530.

Bhat, A. N., Landa, R. J., & Galloway, J. C. (2011). Current perspectives on motor functioning in infants, children, and adults with autism spectrum disorders. *Physical Therapy, 91*(7), 1116–1129.

Bloch, C., Falter-Wagner, C., Georgescu, A. L., & Vogeley, K. (2019). INTRApersonal synchrony as constituent of INTERpersonal synchrony and its relevance for autism spectrum disorder. *Frontiers in Robotics and AI, 6*, 73.

Bölte, S., Poustka, F., & Constantino, J. N. (2008). Assessing autistic traits: Cross-cultural validation of the social responsiveness scale (SRS). *Autism Research*, *1*(6), 354–363.

Butler, E. A. (2015). Interpersonal affect dynamics: It takes two (and time) to tango. *Emotion Review, 7*(4), 336–341.

Butler, E. A. (2017). Emotions are temporal interpersonal systems. *Current Opinion in Psychology*, *17*, 129–134.

Cappella, J. N. (1997). Behavioral and judged coordination in adult informal social interactions: Vocal and kinesic indicators. *Journal of Personality and Social Psychology, 72*(1), 119.

Capps, L., Kasari, C., Yirmiya, N., & Sigman, M. (1993). Parental perception of emotional expressiveness in children with autism. *Journal of Consulting and Clinical Psychology, 61*(3), 475.

Charman, T., Swettenham, J., Baron-Cohen, S., Cox, A., Baird, G., & Drew, A. (1997). Infants with autism: An investigation of empathy, pretend play, joint attention, and imitation. *Developmental Psychology, 33*(5), 781.

Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: The perception–behavior link and social interaction. *Journal of Personality and Social Psychology, 76*(6), 893.

Chartrand, T. L., Maddux, W. W., & Lakin, J. L. (2005). Beyond the perception-behavior link: The ubiquitous utility and motivational moderators of nonconscious mimicry. *The New Unconscious*, 334–361.

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

Crompton, C. J., Ropar, D., Evans-Williams, C. V., Flynn, E. G., & Fletcher-Watson, S. (2019). Autistic peer-to-peer information transfer is highly effective. *Autism, 24*(7), 1704–1712.

Dahan, A., Noy, L., Hart, Y., Mayo, A., & Alon, U. (2016). Exit from synchrony in joint improvised motion. *PLoS ONE, 11*(10), e0160747.

de Marchena, A., & Eigsti, I. M. (2010). Conversational gestures in autism spectrum disorders: Asynchrony but not decreased frequency. *Autism Research, 3*(6), 311–322.

Dean, M., Harwood, R., & Kasari, C. (2017). The art of camouflage: Gender differences in the social behaviors of girls and boys with autism spectrum disorder. *Autism, 21*(6), 678–689.

Decety, J. (2010). The neurodevelopment of empathy in humans. *Developmental Neuroscience, 32*(4), 257–267.

Decety, J., & Lamm, C. (2006). Human empathy through the lens of social neuroscience. *The Scientific World Journal, 6*, 1146–1163.

Delaherche, E., Chetouani, M., Mahdhaoui, A., Saint-Georges, C., Viaux, S., & Cohen, D. (2012). Interpersonal synchrony: A survey of evaluation methods across disciplines. *IEEE Transactions on Affective Computing, 3*(3), 349–365.

Dimitroff, S. J., Kardan, O., Necka, E. A., Decety, J., Berman, M. G., & Norman, G. J. (2017). Physiological dynamics of stress contagion. *Scientific Reports, 7*(1), 1–8.

Dvir, T., Lotan, N., Viderman, R., & Elefant, C. (2020). The body communicates: Movement synchrony during music therapy with children diagnosed with ASD. *The Arts in Psychotherapy, 69*, 101658.

Feniger-Schaal, R., Noy, L., Hart, Y., Koren-Karie, N., Mayo, A. E., & Alon, U. (2016). Would you like to play together? Adults' attachment and the mirror game. *Attachment and Human Development, 18*(1), 33–45.

Fitzpatrick, P., Frazier, J. A., Cochran, D. M., Mitchell, T., Coleman, C., & Schmidt, R. C. (2016). Impairments of social motor synchrony evident in autism spectrum disorder. *Frontiers in Psychology, 7*, 1323.

Fournier, K. A., Hass, C. J., Naik, S. K., Lodha, N., & Cauraugh, J. H. (2010). Motor coordination in autism spectrum disorders: A synthesis and meta-analysis. *Journal of Autism and Developmental Disorders, 40*(10), 1227–1240.

Frazier, T. W., Strauss, M., Klingemier, E. W., Zetzer, E. E., Hardan, A. Y., Eng, C., & Youngstrom, E. A. (2017). A meta-analysis of gaze differences to social and nonsocial information between individuals with and without autism. *Journal of the American Academy of Child and Adolescent Psychiatry, 56*(7), 546–555.

Galbusera, L., Finn, M. T., Tschacher, W., & Kyselo, M. (2019). Interpersonal synchrony feels good but impedes self-regulation of affect. *Scientific Reports, 9*(1), 1–12.

Georgescu, A. L., Koeroglu, S., Hamilton, A. F., Vogeley, K., Falter-Wagner, C. M., & Tschacher, W. (2020). Reduced nonverbal interpersonal synchrony in autism spectrum disorder independent of partner diagnosis: A motion energy study. *Molecular Autism, 11*(1), 1–14.

Golan, O., Baron-Cohen, S., & Hill, J. (2006). The Cambridge mindreading (CAM) face-voice battery: Testing complex emotion recognition in adults with and without Asperger syndrome. *Journal of Autism and Developmental Disorders, 36*(2), 169–183.

Golan, O., Sinai-Gavrilov, Y., & Baron-Cohen, S. (2015). The Cambridge mindreading face-voice battery for children (CAM-C): Complex emotion recognition in children with and without autism spectrum conditions. *Molecular Autism, 6*(1), 22.

Gordon, I., & Feldman, R. (2015). A biopsychosocial perspective on synchrony and the development of human parental care. In S. D. Calkins (Ed.), *Handbook of infant biopsychosocial development* (pp. 283–312). The Guilford Press.

Gordon, I., Gilboa, A., Cohen, S., & Kleinfeld, T. (2020). The relationship between physiological synchrony and motion energy synchrony during a joint group drumming task. *Physiology and Behavior, 224*, 113074.

Gordon, I., Pratt, M., Bergunde, K., Zagoory-Sharon, O., & Feldman, R. (2017). Testosterone, oxytocin, and the development of human parental care. *Hormones and Behavior, 93*, 184–192.

Green, L., Fein, D., Modahl, C., Feinstein, C., Waterhouse, L., & Morris, M. (2001). Oxytocin and autistic disorder: Alterations in peptide forms. *Biological Psychiatry, 50*(8), 609–613.

Gresham, F., & Elliott, S. N. (2008). *Social skills improvement system rating scales*. Minneapolis, MN: Pearson Assessments.

Gresham, F. M., Elliott, S. N., Vance, M. J., & Cook, C. R. (2011). Comparability of the social skills rating system to the social skills improvement system: Content and psychometric comparisons across elementary and secondary age levels. *School Psychology Quarterly*, *26*(1), 27.

Grossman, R. B., Edelson, L. R., & Tager-Flusberg, H. (2013). Emotional facial and vocal expressions during story retelling by children and adolescents with high-functioning autism. *Journal of Speech, Language, and Hearing Research, 56*(3), 1035–1044.

Hamilton, A. F. D. C. (2013). Reflecting on the mirror neuron system in autism: A systematic review of current theories. *Developmental Cognitive Neuroscience, 3*, 91–105.

Hess, U., & Blairy, S. (2001). Facial mimicry and emotional contagion to dynamic emotional facial expressions and their influence on decoding accuracy. *International Journal of Psychophysiology, 40*(2), 129–141.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics, 6*(2), 65–70.

Kaur, M., Srinivasan, S. M., & Bhat, A. N. (2018). Comparing motor performance, praxis, coordination, and interpersonal synchrony between children with and without Autism spectrum disorder (ASD). *Research in Developmental Disabilities, 72*, 79–95.

Kirschner, S., & Tomasello, M. (2010). Joint music making promotes prosocial behavior in 4-year-old children. *Evolution and Human Behavior, 31*(5), 354–364.

Kleinbub, J., & Ramseyer, F. (2018). rMEA: Synchrony in motion energy analysis (MEA) time-series.

Koehne, S., Behrends, A., Fairhurst, M. T., & Dziobek, I. (2016). Fostering social cognition through an imitation-and synchronization-based dance/movement intervention in adults with autism spectrum disorder: A controlled proof-of-concept study. *Psychotherapy and Psychosomatics, 85*(1), 27–35.

Kupper, Z., Ramseyer, F., Hoffmann, H., & Tschacher, W. (2015). Nonverbal synchrony in social interactions of patients with schizophrenia indicates socio-communicative deficits. *PLoS ONE, 10*(12), e0145882.

Lai, M. C., Lombardo, M. V., Ruigrok, A. N. V., Chakrabarti, B., Auyeung, B., Szatmari, P., & Consortium MA. (2017). Quantifying and exploring camouflaging in men and women with autism. *Autism, 21*(6), 690–702.

Lakin, J. L., & Chartrand, T. L. (2003). Using nonconscious behavioral mimicry to create affiliation and rapport. *Psychological Science, 14*(4), 334–339.

Lakin, J. L., Jefferis, V. E., Cheng, C. M., & Chartrand, T. L. (2003). The chameleon effect as social glue: Evidence for the evolutionary significance of nonconscious mimicry. *Journal of Nonverbal Behavior, 27*(3), 145–162.

Lawrence, E. J., Shaw, P., Baker, D., Baron-Cohen, S., & David, A. S. (2004). Measuring empathy: Reliability and validity of the Empathy Quotient. *Psychological Medicine*, *34*(5), 911–920.

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

Livingston, L. A., & Happé, F. (2017). Conceptualising compensation in neurodevelopmental disorders: Reflections from autism spectrum disorder. *Neuroscience and Biobehavioral Reviews, 80*, 729–742.

Livingston, L. A., Colvert, E., Social Relationships Study Team, Bolton, P., & Happé, F. (2019). Good social skills despite poor theory of mind: exploring compensation in autism spectrum disorder. *Journal of Child Psychology and Psychiatry, 60*(1), 102–110.

Lord, C., Rutter, M., DiLavore, P., Risi, S., Gotham, K., & Bishop, S. (2012). *Autism diagnostic observation schedule–2nd edition (ADOS-2)*. Western Psychological Corporation.

Marsh, K. L., Isenhower, R. W., Richardson, M. J., Helt, M., Verbalis, A. D., Schmidt, R. C., & Fein, D. (2013). Autism and social disconnection in interpersonal rocking. *Frontiers in Integrative Neuroscience, 7*, 4.

McNaughton, K. A., & Redcay, E. (2020). Interpersonal synchrony in autism. *Current Psychiatry Reports, 22*(3), 12.

Minio-Paluello, I., Baron-Cohen, S., Avenanti, A., Walsh, V., & Aglioti, S. M. (2009). Absence of embodied empathy during pain observation in Asperger syndrome. *Biological Psychiatry, 65*(1), 55–62.

Neumann, R., & Strack, F. (2000). "Mood contagion": The automatic transfer of mood between persons. *Journal of Personality and Social Psychology, 79*(2), 211.

Noel, J. P., De Niear, M. A., Lazzara, N. S., & Wallace, M. T. (2017). Uncoupling between multisensory temporal function and nonverbal turn-taking in autism spectrum disorder. *IEEE Transactions on Cognitive and Developmental Systems, 10*(4), 973–982.

Ochi, K., Ono, N., Owada, K., Kojima, M., Kuroda, M., Sagayama, S., & Yamasue, H. (2019). Quantification of speech and synchrony in the conversation of adults with autism spectrum disorder. *PLoS ONE, 14*(12), e0225377.

Parkinson, B., & Simons, G. (2012). Worry spreads: Interpersonal transfer of problem-related anxiety. *Cognition and Emotion, 26*(3), 462–479.

Rabin, S. J., Israel-Yaacov, S., Laugeson, E. A., Mor-Snir, I., & Golan, O. (2018). A randomized controlled trial evaluating the Hebrew adaptation of the PEERS® intervention: Behavioral and questionnaire-based outcomes. *Autism Research*, *11*(8), 1187–1200. https://doi.org/10.1002/aur.1974

Rabin, S. J., Laugeson, E. A., Mor-Snir, I., & Golan, O. (2020). An Israeli RCT of PEERS®: Intervention effectiveness and the predictive value of parental sensitivity. *Journal of Clinical Child and Adolescent Psychology, 1*, 1–17.

Ramseyer, F. T. (2020). Motion energy analysis (MEA): A primer on the assessment of motion from video. *Journal of Counseling Psychology, 67*(4), 536.

Ramseyer, F., & Tschacher, W. (2011). Nonverbal synchrony in psychotherapy: Coordinated body movement reflects relationship quality and outcome. *Journal of Consulting and Clinical Psychology, 79*(3), 284.

Ramseyer, F., Ebert, A., Roser, P., Edel, M. A., Tschacher, W., & Brüne, M. (2020). Exploring nonverbal synchrony in borderline personality disorder: A double-blind placebo-controlled study using oxytocin. *British Journal of Clinical Psychology, 59*(2), 186–207.

Randall, A. K., Corkery, S. A., Duggi, D., Kamble, S. V., & Butler, E. A. (2011). "We're having a good (or bad) day": Differences in emotional synchrony in married couples in the United States and India. *Family Science, 2*(3), 203–211.

Richardson, D. C., Dale, R., & Kirkham, N. Z. (2007). The art of conversation is coordination. *Psychological Science, 18*(5), 407–413.

Romero, V., Fitzpatrick, P., Roulier, S., Duncan, A., Richardson, M. J., & Schmidt, R. C. (2018). Evidence of embodied social competence during conversation in high functioning children with autism spectrum disorder. *PLoS ONE, 13*(3), e0193906.

Shamay-Tsoory, S. G. (2011). The neural bases for empathy. *The Neuroscientist, 17*(1), 18–24.

Shamay-Tsoory, S. G., Saporta, N., Marton-Alper, I. Z., & Gvirts, H. Z. (2019). Herding brains: A core neural mechanism for social alignment. *Trends in Cognitive Sciences, 23*(3), 174–186.

Sigman, M. D., Kasari, C., Kwon, J. H., & Yirmiya, N. (1992). Responses to the negative emotions of others by autistic, mentally retarded, and normal children. *Child Development, 63*(4), 796–807.

Srinivasan, S. M., Eigsti, I. M., Gifford, T., & Bhat, A. N. (2016). The effects of embodied rhythm and robotic interventions on the spontaneous and responsive verbal communication skills of children with Autism Spectrum Disorder (ASD): A further outcome of a pilot randomized controlled trial. *Research in Autism Spectrum Disorders, 27*, 73–87.

Travis, L., Sigman, M., & Ruskin, E. (2001). Links between social understanding and social behavior in verbally able children with autism. *Journal of Autism and Developmental Disorders, 31*(2), 119–130.

Trevisan, D. A., Hoskyn, M., & Birmingham, E. (2018). Facial expression production in autism: A meta-analysis. *Autism Research, 11*(12), 1586–1601.

Tschacher, W., Rees, G. M., & Ramseyer, F. (2014). Nonverbal synchrony and affect in dyadic interactions. *Frontiers in Psychology, 5*, 1323.

Valdesolo, P., & DeSteno, D. (2011). Synchrony and the social tuning of compassion. *Emotion, 11*(2), 262.

van Steensel, F. J., & Heeman, E. J. (2017). Anxiety levels in children with autism spectrum disorder: A meta-analysis. *Journal of Child and Family Studies, 26*(7), 1753–1767.

Venuti, P., Bentenuto, A., Cainelli, S., Landi, I., Suvini, F., Tancredi, R., & Muratori, F. (2017). A joint behavioral and emotive analysis of synchrony in music therapy of children with autism spectrum disorders. *Health Psychology Report, 5*(2), 162–172.

Wass, S. V., Smith, C. G., Clackson, K., Gibb, C., Eitzenberger, J., & Mirza, F. U. (2019). Parents mimic and influence their infant's autonomic state through dynamic affective state matching. *Current Biology, 29*(14), 2415–2422.

Wechsler, D. (2008). Wechsler adult intelligence scale–Fourth Edition (WAIS–IV). *NCS Pearson, 22*(498), 816–827.

Wechsler, D. (2014). *Wechsler intelligence scale for children-fifth edition technical and interpretive manual*. NCS Pearson.

Zampella, C. J., Bennetto, L., & Herrington, J. D. (2020). Computer vision analysis of reduced interpersonal affect coordination in youth with autism spectrum disorder. *Autism Research*. https://doi.org/10.1002/aur.2334

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ester Zadok is a doctoral student at the Department of Psychology, Bar-Ilan University, Israel.

Ilanit Gordon is an Associate Professor at the Department of Psychology, Bar-Ilan University, Israel, and the Director of the Social Neuroscience Lab at the Gonda Multidisciplinary Brain Research Center.

Roni Navon is a MA graduate at the Department of Psychology, Bar-Ilan University, Israel.

Shai Joseph Rabin is a PhD graduate at the Department of Psychology, BarIlan University, Israel.

Ofer Golan is an Associate Professor and the head of the Autism research lab at the Department of Psychology, Bar Ilan University, Israel.