Do we really know anything about interpersonal motor synchrony in Autism? A systematic review and meta-analysis

ANALYSES REPORT

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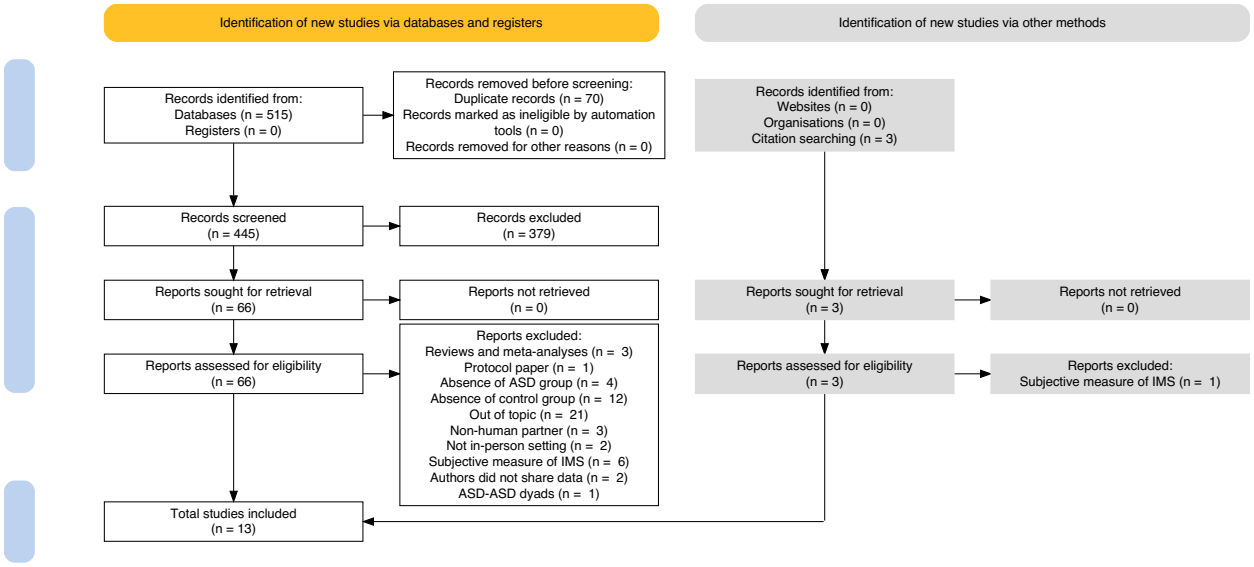
Prisma flow diagram



Effect sizes

To calculate the Hedge's g, we used the `metafor::escalc` (Viechtbauer, 2010). Then, `MAd::agg` was used to compute an aggregated effect size for each study (Del Re & Hoyt, 2014). Since correlation among outcomes was unknown, we considered r =.5 to be the most plausible (reported in the paper and here). See Supplementary Materials for r =.7 and r =.9.

Deacriptives of the included studies can be found in *Table 1.* Note that Comparison group has been used as X_1 and Autistic group as X_2, therefore positive Hedge's g are in favour of TD, while lower are in favour of ASD.

Table 1: Descriptives of the studies included

			Comparison Group					Autistic Group							
					Age					Age					
ID	Authors	Country	N	M/F ratio	range	mean	sd	N	M/F ratio	range	mean	sd	Type of Synchrony	Hedge's g	var
1	Brezis et al., 2017	Israel	35	28:7	19 - 45	25.90	6.37	34	31:3	20 - 45	28.60	6.26	instructed	0.66	0.04
2	Fitzpatrick et al., 2013	USA	3	1:2	4 - 5.6	4.80	0.75	5	4:1	5 - 7.4	6.21	1.17	instructed	0.21	0.34
3	Fitzpatrick et al., 2017	USA	27	21:6	6.33 - 10.8	8.24	1.46	23	20:3	6.08 - 10.75	8.08	1.44	instructed	1.00	0.05
4	Fitzpatrick et al., 2016	USA	9	7:2	12 - 16	14.44	1.13	9	8:1	12 - 17	13.67	1.94	instructed	0.34	0.13
5	Fulceri et al., 2018	Italy	11	9:2	6.3 - 9.8	7.57	0.71	11	10:1	5.11 - 10.3	7.82	1.32	spontaneous	0.88	0.11
6	Georgescu et al., 2020	Germany	10	6:4	33 - 51	41.80	8.86	9	5:4	30 - 50	40.72	10.45	spontaneous	0.83	0.12
7	Kawasaki et al., 2017	USA	24	12:12	18.9 - 32.1	25.60	6.60	24	14:10	22 - 36.4	29.20	7.20	instructed	0.83	0.09
8	Kruppa et al., 2021	Germany	41	18:23	8 - 18	12.66	2.79	18	18:0	8 - 18	13.54	2.96	instructed	0.62	0.06
9	Lampi et al., 2020	USA	47	34:13	6 - 10	7.85	1.49	50	34:7	6 - 10	8.02	1.44	spontaneous	0.83	0.03
10	Liu et al., 2021	USA	16	10:6	1.66 - 4.33	2.99	0.70	13	10:3	1.75 - 5.75	3.88	0.85	spontaneous	3.78	0.11
11	Marsh et al., 2013	USA	7	4:3	2.8 - 4.6	3.75	0.12	7	5:2	3.8 - 4.1	3.94	0.74	spontaneous	0.21	0.31
12	Noel et al., 2018	USA	15	11:4	8.9 - 14.5	10.94	2.13	12	8:4	7.9 - 16.5	12.20	3.75	spontaneous	0.24	0.11
13	Yoo et al., 2018	Korea	42	23:19	11 - 16	13.50	0.80	10	10:0	11 - 16	13.40	1.40	spontaneous	0.44	0.08

Please note that when asynchrony measures were collected (i.e. Fulceri et al, 2018; Yoo et al., 2018) we used the *negative of the absolute value*, such that the lower the value is, the lower the asynchrony. For example, Yoo et al. state that their measure of asynchrony consists in the difference between the onset timing of tapping and the onset timing of cueing. This means that the closer the value is to 0, the highest the synchrony, while positive and negative values would both reflect asynchrony. In order to have a measure of synchrony, we therefore took the absolute values and reversed them to negative.

Similarly, when reaction times were collected (Fulceri et al., 2018; Kruppa et al., 2021), we took their negatives as higher values would otherwise reflect asynchrony rather than synchrony. In fact, Fulceri et al., specify that their measure of reaction times consists in the difference, in milliseconds, between the Child Start Time and the Experimenter Start Time; therefore the lower the value, the highest the synchrony.

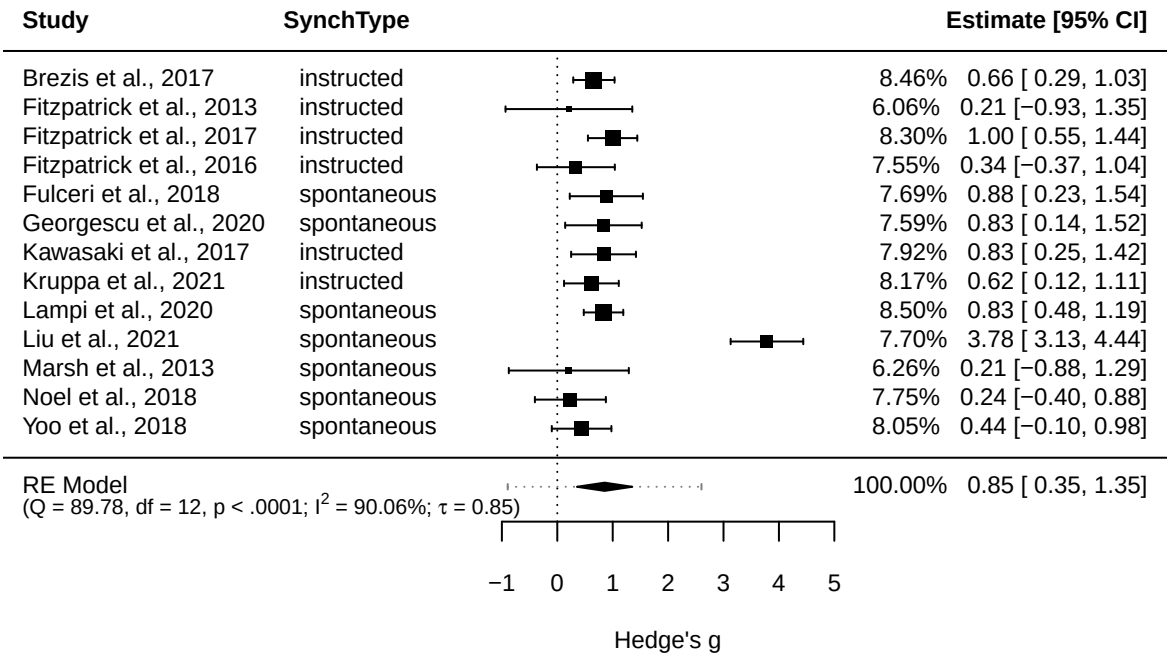
Meta-analysis

Models

```
##
## Random-Effects Model (k = 13; tau^2 estimator: REML)
##
##   logLik  deviance       AIC       BIC      AICc
## -16.0955   32.1909   36.1909   37.1607   37.5242
##
## tau^2 (estimated amount of total heterogeneity): 0.7307 (SE = 0.3433)
## tau (square root of estimated tau^2 value):      0.8548
## I^2 (total heterogeneity / total variability):   90.06%
## H^2 (total variability / sampling variability):  10.06
##
## Test for Heterogeneity:
## Q(df = 12) = 89.7806, p-val < .0001
##
## Model Results:
##
## estimate      se    zval    pval   ci.lb   ci.ub
##   0.8534  0.2547  3.3500  0.0008  0.3541  1.3527  ***
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## Mixed-Effects Model (k = 13; tau^2 estimator: REML)
##
##   logLik  deviance       AIC       BIC      AICc
## -14.9281   29.8562   35.8562   37.0499   39.2848
##
## tau^2 (estimated amount of residual heterogeneity):     0.7596 (SE = 0.3714)
## tau (square root of estimated tau^2 value):             0.8716
## I^2 (residual heterogeneity / unaccounted variability): 90.03%
## H^2 (unaccounted variability / sampling variability):   10.03
## R^2 (amount of heterogeneity accounted for):            0.00%
##
## Test for Residual Heterogeneity:
## QE(df = 11) = 86.0983, p-val < .0001
##
## Test of Moderators (coefficient 2):
## QM(df = 1) = 0.6403, p-val = 0.4236
##
## Model Results:
##
##                         estimate      se    zval    pval    ci.lb   ci.ub
## intrcpt                   0.6303  0.3802  1.6579  0.0973  -0.1149  1.3756  .
## synch_typespontaneous     0.4157  0.5195  0.8002  0.4236  -0.6026  1.4340
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Forest plot



Prediction interval

```
##
##    pred     se  ci.lb  ci.ub   pi.lb  pi.ub
##  0.8534 0.2547 0.3541 1.3527 -0.8948 2.6017
```

Funnel plot

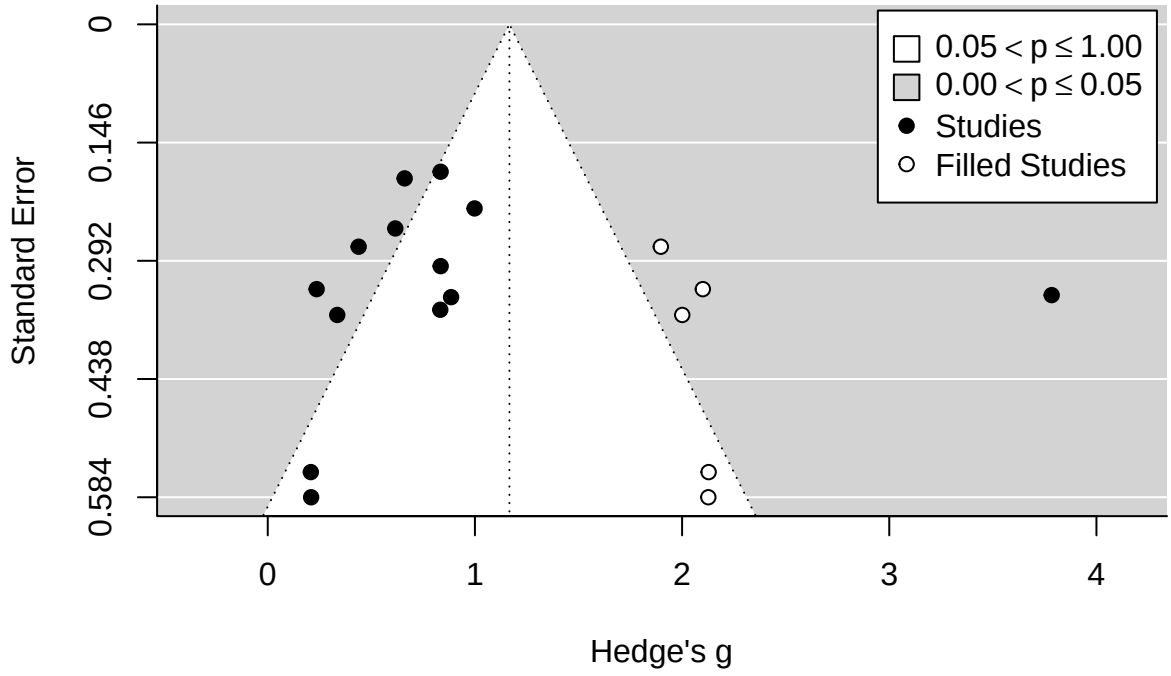


Table 2: Leave-one-out sensitivity analysis

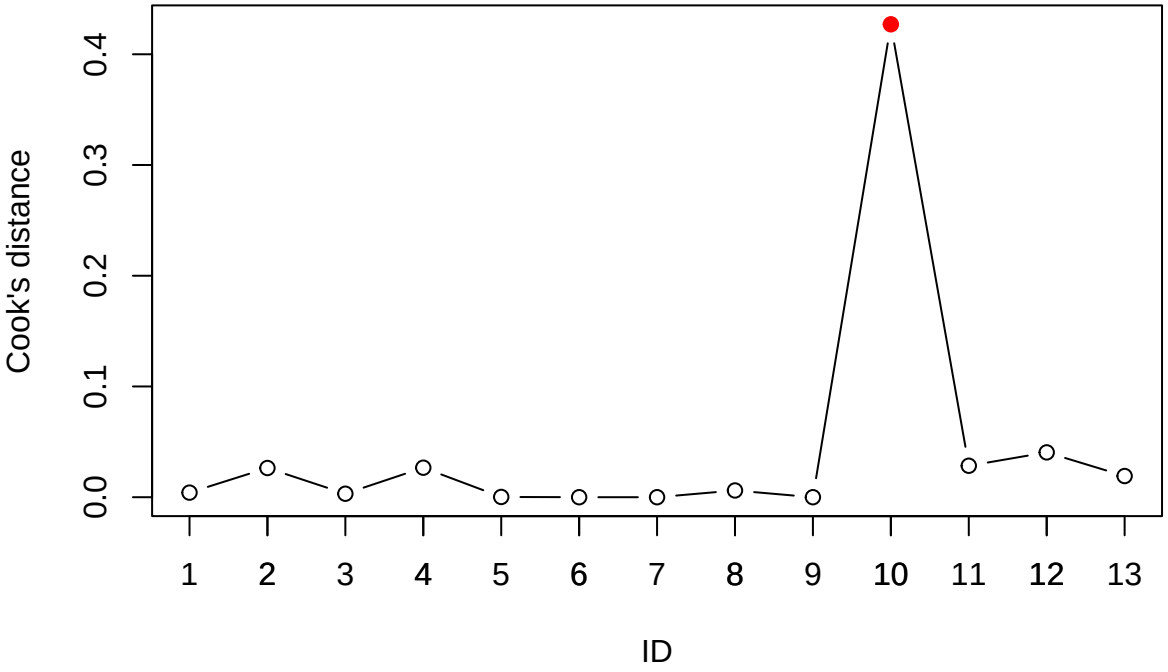
Authors	Estimate	I2	tau	CI	PI
Brezis et al., 2017	0.87	90.08	0.90	[0.32;1.42]	[-0.98;2.72]
Fitzpatrick et al., 2013	0.89	91.03	0.88	[0.37;1.42]	[-0.9;2.69]
Fitzpatrick et al., 2016	0.90	90.89	0.88	[0.36;1.43]	[-0.92;2.71]
Fitzpatrick et al., 2017	0.84	90.54	0.90	[0.29;1.39]	[-1.01;2.69]
Fulceri et al., 2018	0.85	91.12	0.90	[0.31;1.39]	[-1;2.69]
Georgescu et al., 2020	0.85	91.15	0.90	[0.31;1.40]	[-0.99;2.7]
Kawasaki et al., 2017	0.85	91.00	0.90	[0.31;1.40]	[-0.99;2.7]
Kruppa et al., 2021	0.87	90.69	0.90	[0.33;1.42]	[-0.97;2.72]
Lampi et al., 2020	0.85	90.00	0.91	[0.31;1.40]	[-1;2.71]
Liu et al., 2021	0.69	0.00	0.00	[0.53;0.84]	[0.53;0.84]
Marsh et al., 2013	0.90	91.01	0.88	[0.37;1.42]	[-0.9;2.69]
Noel et al., 2018	0.90	90.67	0.88	[0.37;1.44]	[-0.89;2.7]
Yoo et al., 2018	0.89	90.68	0.89	[0.35;1.43]	[-0.94;2.72]

```
##
## Estimated number of missing studies on the right side: 5 (SE = 2.2785)
##
## Random-Effects Model (k = 18; tau^2 estimator: REML)
##
##   logLik  deviance       AIC       BIC      AICc
## -23.3410   46.6819   50.6819   52.3483   51.5390
##
## tau^2 (estimated amount of total heterogeneity): 0.7668 (SE = 0.3065)
## tau (square root of estimated tau^2 value):      0.8757
## I^2 (total heterogeneity / total variability):   89.40%
## H^2 (total variability / sampling variability):  9.43
##
## Test for Heterogeneity:
## Q(df = 17) = 130.3017, p-val < .0001
##
## Model Results:
##
## estimate      se    zval    pval   ci.lb   ci.ub
##   1.1665  0.2233  5.2240  <.0001  0.7288  1.6041  ***
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Sensitivity analysis

Leave-One-Out

Cook's distance



Overview of the studies included in the systematic review

Table 3: Overview of the studies included in the systematic review

Authors, Year	Task	Measure	Dyads	Type of synchrony	Take home message
Brezis et al., 2017	Mirroring each other while moving handles along parallel tracks: alternate leading, following, or joint improvisation with no pre-specified roles	Percentage and duration of Co-Confident periods	Adult-adult	Instructed	ASD participants showed less periods of synchrony, particularly in the follower role, compared to when they were leading, or no specific roles were established. Overall, they also showed shorter periods of synchrony. General motor abilities among ASD participants accounted for some, but not all, of their reduced synchrony in the follower role. General social skills did not predict interpersonal motor synchrony levels.
Chen et al., 2022	Preschoolers were invited to play with their teacher using some toys such as blocks, a set of toys for cooking, and two magnetic robots	Windowed cross-correlation of body movements time series (head, trunk, right arm) computed by means automated human pose estimator. Based on videos, the authors segmented episodes of two ways interaction from oneway adult engagement only.	Child-teacher	Spontaneous	Diminished synchrony was observed in both TD and ASD when only adults exhibited social engagement compared to situations where both adults and children interacted. In two-way interactions, the ASD group displayed decreased IMS in the upper body and trunk compared to the TD group, whereas during one-way adult engagement, the ASD group exhibited heightened IMS in the head.
Delaherche et al., 2013	Participants had to build a puppet from multiple elements together with their therapist, in three conditions: when seeing the therapist performing actions, when hearing instructions on how to put the puppet together, when giving instructions.	Windowed cross-correlation of motion energy time series (ROIs: child, therapist - each had global, posture, hands regions)	Child-adult	Instructed	The presence of a folding screen obstructing others' sight in the conditions where the child only heard or gave instrustions made synchronization harder especially for the ASD children, in fact the TD group tended to be more in sync with the therapist's movement despite the folding screen.
Fitzpatrick et al., 2013	Social synchronisation: the experimenter demonstrates several movements directed to objects, own body or space, then asks the child to do them together	Relative phase to calculate the frequency of occurrence in each relative phase region	Child-adult	Instructed	The ASD group showed reduced simultaneous synchronisation only in object-directed movements. There is no clear evidence on whether interpersonal motor synchrony is impaired in autism.
Fitzpatrick et al., 2016	Pendulum coordination paradigm: adolescents swung the pendulum with the dominant hand while facing the parents swinging the pendulum with the non-dominant hand	Circular variance of relative phase	Adolescent-parent	Instructed	ASD adolescents showed less synchronisation in both spontaneous and intentional interpersonal coordination.
Fitzpatrick et al., 2017	Social synchronisation: the experimenter demonstrates several movements directed to objects, own body or space, then asks the child do to them together	Weighted coherence from the time series movements of the child and experimenter	Child-adult	Instructed	ASD children exhibited lower social synchronisation ability than TD children in all types of social motor synchronisation tasks. The ASD group performed drumming movements that were slower and more variable in both spacing and timing than TD.
Fulceri et al., 2018	Cooperative joint action: the child had to move their arm to insert a "banana" coin into a "monkey" box that was moved by the experimenter, thus coordinating with the experimenter's movement.	Reaction times, Coefficient of variation of reaction times, Movement time, Asynchrony of reaching	Child-adult	Spontaneous	ASD children showed reduced coordination with the adult as captured by some kinematic parameters, especially when the final destination of the movement was not known beforehand.
Georgescu et al., 2020	Guided conversations (i.e., a cooperative or competitive conversation on an instructed topic)	Windowed cross-lagged correlations of the motion energy time series (ROIs: head and body of each participant)	Adult-adult	Spontaneous	In a conversational setting, dyads with at least one ASD participant, compared to TD-only dyads, showed reduced interpersonal motor synchrony. This was not due to the quantity of movement produced, which did not differ between groups.
Glass and Yuill, 2023	Tablet-based games where participants had to cooperate to find the matching colors in a series of dots (Colors, designed with no additional design features to facilitate collaboration) and match and sort pictures based on their categories (Connect, designed to support collaboration by facilitating engagement and other-awareness)	Windowed cross-lagged correlations of the motion energy time series	Child-child	Spontaneous	In both the shared tablet activities—Connect and Colours—the neurotypical group exhibited comparable motor synchrony to the autistic group in Colours, yet demonstrated lower IMS in Connect. Interestingly, the autistic group maintained similar IMS levels across both activities, indicating that within specific social contexts and task types, autistic children exhibit comparable or even heightened synchronization abilities compared to neurotypical children.
Kawasaki et al., 2017	Social synchronisation: participants were instructed to tap two keys back and forth at a time interval equal to that of the partner. The tapping tempo was not predetermined nor directed	Rates of synchronised tapping (based on tapping intervals)	Adult-adult	Instructed	ASD adults had lower rates of synchronisation with TD partners. Synchronisation rate was correlated with autism severity. Differences in theta activity measured by EEG were also found in the ASD group. Potential associations between theta activity, synchronisation rate, and symptom severity are discussed.
Kruppa et al., 2021	Computer based game, in which participants had to cooperate or compete to press a button and make a dolphin jump, and catch the ball	Mean of the absolute differences in response times of each dyad	Child-parent, child-stranger	Instructed	Overall, higher synchrony occurred during competition compared to cooperation, and with the stranger compared to the parent. ASD children were less synchronous than TD children, across conditions and partners. No group differences were observed at the neural level (wavelet coherence from fNIRS signals).
Lampi et al., 2020	Interpersonal hand-clapping	Weighted coherence from the time-series movements	Child-adult	Spontaneous	In the ASD group, poorer interpersonal motor synchrony was associated with higher levels of Restricted and Repetitive Behaviours.
Liu et al., 2021	Caregiver-child dyads are involved in a musical (song) and non-musical (picture) book-sharing activity	Windowed cross-correlation of motion energy time-series (ROIs: child, adult)	Child-caregiver (either parent or other)	Spontaneous	ASD children showed lower motor synchrony with their caregiver compared to their typically developing peers, regardless of the shared book being musical or non-musical.
Marsh et al., 2013	A parent read a storybook to the child while sitting in their own rocking chair and rocking throughout to a set tempo. Children sit on their own rocking chairs while listening.	Continuous relative phase to calculate the average amount of time the dyad spent in a given relative phase	Child-parent	Spontaneous	ASD children exhibited significantly less in-phase rocking with their parents than TD children, thus showing reduced spontaneous synchronisation. The authors argue that unintentional low-level motor synchronisation could contribute to core impairments observed in autism (i.e., engage in joint attention, joint action, and mimicry)
Noel et al.,	Non-verbal synchrony (i.e., head,	Pearson correlation of	Child-	Sponta-	ASD children, compared to TD, showed reduced motor