Physiology & Behavior 224 (2020) 113074

Contents lists available at ScienceDirect

Physiology & Behavior

journal homepage: www.elsevier.com/locate/physbeh

The relationship between physiological synchrony and motion energy synchrony during a joint group drumming task

Ilanit Gordon[a,b,*], Avi Gilboa[c], Shai Cohen[c], Tomer Kleinfeld[a,b,c]

[a] Department of Psychology, Bar-Ilan University, Ramat-Gan, Israel
[b] The Gonda Multidisciplinary Brain Research Center, Bar-Ilan University, Ramat-Gan, Israel
[c] The Department of Music, Bar-Ilan University, Ramat-Gan, Israel

ARTICLE INFO

Keywords:
Physiological synchrony
Motion energy synchrony
Groups
Drumming
Interbeat-Intervals
MEA

ABSTRACT

Coordination with others in groups is crucial to group cohesion and function, yet only scant research addressed behavioral and physiological interpersonal synchrony in groups during shared activities. We present data from 39 triads instructed to drum together. Based on video-recordings of the task and participants' electrocardiograms, we computed physiological synchrony in cardiologic interbeat intervals and behavioral motion energy synchrony among group members as they were drumming together. Overall, behavioral and physiological synchrony were positively associated with continuous shifts from positive correlations to non-significant ones throughout the task. Results shed light on the relational components of group bonding and elucidate the dynamic interactions between physiological and behavioral synchrony at the group level.

1. Introduction

Belonging to groups is a fundamental aspect of everyday life, our identity, and the way we function in society. Group theory has long emphasized the importance of understanding how individuals bond to form cohesive and efficacious groups [4]. Despite the inherent multilevel structure of groups, to date, much of the literature and operationalization has focused on exploring individual level contributions as the basic building block for analyses, and then further extrapolating this information to learn about the group (Ballard et al., 2019; [27]). Understanding the sources of variance between individuals in groups is now at the core of group theory and critical for the realization of the building blocks of group functioning [16,18,26]. Focusing on interpersonal processes in groups will allow us to extend beyond the individual, an essential step in understanding how groups form, bond, and function [11].

Interpersonal synchrony is the co-variation of behavioral, physiological, or emotional functions over time between two or more individuals [15] and is considered a ubiquitous evolutionary-based mechanism supporting pro-sociality and bonding [14,21,22]. One way to assess physiological interpersonal synchrony is to calculate the continuous covariation between cardiological interbeat intervals (IBI) of group members. IBI represents the time between two consecutive heartbeats and it is regulated by both sympathetic and parasympathetic branches of the autonomic nervous system (ANS). IBI Synchrony has been shown to support social bonding [6], and can emerge among group members during a shared state, perhaps owing to common emotions, communicative cues [9,10] or cooperation [16].

In this study we suggest that motion synchrony may also covary with IBI synchrony. Motion energy (ME) synchrony (F. T. [20]) is an objective measure of nonverbal behavioral synchrony derived automatically from videos. ME synchrony and its influences have been extensively examined in healthy and patient populations (for recent examples see [7,8]. ME synchrony was predictive of the quality of therapist-client relationships and psychotherapy outcomes (F. [19]), as well as changes in affect in dyadic interactions [24]. The aim of the current study was to assess the dynamics of the association between IBI synchrony and ME synchrony in 38 three-person groups during a novel drumming task in which participants were asked to improvise together freely. Group drumming was chosen as it is an activity that encourages synchronicity in tempo and can bring about conjoint body language which the ME analysis may capture. We hypothesized that ME and IBI synchrony will have a positive correlation.

2. Material and methods

2.1. Participants

Participants were non-musicians, undergraduate students in the Department of Psychology at Bar-Ilan University. The study was a part

* Corresponding author at: Department of Psychology and The Gonda Multidisciplinary Brain Research Center, Bar-Ilan University, Ramat-Gan, Israel.
E-mail address: ilanit.gordon@biu.ac.il (I. Gordon).

https://doi.org/10.1016/j.physbeh.2020.113074
Received 13 May 2020; Received in revised form 9 July 2020; Accepted 10 July 2020
Available online 11 July 2020
0031-9384/

of a larger study comprising 51 triads. For technical reasons, we had 39 usable ceiling video-recordings, the most suitable angle in our lab's setup for the MEA. One group's physiological data were corrupted and thus we report data from 114 individuals (91 women) nested in 38 triads. Participants' mean age was 22.41 years (SD = 1.93).

2.2. Procedure

The study was approved by the Department of Psychology's IRB ethical committee. Participants were asked to hydrate and avoid caffeinated drinks/nicotine two hours prior to the lab-visit. Upon arrival, the experimenter explained the procedure and participants signed informed consent. Participants' electrocardiograms were monitored throughout the study via electrodes (MindWare Technology's MindWare Mobile Impedance Cardiograph, Gahanna, OH). Participants were seated around a Roland V-drum electronic drum-set, modified for the study to comprise three drum-pads. Participants were instructed to drum using their dominant hand and avoid talking during the session. The study was videotaped from three angles (30 frames-per-second cameras synchronized with each other and with physiological recordings) capturing group members' faces and bodies. Following an initial drumming task[1] which is not the focus of the current report, participants were asked to freely play together on the drums for 4 minutes. Results from this improvisation task are presented in the current report.

2.3. Measures

2.3.1. Physiological measures: cardiological IBIs

2.3.1.1. Collection. Electrocardiograms were obtained from group members using a standard lead-II configuration. Respiratory data were derived from the standard tetrapolar electrode procedure for the impedance cardiogram described elsewhere [23]. Electrodes were transmitting synchronously and wirelessly to the control room at 500 Hz sampling rate.

2.3.1.2. Pre-processing. Electrocardiograms were analyzed in MindWare Technology's HRV 3.1.4 application where they were amplified by a gain of 1000, and filtered with a hamming windowing function. Visual inspection and manual editing of the data by trained RAs ensured removal of artifacts and ectopic beats [1]. The resulting IBI time-series was spline-interpolated using Matlab 2019a (The MathWorks, Inc.) for every 500 milliseconds to obtain an equal interval time-series.

2.3.1.3. Computing group-level IBI synchronization. In line with previous research [6,10], we ran a series of cross-correlation-function (CCF) with a temporal lag of 3-seconds on the interpolated IBI time-series for each group member using Matlab. We then extracted the maximal degree of correlation between each dyad's time-series. A group synchronization score was calculated as the mean of each group's three dyadic maximal correlations.

2.3.2. Motion energy analysis (MEA; [20])

MEA is an objective automated method to calculate motion synchrony between two individuals. By monitoring continuous changes in pixels from frame to frame between consecutive video frames in predefined regions of interest (ROI), the MEA software assesses body motion from a participant in their ROI (see Ramseyer [20] for full description of the MEA procedure which we followed). Video recordings from the improvisation sessions (mp4 format) were analyzed. One ROI per participant was chosen (Fig. 1). To quantify ME synchrony, we used the accompanying rMEA R package [13] which involves CCF analyses with the following parameters chosen according with the methodological guidelines [20] and the nature of our data: within a window of 5 s, in 60 s segments overlapping by 30 s. We extracted the absolute value of ME synchrony at lag-zero (representing concurrent synchronization), yielding one global value for every 60-second segment. These values across overlapping segments were then averaged to a single ME synchrony score for every pair within our group. Finally, all pairs' scores were averaged to reach a single lag-zero ME synchrony group score.

3. Results

All analyses were performed in IBM's SPSS 25 and Jamovi 1.1.4.0. Fig. 2 shows a violin chart of the distribution of all ME dyadic correlations within our data. On the right we present the real data set (117 dyads) and on the left we present ME correlations from all random pairs in our data (8892 shuffled dyads). As can be seen, the real data set comprises higher ME correlations compared to the shuffled data, which supports the notion that ME synchrony in drumming groups was significantly larger than random and due to the actual group interaction and not spurious or due to similar task conditions across all groups. Results of Welch's t-test show that indeed scores in the random data set were lower than those in the real data set: $t\ (116)$ = -16.3, $p < .001$; *Cohen's* d = -1.51 (Random: M = 0.108, SD = 0.04; Real: M = 0.175, SD = 0.11).

ME synchrony and IBI synchrony during the improvisation session were positively related: *Pearson's* r = 0.429, p = .007, *95%CI* = 0.127–0.659.

To explore dyadic-level contribution in ME synchrony to physiological synchrony, we also assessed the three dyadic ME synchronies in all the groups: 'lowest', 'medium', and 'highest'. See Table 1 for descriptive statistics on these dyadic ME correlations.

A Pearson's correlation matrix for 'lowest', 'medium', and 'highest' dyadic correlations, and their relationship to ME synchrony can be seen in Table 2.

As can be seen in Table 2, dyadic ME correlations comprising group ME synchrony were highly positively correlated (lowest-medium: r = 0.928, $p < .001$; highest-lowest: r = 0.762, $p < .001$; medium-highest: r = 0.705, $p < .001$). Additionally, each dyadic correlation was positively associated with group ME synchrony. Interestingly, only the highest dyadic ME correlation within a group was as strongly and as significantly related to group IBI synchrony as the group ME synchrony aggregated score.

To assess the dynamics of changes in the association between ME synchrony and IBI synchrony, we segmented the ME and IBI data from the improvisation task to non-overlapping 30-second windows, which will provide enough data points to explore dynamical changes in associations and also give of enough data to calculate meaningful IBI and ME data. Not all groups had full ME data for the final 8th 30-seconds segment (which is required for getting and ME synchrony score), and so we present here information from the first seven segments comprising 3.5 min of the interaction. See Fig. 3 for ME and IBI synchrony density and correlation plots in every 30-seconds segment. Fig. 4 displays the dynamical changes in ME and IBI synchrony correlations as well as the dynamics of ME synchrony and IBI synchrony on their own. As can be seen, although ME synchrony and IBI synchrony seem consistent throughout the improvisation task, the relationship between the two continuously shifts from positively significant to insignificant.

4. Discussion

This study sheds light on the relationship between behavioral and physiological synchrony during group interactions, a relationship which we know very little about despite the critical importance of group bonding and cohesion to everyday life. We show for the first time

[1] We note first that no correlations were found between the initial conditions of the drumming task that preceded the improvisation session and physiological synchrony (*Pearson's* r = .133, p = .373) or ME synchrony (*Pearson's* r = .065, p = .693).

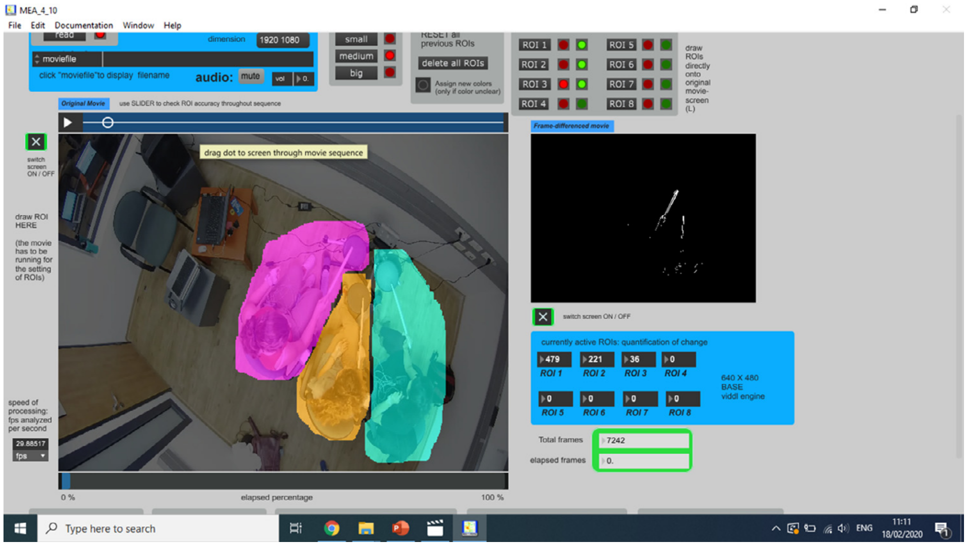

Fig. 1. A snapshot of the MEA software in action, analyzing one video collected from our study. The three predefined ROIs appear in three different colors, each capturing the whole body of a single participant. All analysis parameters can be seen in the screenshot.

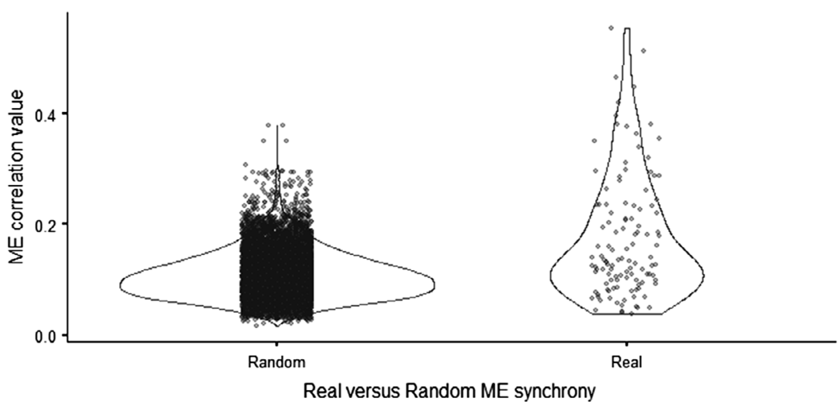

Fig. 2. Violin plots depicting the dispersion of ME synchrony scores in our data set. On the left we show a plot of all possible random dyads generated by the rMEA package. On the right, we present all real dyads from actual drumming groups in our data.

Table 1
Descriptive statistics for the three dyadic ME synchronies in the study's groups.

	lowest ME dyadic correlation	medium ME dyadic correlation	highest ME dyadic correlation
N	39	39	39
Mean	0.119	0.161	0.247
Median	0.090	0.140	0.230
Standard deviation	0.080	0.083	0.124
Minimum	0.040	0.060	0.070
Maximum	0.380	0.420	0.560

that ME synchrony and IBI synchrony during a shared drumming session are positively associated. These results fit with the general sense that both ME synchrony and IBI synchrony yield prosocial effects [15,17,22]. Our results cannot infer causal relationships as IBI synchrony and ME synchrony were assessed simultaneously, and yet we introduce here a potential behavioral-motor mechanism that can be explored in future studies with a causal design and may explain previous reports on the emergence of IBI synchrony during shared states [16].

Dyadic ME scores comprising group synchrony were all positively related to each other and to physiological synchrony, yet only dyads with the strongest ME synchrony in a group were as strongly and significantly related to IBI synchrony as the aggregated group-level ME score. Possibly, dyads within the group that coordinate motion most intensely are dyads that drive the effect in this study. Pairs that were less coordinated in their motion had a weaker association to group physiological synchrony. Future studies are required to assess if dyads that are more strongly synchronized can overpower other group members and therefore contribute more to performance and what are the consequences of variance in synchronies between dyads forming a group. This result highlights the fact that dyadic-level representations gives us insight into the dynamics that shape groups [16,26]. If indeed a strong dyad can influence the entire triad, we might ask how far the influence of a dyad can go: Will it overshadow a group of four or five or even more? This is to be examined in further studies. In any case, we argue that this finding further emphasizes the importance of identifying interpersonal behavioral and physiological processes to reach a crystallized understanding of groups.

The main result of the study adds to the relatively inconsistent current knowledge regarding covariation of behavioral and ANS synchrony [15,17], which should not always be expected [17], as both physiological and behavioral synchrony are multifaceted composites [12,25]. Results vary according to: (1) the physiological/behavioral measure (2) the calculation of synchrony, and (3) the context. Specifically, regarding context, we did not control for gender or gender composition in the groups as this was not the focus of the current study.

Table 2
Correlation matrix for group IBI synchrony and the three dyadic ME correlations: 'lowest', 'medium' and 'high'.

		Group IBI synchrony	lowest ME dyadic correlation	medium ME dyadic correlation	highest ME dyadic correlation
Group IBI synchrony	Pearson's r	—			
	p-value	—			
lowest ME dyadic correlation	Pearson's r	0.337*	—		
	p-value	0.019	—		
medium ME dyadic correlation	Pearson's r	0.335*	0.928***	—	
	p-value	0.020	< .001	—	
highest ME dyadic correlation	Pearson's r	0.487***	0.705***	0.762***	—
	p-value	< .001	< .001	< .001	—
	95% CI Upper	1.000	1.000	1.000	—
	95% CI Lower	0.249	0.540	0.621	—

Note. H_a is positive correlation.
Note. * $p < .05$, ** $p < .01$, *** $p < .001$, one-tailed.

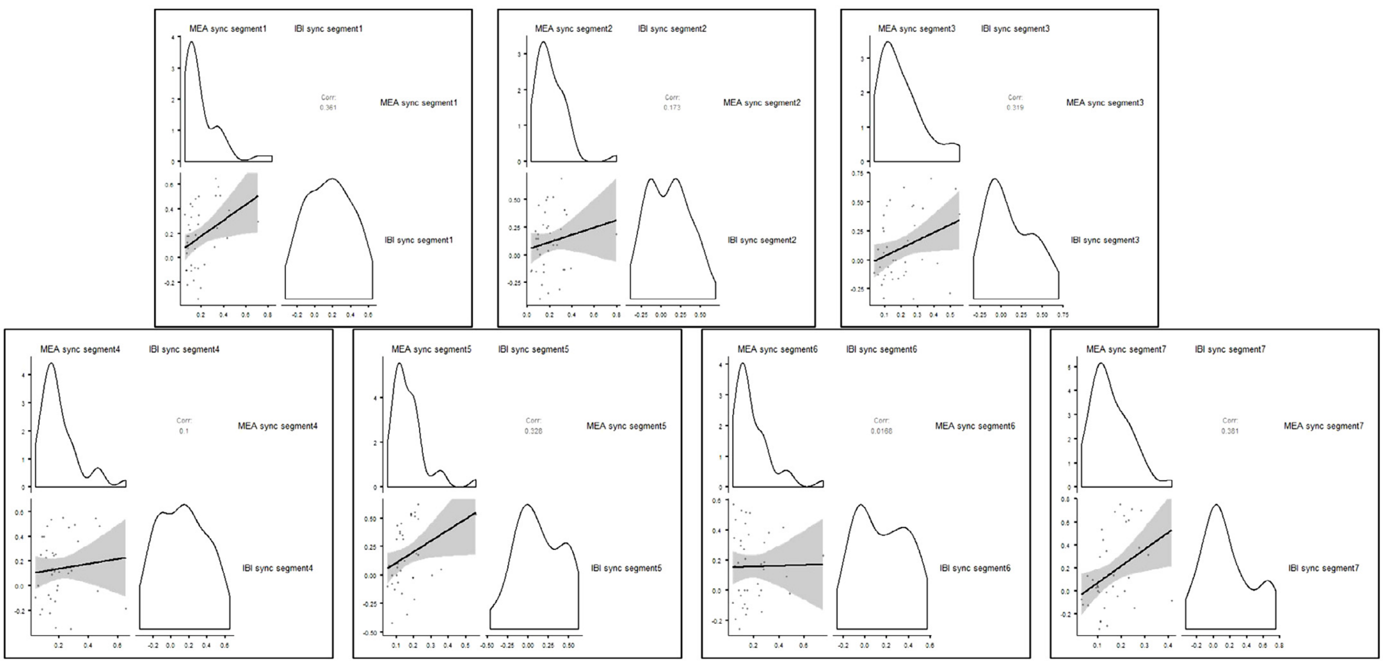

Fig. 3. We present the scatter plot (with 95% confidence intervals) for ME synchrony scores and IBI synchrony scores every 30 s throughout the improvisation session. In each panel you can also see the density plots for ME synchrony scores and IBI synchrony scores separately.

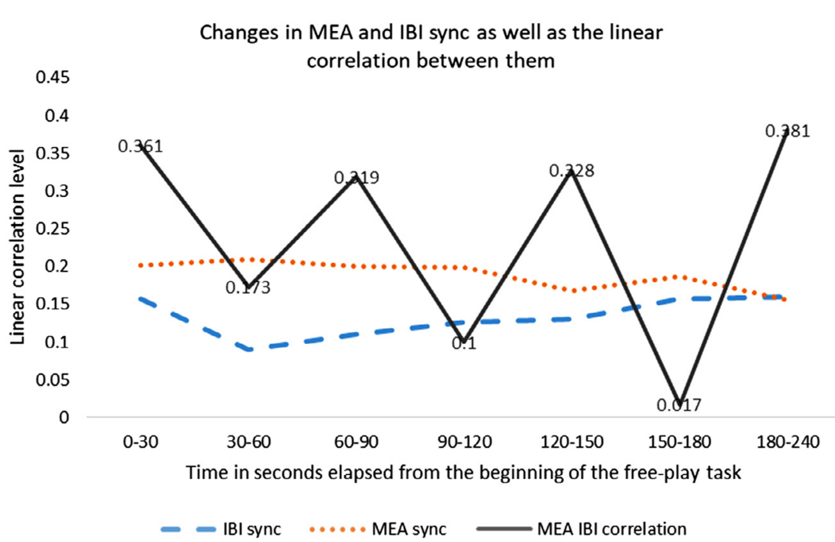

Fig. 4. Group ME synchrony and group IBI synchrony scores for every 30 s throughout the improvisation session. In the black line we present the dynamical changes in correlation between ME synchrony and IBI synchrony.

Future studies should aim to test for gender effects in their design, as there is evidence indicating that gender influences synchrony [5]. Nevertheless, our results reveal that the overall positive association between motion and physiological synchrony is comprised of continuous shifts from positive relationships to very small ones. Recently, we suggested that shifts from synchrony to asynchrony represent an adaptive aspect of the interpersonal system as they denote metastability and flexibility: features of synchrony essential for dynamic social exchanges [2,15]). We already know that more synchrony is not always beneficial or indicative of better outcomes [3] and as such describing the dynamical entries and withdrawals from synchrony, as we did in this study, allows us to unpack flexibility that may be a marker of more optimal social exchanges. Here we show that such dynamic shifts occur at the group level, but not in synchrony itself, conversely in the alignment between different modalities of synchrony. Future studies should address how these dynamics in behavioral and physiological synchrony covariation support group formation, cohesion, and performance.

Funding sources

Funding: This work was supported by the Israel Science Foundation [grant numbers 2096/15, 1726/15]; and Funding provided by Negotiation and Team Resources under the NTR-INGroup research grant program.

Declaration of Competing Interest

Authors declare no conflict of interest.

Acknowledgments

Nir Milstein, Nir Haimovich, Shay Pinhasi, Gili Levy, Nofit Fraizait, Stav Hadar, Yaniv Kanat-Maymon, Yarin Striet.

References

[1] G.G. Berntson, J. Thomas Bigger Jr, D.L. Eckberg, P. Grossman, P.G. Kaufmann, M. Malik, P.H. Stone, Heart rate variability: origins, methods, and interpretive caveats, Psychophysiology 34 (6) (1997) 623–648.

[2] S.M. Boker, J.L. Rotondo, Symmetry building and symmetry breaking in synchronized movement, Mirror Neurons Evol. Brain Lang. 42 (2002) 163.

[3] E.A. Butler, Temporal interpersonal emotion systems: The “TIES” that form relationships, Pers. Soc. Psychol. Rev. 15 (4) (2011) 367–393.

[4] C.R. Evans, K.L. Dion, Group cohesion and performance: A meta-analysis, Small Group Res. 22 (2) (1991) 175–186.

[5] R. Feldman, Infant–mother and infant–father synchrony: The coregulation of positive arousal, Infant Ment. Health J. 24 (1) (2003) 1–23.

[6] R. Feldman, R. Magori-Cohen, G. Galili, M. Singer, Y. Louzoun, Mother and infant coordinate heart rhythms through episodes of interaction synchrony, Infant Behav. Dev. 34 (4) (2011) 569–577.

[7] K. Fujiwara, M. Kimura, I. Daibo, Rhythmic features of movement synchrony for bonding individuals in dyadic interaction, J. Nonverbal Behav. 44 (1) (2020) 173–193.

[8] A. Georgescu, S. Koeroglu, C de, A. Hamilton, K. Vogeley, C. Falter-Wagner, W. Tschacher, Reduced nonverbal interpersonal synchrony in autism spectrum disorder independent of partner diagnosis: a motion energy study, Mol. Autism 11 (1) (2020) 1–14.

[9] Y. Golland, Y. Arzouan, N. Levit-Binnun, The mere co-presence: Synchronization of autonomic signals and emotional responses across co-present individuals not engaged in direct interaction, PLoS One 10 (5) (2015) e0125804.

[10] Y. Golland, D. Mevorach, N. Levit-Binnun, Affiliative zygomatic synchrony in co-present strangers, Sci. Rep. 9 (1) (2019) 3120.

[11] I. Gordon, J.F. Leckman, D.N. Berg, From attachment to groups: tapping into the neurobiology of our interconnectedness, J. Am. Acad. Child & Adolesc. Psychiatry 53 (2) (2014) 130–132.

[12] J.L. Helm, J.G. Miller, S. Kahle, N.R. Troxel, P.D. Hastings, On measuring and modeling physiological synchrony in dyads, Multivar. Behav. Res. 53 (4) (2018) 521–543.

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

[14] J. Launay, B. Tarr, R.I. Dunbar, Synchrony as an adaptive mechanism for large-scale human social bonding, Ethology 122 (10) (2016) 779–789.

[15] O. Mayo, I. Gordon, In and out of synchrony—Behavioral and physiological dynamics of dyadic interpersonal coordination, Psychophysiology (2020).

[16] D. Mønster, D.D. Håkonsson, J.K. Eskildsen, S. Wallot, Physiological evidence of interpersonal dynamics in a cooperative production task, Physiol. Behav. 156 (2016) 24–34.

[17] R.V. Palumbo, M.E. Marraccini, L.L. Weyandt, O. Wilder-Smith, H.A. McGee, S. Liu, M.S. Goodwin, Interpersonal autonomic physiology: A systematic review of the literature, Pers. Soc. Psychol. Rev. 21 (2) (2017) 99–141.

[18] S. Paruchuri, J.E. Perry-Smith, P. Chattopadhyay, J.D. Shaw, New Ways of Seeing: Pitfalls and Opportunities In Multilevel Research, Academy of Management Briarcliff Manor, NY, 2018.

[19] F. Ramseyer, W. Tschacher, Nonverbal synchrony in psychotherapy: coordinated body movement reflects relationship quality and outcome, J. Consult. Clin. Psychol. 79 (3) (2011) 284.

[20] F.T. Ramseyer, Motion Energy Analysis (MEA). A primer on the assessment of motion from video, J. Couns. Psychol. (2019).

[21] P. Reddish, J. Bulbulia, R. Fischer, Does synchrony promote generalized prosociality, Religion, Brain Behav. 4 (1) (2014) 3–19.

[22] M. Rennung, A.S. Göritz, Prosocial consequences of interpersonal synchrony, Z. Psychol. (2016).

[23] A. Sherwood, M.T. Allen, J. Fahrenberg, R.M. Kelsey, W.R. Lovallo, L.J. Van Doornen, Methodological guidelines for impedance cardiography, Psychophysiology 27 (1) (1990) 1–23.

[24] W. Tschacher, G.M. Rees, F. Ramseyer, Nonverbal synchrony and affect in dyadic interactions, Front. Psychol. 5 (2014) 1323.

[25] R.R. Vallacher, A. Nowak, M. Zochowski, Dynamics of social coordination: The synchronization of internal states in close relationships, Interact. Stud. 6 (1) (2005) 35–52.

[26] S. Wallot, P. Mitkidis, J.J. McGraw, A. Roepstorff, Beyond synchrony: joint action in a complex production task reveals beneficial effects of decreased interpersonal synchrony, PLoS One 11 (12) (2016).

[27] F.J. Yammarino, J. Gooty, Cross-level models, in: S.E. Humphrey, J.M. LeBreton (Eds.), The Handbook of Multilevel Theory, Measurement, and Analysis, American Psychological Association., Washington, DC:, 2019(Editors-in-Chief).