Journal of Nonverbal Behavior (2021) 45:107–126
https://doi.org/10.1007/s10919-020-00341-3

ORIGINAL PAPER

Movement Synchrony in the Mirror Game

Rinat Feniger-Schaal[1] · Désirée Schönherr[2] · Uwe Altmann[2] · Bernhard Strauss[2]

Accepted: 21 September 2020 / Published online: 1 October 2020

Abstract

The significance of the body-mind link and the contribution of nonverbal communication in the context of psychotherapy is enjoying increased interest. Yet, the main measurements used in psychotherapy studies rely mostly on verbal measures, missing other channels of communication that would allow rich and implicit, nonverbal information. The present study is a first step toward using the mirror game (MG) as a standardized mimicry task that involves the assessment of movement synchrony as a nonverbal outcome measure for psychotherapy research. The aims of the study were twofold: (a) to investigate the possibility of automated analysis of synchrony in the MG, detecting the different roles of leadership in the game, and (b) to validate the synchrony quantified by computer algorithms with a human-rated prosocial scale. All participants ($N=33$) played the MG with a gender-matched expert player. Body motions of interacting pairs were assessed using motion energy analysis. Frequency of movement synchrony was computed by windowed cross-lagged correlation and a peak-picking algorithm. Independent observers rated items with respect to prosocial parameters, using the MG scales. The algorithm allowed to differentiate quite accurately between the various roles of leadership. Significant correlations were found between the MG human-rated scales and computer-detected synchrony. High frequency of synchronized movements was linked with high levels of having fun, shared affect, and reference to the other, and with low negative affect. The MG provides a standardized and flexible paradigm for the investigation of movement synchrony. The use of both automated detection and human rating reveals the potential application of the MR in research and clinical use.

Keywords Mirror game · Movement synchrony · Motion energy analysis · Windowed cross-lagged correlation · Psychotherapy · Leading/following

Rinat Feniger-Schaal and Désirée Schönherr have contributed equally to this article.

✉ Rinat Feniger-Schaal
rinatfen@gmail.com; rfenigers@univ.haifa.ac.il

1 Center for the Study of Child Development, School of Creative Arts Therapies, University of Haifa, 199 Aba Khoushy Av., 3498838 Haifa, Israel

2 Institute of Psychosocial Medicine and Psychotherapy, Jena University Hospital, Jena, Germany

Movement Synchrony in the Mirror Game

The significance of the body-mind link and the contribution of nonverbal communication to psychotherapy research is enjoying increased interest (Koole and Tschacher 2016). This interest is expanding beyond the inner circle of practitioners who focus on body, movement, and dance, to the areas of mainstream psychotherapy research. Nevertheless, the main measurements used in psychotherapy studies rely mostly on verbal measures, missing other channels of communication that would allow rich and implicit nonverbal information (Harrigan et al. 2008). Clinical research in psychotherapy is lacking an assessment measure that uses movement and nonverbal behavior. One promising approach seems to be the investigation of movement synchrony between patient and therapist as a predictor of the success of therapy (Altmann et al. 2019; Paulick et al. 2018b; Ramseyer and Tschacher 2011; Schoenherr et al. 2019b). The present study is an initial step toward using the mirror game (MG) as a standardized mimicry task that involves the assessment of movement synchrony as a possible nonverbal measure for psychotherapy research.

Nonverbal Synchrony

Studies have shown that the capacity to establish nonverbal synchrony may be fundamental, as it constitutes the basis for social connection (Rennung and Göritz 2016). Nonverbal synchrony refers to instances in which the movements (or other expressions, such as voice or gaze) of two or more people overlap in time and form (although the movement need not be exactly replicated for it to be synchronized; Altmann et al. 2019; Rennung and Göritz 2016). Hence, movement synchrony is a particular kind of “behavioral mimicry” (Vicaria and Dickens 2016), in which the time lag between the repeated movement is close to zero (depending on the operationalized definition and measurement method). Coordinated movements in interpersonal interaction such as movement synchrony are a central feature of social life, from dancing, playing together, talking, to almost any dyadic interaction (Berliner 2009; Seham 2001; Gaziv et al. 2017; Reddish et al. 2013).

Research in the area of nonverbal synchrony has become prominent, with extensive literature dedicated to investigating its causes and consequences (Vicaria and Dickens 2016). A recent meta-analysis summarized 42 studies that used experimentally manipulated synchronous actions to examine their effect on cognition, perception, behavior, and affect (Mogan et al. 2017), emphasizing the scope of nonverbal synchrony studies in various domains.

The most predominant topic studied in connection with nonverbal synchrony is the prosocial and emotional consequence of synchronized movements. For example, researchers have reported nonverbal synchrony as a prerequisite for empathy (Valdesolo and DeSteno 2011) and successful cooperation (Valdesolo et al. 2010; Rabinowitch and Meltzoff 2017). Parent–child synchronization was linked to a variety of positive outcomes in the child, such as the development of secure attachment (Isabella and Belsky 1991), self-regulation (Lindsey et al. 2009), social abilities within the peer group (Harrist et al. 1994; Lindsey et al. 2010; Sroufe and Fleeson 1986), high self-confidence (Lindsey et al. 2008), and emotional regulation (Feldman 2007). A meta-analysis of 60 studies summarized the prosocial consequences of nonverbal synchrony (Rennung and Göritz 2016), stressing the role of synchrony in social interaction.

The Study on Synchrony

The research interest in nonverbal synchrony is growing, producing both more questions and more methods to investigate this area. Overall, the studies on nonverbal synchrony follow two main approaches, using laboratory versus naturalistic settings. Earlier experiments on nonverbal synchrony applied mostly a simple rhythmic movement (such as tapping or clapping) to examine the correlations and outcomes of such a dyadic task. For example, synchronized tapping (Hove and Risen 2009; Repp 2005), walking (Wiltermuth and Heath 2009), or swinging (Rabinowitch and Meltzoff 2017) increase the sense of belonging and cooperation (Chartrand and Bargh 1999; Julien et al. 2000). Studies of this type focused mostly on between-groups differences, examining the effect of synchrony versus lack of synchrony in various domains. The advantage of these studies lies in the fact that synchrony is manipulated under standardized experimental conditions, therefore, conclusions can be drawn without considering the biasing influences of the setting, but generalizability to interpersonal interactions in natural contexts is limited.

More recent studies started examining nonverbal synchrony using naturalistic, non-manipulated tasks, in a relatively stationary setting, such as psychotherapy sessions (Altmann et al. 2019; Ramseyer and Tschacher 2011, Schoenherr et al. 2019b) and dyadic conversations (Gaziv et al. 2017). These studies seek individual differences, examining the presence or absence of movement synchrony and its correlates in a setting that is not primarily a movement task. It has been demonstrated, however, that the conclusions drawn from these types of experiments depend largely on the type of interaction within the sessions. For example, it makes a difference whether synchrony is shown during a problem-solving task or in an interaction aimed at establishing therapeutic alliance. This is consistent with various studies underlining the context-dependence of the influence of synchrony (Altmann 2011; Leander et al. 2012; Paxton and Dale 2013; Tschacher et al. 2014), possibly because of the fact that the extent of synchrony in naturalistic tasks varies greatly.

Mirror Game

In the present study, we used a standardized movement task that enables individual expression while creating a synchronized movement. Therefore, we chose to use the mirror game (MG) to examine dyadic interaction in motion. The MG has the potential to close the gap between research in a naturalistic and an experimental setting, and offer a simple nonverbal assessment for various socio-emotional domains that can be assessed before, during, and after psychotherapy.

The MG is a common mimicry exercise used in theatre (Spolin 1999), drama, and dance/movement therapy (Boal 2013; McGarry and Russo 2011). In the MG, players mimic each other's full-body movements in three rounds, alternately taking the roles of leader and follower. In the first round, one player leads and the other follows; in the second round, they switch roles, and in the last round, there is no designated leader or follower. The MG is commonly used to enhance empathy and emotional understanding of others and to promote the participants' ability to enter a state of togetherness and remain in it (Schechner 1994).

In recent years, there has been growing interest in using the MG as an experimental paradigm for measuring states of togetherness (Noy et al. 2011). This is possibly due to the simplicity of the MG as a nonverbal dyadic task. Pioneering research on MG was conducted by Noy, Dekel, and Alon (2011) and by Hart et al. (2014a, b). To automatically assess the quality of interaction during MG, these studies employed handles that players were required to move along parallel tracks, in one dimension. The study by Noy et al. (2011), the first of its kind, detected intervals of "togetherness motion," during which players exhibited complex, smooth, and synchronized motion. The studies that used the one-dimension MG mark the beginning of a scrutinized examination of the MG, however, its implication in clinical use is limited due to the use of a specific device.

In later studies, Noy and colleagues (Noy et al. 2015) identified correlations between physiological markers and the sense of togetherness experienced while playing the MG: Hart et al. (2014a, b) examined the individual versus shared characteristics of motion; Zhai et al. (2014) developed a computerized version of the MG, which was intended for use in the rehabilitation of individuals with social deficits; Gueugnon et al. (2016) used MG to assess the connection between movement synchrony and improvisation; Słowinski et al. (2017) found that MG can serve as a socio-motor biomarker for schizophrenia; finally, Himberg et al. 2018) explored group dynamics during MG. None of these studies, however, measure full-body dyadic synchrony during MG.

In the present study, we used the MG as a movement task to provide an opportunity for individual expression and dyadic synchronization of body movement. Our setting was more complex than tapping tasks and less stationary than psychotherapy sessions. It allowed a deliberate expression of movement in an interpersonal context. In addition, we sought to use automated computerized analysis of synchrony and to compare it with human ratings. Thus, our study targeted both the context and the method of movement synchrony detection.

Synchrony and Methodological Issues

The discussion of methodological issues regarding nonverbal synchrony has a long tradition. For example, McDowall (1978) stressed measurement issues of accuracy in time when using human coding of micro-behavior. Human ratings, however, have the disadvantage: to establish high reliability, several human raters are needed to evaluate synchrony in one video (Altmann 2011; Bernieri et al. 1988). Therefore, the process of coding synchrony by human raters is extremely time-consuming.

Since the turn of the millennium, the number of studies that used computer-based coding of nonverbal behaviors increased significantly. For example, Boker et al. (2002) used a 3D motion tracker and studied the resulting time series with window-cross-lagged correlation, which allowed the quantification of movement synchrony and leading/following during synchronization. Watanabe (1983), followed by Ramseyer and Tschacher (2010, 2011), introduced automated coding of motion intensity using motion energy analysis (MEA) in the clinical research of movement synchrony. Yet, there has been only limited investigation of the validity of these methods to measure synchrony. Two published studies examined the validity of computerized methods systematically. These studies tested (a) whether different algorithms for synchrony detection produce equal synchrony indices, and (b) which parameter settings of algorithms (e.g., bandwidth, extent of smoothing) lead to the most valid identification of synchrony with respect to simulated data and human-rated synchrony (Schoenherr et al. 2019a). Results of these studies showed that not all algorithms used for movement synchrony detection produce the same results; rather, they measure different facets of movement synchrony, such as the strength of synchrony versus its frequency. A significant but low correlation was found between movement synchrony coded by human raters and that produced by computerized detection (Schoenherr et al. 2019a). This implies that the methodology used to detect synchrony is critical even in applying computerized methods, and that more studies are needed to validate synchrony scores based on external criteria (e.g., specific designs and outcome variables).

Additionally, validation of computerized measures of leading/following (driving/driven; initiation/imitation) is still lacking. Every social interaction contains the roles of leading and following, including psychotherapy sessions, conversations, and dancing. Studies on psychotherapy showed that the consequences of synchrony led by the therapist and synchrony led by the client are not the same (Ramseyer and Tschacher 2011; Schoenherr et al. 2019a, b). The MG is well suited to study the meaning of the two roles of leading and following, because these roles can be manipulated by the instructions of the task.

The Present Study

This pilot study is part of a larger project that explores the MG as a nonverbal task that can be used as an assessment tool to examine the ability of the players to synchronize, as well as their other related nonverbal expressions. In the present study, we explored the possibility of the automated detection of synchrony and different role-taking during the MG. Using automated detection, we examined the correlation between the computerized method of assessment and the human rating.

Research Aims and Hypotheses

1. A computerized method is used to study the MG and identify the leading/following measures in different stages of the game. We hypothesized that in the first stage of the game, when the participant is instructed to lead movements and the experimenter is instructed to follow them, there will be higher synchrony led by the participant than the synchrony led by the experimenter. In the second stage of the game, when the experimenter is instructed to lead the movement, we expect higher synchrony led by the experimenter than the synchrony led by the participant. In the third stage, when there is no designated leader, we expect to see no significant differences in synchrony led by either player.
2. External validity is examined with the correlations between automated ratings of movement synchrony and human ratings of prosocial expression during the MG. According to the literature reviewed above, we hypothesized that more movement synchrony is associated with positive affect and relatedness to the other player.
3. The final aim of the study is to set the stage for future use of the MG in a clinical setting.

Method

Ethics Statement

The Institutional Review Board (IRB) at the University of Haifa approved the described experiments, including the written consent procedure (approval number 086/13). All the participants provided written informed consent to participate in the study.

Participants

Thirty-three participants took part in the study, 16 females, mean age = 33.03 years (SD = 5.87 range 25–47), mean number of years of education = 19.88 (*SD* = 2.74). All participants were Israeli Jews. Twenty-nine (85.88%) were native Hebrew speakers (as indication of their cultural background), four others spoke either English, Russian, or another European language as their first language. Three participants (8.3%) defined themselves as Orthodox Jews, four others (11.8%) defined themselves as Conservative Jews, 26 (73.5%) defined themselves as non-religious. Twenty-one participants were married, five were in a relationship, three were divorced, and four were single. Twenty-four had no previous experience with the MG, six had some, and three participants had extensive experience with the MG. Twenty-five had no improvisational experience of any kind (movement, music, drama), seven had some experience in improvisation, and one had extensive experience. All participants were students and staff at the Weizmann Institute of Science who volunteered to take part in the study. This is a secondary analysis of the data recruited for a larger study. The original sample included 48 participants, but some of the videos had poor quality and could not be used in the present study.

Procedure and Measures

Participants played the MG with a gender-matched expert player. There were two experimenters, one male and one female (aiming to control for gender differences in movement; Bente et al. 1998; Gaggioli et al. 2019), both in their early thirties, with extensive experience in the MG. The experimenters were blind to all study hypotheses.

The MG

Participants were instructed to play the MG, which involved mirroring each other's movements while assuming the different roles of leader and follower (see the instructions of the MG below, and Fig. 1 for examples of the MG setting). The MG consisted of three rounds of five minutes each: in the first round, the participant led, in the second, the experimenter, and in the last round, there was no designated leader. All games were videotaped. For computerized analysis, videos had to be clear, of reasonable quality, free from reflection from behind (for example, from windows), without the two players switching places (overlapping).

The MG instructions were as follows:

> We will play together the Mirror Game. This is a game without words. We will create movements together. The aim of the game is simply to produce movement together, like a conversation in movement. This is not a competition. There is no right or wrong. Any movement you make is fine. There are three five-minute rounds. In the first round, you will be the "leader," so that you will make movements and I will imitate you as accurately as I can. After five minutes, we will change roles, I will be the leader, and you will imitate me. In the third round we will try to make movements together without a designated leader. The ring of the clock will give us a sign to move to the next round, without a break. Any questions? So we begin.

Fig. 1 Examples of the mirror game setting

> **Prompting:** If the participant plays the game wrong or does not understand the rules, the experimenter may repeat the instruction one more time. If the participant fails to understand the game after the second explanation, the experimenter can demonstrate it by leading for one minute. In case the participant has more questions during the game, the experimenter should say: "I will be happy to answer further questions at the end of the game."

Assessment of Body Movements

First, the individual body movement was assessed by the *frame-differencing method*[1] of motion energy analysis (MEA; Altmann 2013; Grammer et al. 1999; Ramseyer and Tschacher 2011). For each consecutive pair of video frames, the algorithm counted the number of pixels in which the grey intensity[2] changed from t to $t+1$ significantly (in accordance with Altmann 2013, we applied a threshold of 12). Given a stable background with no camera pans or zooming, the sum score corresponds to the intensity of all visible body movements for time point t. To differentiate between the movements of the participant and experimenter, we defined regions of interest (ROIs). The ROIs covered the entire body of a person. As a result, for each video, we obtained a time series pair (one for the participant and one for the experimenter) representing the time course of motion intensity. Before applying MEA, we converted all video files to the same video format, using Any Video

[1] "Frame-differencing method"is a technical term in computer vision science. It means that two subsequent video frames are analysed. In the case of MEA: the number of pixels whose color intensity changed from t to t + 1 is counted.

[2] "Grey intensity"is a technical term of computer vision science. A video consists of an ordered series of frames. A frame is a digital picture that consists of pixel. In a color video, a pixel consists of the intensity of red, blue and green. In black and white videos, the pixel consists only the grey intensity. Moreover, in a color video, we can convert the intensity of red, blue, and green into one grey value. This is done in MEA.

Converter 3.0 (AVC 2009): size 640×480, 2000 kbps, frame rate 25 frames/s. We annotated the different stages of the MG using the ELAN software (https://tla.mpi.nl/tools/tla-tools/elan/download/).

During the MG, it may happen that one person is moving into the ROI of the other. Therefore, we defined a ROI between both persons' ROIs. If grey changes are registered in this ROI, both persons are moving closer to each other, increasing the risk that the movements of one person are detected by both persons' ROIs, leading to artificial synchrony. Thus, we used activity in the ROI between the two participants as a cue to investigate sequences manually. If an overlap of movements was detected, the interval was coded as missing. In some videos, persons crossed sides. If this change was not permanent, the respective sequence was set to missing. If they changed sides permanently, we recoded the time series (e.g., time series until minute 2: column 1 participant, column 2: experimenter; after minute 2, vice versa).

After conducting MEA, we standardized the resulting motion energy time series, dividing each value by the respective ROI size, then multiplied the result by 100. Thus, a value of 13 means that 13% of the ROI was activated. To smooth the time series, we applied a moving median with a bandwidth of 5 frames. To improve the detection of synchrony, we logarithmized the standardized time series to match the peak heights of the time series, so that movements of different sizes were also determined as synchronous movements. The parameter settings of the algorithm (including smoothing and transformation) were validated based on Schoenherr et al. (2019a).

Computation of Synchrony Values

To determine the frequency of movement synchrony and the role of leading/following, we first applied a windowed cross-lagged correlation (WCLC) to the data, with overlapping windows and a bandwidth of 125 frames (=5 s), with a step size of 1 frame (=.04 s) and a maximum time lag of 125 frames (=5 s). We used the scripts of Altmann (2011, 2013), available at GitHub: https://github.com/10101-00001/sync_ident. After the WCLC, we used the peak-picking algorithm to determine synchrony intervals within the time series. The reason for using the WCLC and the peak-picking algorithm is that each interpersonal interaction may contain intervals with movement synchrony and intervals in which people do not show synchrony. Thus, the movement time series of both persons should be highly correlated during the synchronization intervals, and not correlated or weakly correlated when not synchronizing. For a pair of motion energy time series, the WCLC defines one time series as reference. The algorithm moves a window (e.g., 125 frames) from the beginning to the end of the reference time series. At each step, cross-correlations were computed for the window and a set of lagged windows of the other time series (± 125 frames). The output of WCLC is a matrix of correlation coefficients in which the column corresponds to the position of reference window and the line to the time lag of the other window (including time-lag = 0). All coefficients were squared, so that their sign was positive. Next, the peak-picking algorithm was applied to the matrix. If one imagines the matrix as a mountain landscape, the algorithm identifies the mountain ridges. According to Altmann (2011, 2013), a mountain ridge corresponds to a synchronization interval. The result is a list displaying the synchronization intervals with the respective time lag, duration, and synchrony strength. By applying the WCLC and the peak-picking algorithm, it is possible to identify the initiator of the synchronization interval (Altmann et al.

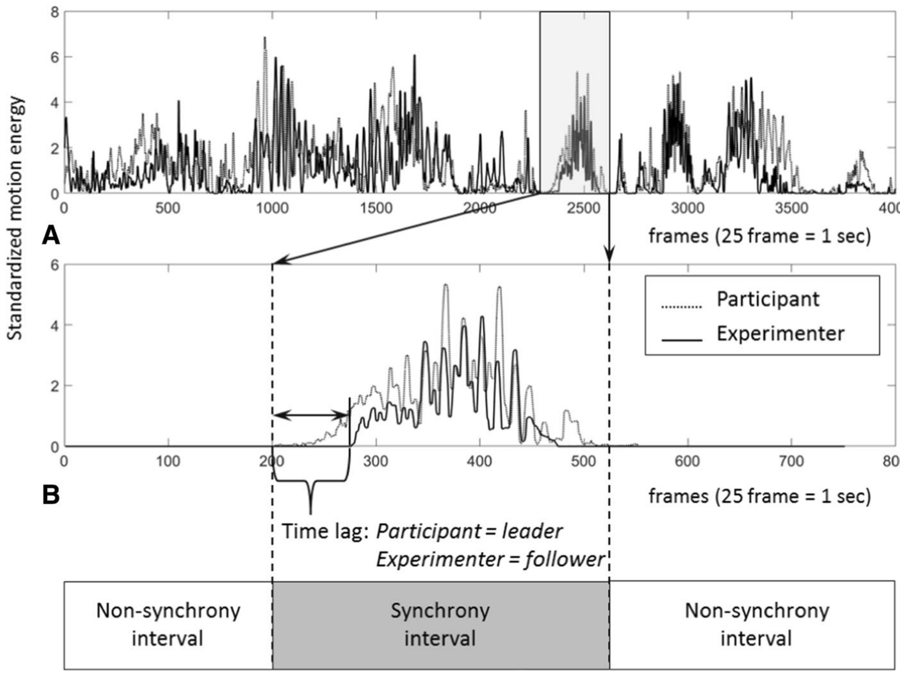

Fig. 2 Two motion energy time series (**a**) with an example classification of non-synchrony and synchrony intervals showing participant leading (**b**). The middle sub-plot shows a synchronization interval with leading of participant

2019; Ramseyer and Tschacher 2011), and to differentiate between synchrony that was initiated by the participant (positive time lag) and synchrony initiated by the experimenter (negative time lag) (Fig. 2). The movement frequency of the participant was in phase 1: $M = 40.1$, min = 1.0, max = 94.7; in phase 2: $M = 34.4$, min = 9.1, max = 60.3; in phase 3: $M = 33.5$, min = .1, max = 84.0.

To differentiate between stages of the MG, we imported the information about the duration of each stage of the ELAN files into MATLAB© and filtered the respective synchrony intervals based on these annotations. We used the list of movement synchrony intervals to determine the total frequency of synchrony (ratio of the sum of synchronous time to total duration), the frequency of movement synchrony initiated by the participant (ratio of the sum of synchronous time with a positive time lag to total duration), and the frequency of synchronous time imitated by the experimenter (ratio of the sum of synchronous time with a negative time lag to total duration). If parts of the time series were labeled as missing because of the reasons explained above, the time series length was adjusted so that these parts were deleted from the time series. This ensured that the ratios of synchrony were comparable. Otherwise, we would underestimate the synchrony in sequences with many missing value specifications. Lastly, we multiplied the frequency scores by 100, so that 1 means that 1% of the interaction was synchronous, and 60 that 60% of the interaction was synchronous.

Human Rater Scales

We used the *Mirror Game Scales (MGSs)* that were designed in our previous study, to code various nonverbal expressions during the MG (see Feniger-Schaal et al. 2018). In the development of the scales, two researchers watched the videos and identified (in a bottom-up-processes) various components that pointed to individual differences in the MG. The identified components were then defined as scales ranging from 1 to 5, and all scales were tested for reliability. In the next stage, three new coders were trained on coding videos (not of the study's participants), until they reached good inter-rater reliability. Scales that the coders could not reach reliability on were taken out. The processes ended with the definition 19 scales. In this study, we compared the MGs with the synchrony measures. Our main interest was on scales that capture affect expression and relatedness to the other. Table 1 presents the description of each scale and the inter-rater reliability.

Missing Data

No rating scale data were missing. With respect to synchrony scores, the synchrony measures of one participant could not be extracted for stage 1 because this stage showed no sufficient video quality.

Statistical Analyses

Regarding the first research aim, we began by listing the descriptive statistics of the various frequencies of synchrony provided by the computerized detection of synchrony for the different stages of the MG. Next, we conducted paired *t*-tests to compare the frequency of synchrony initiated by participants with the frequency of synchrony led by experimenters in each stage. According to Cohen (1992), .2, .5, and .8 are the cut-offs for a small, medium, and large effect. We also compared the different stages of each individual using an analysis of variance (ANOVA) for repeated measurements. As an effect size measure, we reported partial η^2. The cut-off values for small, medium, and large effects are $>.01$, $>.06$, and $>.14$ (Cohen 1992).

To examine the second research aim, we conducted Pearson correlations between the total frequency of computerized detection synchrony in stage 1 and the human-rated MGSs. We chose stage 1 because the participants were leading at this stage. According to Cohen (1988), $r>.3$ is a medium effect size ($>.1$ small, $>.3$ medium, $>.5$ large).

Results

Detection of Following and Leading Using Synchrony Measures

Three synchrony measures, depending on stage of the MG, are reported in Table 2: (a) the frequency of movement synchrony when the participant is the leader of movement synchrony (participant-led synchrony); (b) the frequency of movement synchrony when the experimenter is the leader of synchrony (experimenter-led synchrony); and (c) the overall time of movement synchrony (sum of participant synchrony and experimenter synchrony, called total frequency

Table 1 The MGSs and their inter-rater reliability

The scale	Description	Scoring	ICC
1. The "greeting"	Coding the first 45 s of the game, the way the players introduce themselves and begin the game	High score for appropriate opening of the game, checking the encounter with the other and adapting to the beginning of the game	.913***
2. Tension	Physical indication of tension in the body and face, for example, flexing the shoulders or furrowing the eyebrows	High score for high tension, low score for relaxed, no-tension affect	.788***
3. Negative affect	Facial expressions of negative affect such as anger, boredom, irritation	High score for high negative affect, low score for mostly positive affect	.936***
4. Having fun	Enjoying the encounter, positive affect, playfulness, having fun playing together	High score for the player appearing to enjoy most of the game	.960***
5. Shared affect	The players are sharing affect, like a smile or a facial expression that reflects moments of shared positive emotion	High score for moments of sharing positive affect	.956***
6. Reference to the other	Looking at the other to check whether the partner can follow the movement	High scores for referring to the partner during the game and checking the partner's ability to follow	.915***
7.Gaze aversion	Using body movements (other than arching) that actively break eye contact	High score for more than three incidents of gaze aversion	.758**
8. Eye contact	Making eye contact	High score for direct eye contact during most of the game	.891***
9. Pace	The pace of movement (changes from slow to fast)	High score for a pace that the partner is able to follow	.832***
10. Flow/shift	The flow of the movement	High score for flow of movements that seems like one movement is following the other without abrupt fragmented feel	.911***
11. Breaks	Coding the times when the MG stops (breaks), i.e., the participant asks questions burst into laughter, or stops the game in any other way	High score for no breaking of the game	.972***
12. Competitiveness/teasing	Movement that calls for competition/a sense of teasing	High score for high competitiveness or teasing	.873**
13. Arching	Stretching the back backwards several times during the game -in a way that disconnects eye contact	High score for no arching	.939***
14. Exploration	The extent to which the participant explores a variety of movements	High score for exploratory movements in different dimensions (pace, space, use of the body, etc.)	901***

Table 1 (continued)

The scale	Description	Scoring	ICC
15. Body parts	The use of the different parts of the body: limbs versus the center of the body; robotic movements versus soft and round movements in which the joints are used	High score for rich use of the body including the center of the body, and the performance of shape like movements (as opposed to robotic)	895***
16. Directions of movement	The use of different movement planes: vertical, sagittal, and horizontal	High score for the use of combinations of planes	.596*
17. Distance	The distance between the players	High score for exploring different distances between the players	.910**
18. Unusual behavior	Performing unusual behaviors during the MG, (i.e. pretending to sleep throughout the game or moving only the pelvis for the entire game)	Dichotomous scoring for the presence or absence of unusual behavior	.960***
19. Leader/follower	Coding the roles the participant assumes in the third round of the game:	High score for balanced shifts between the different roles	.933***

*$p \leq .05$, **$p \leq .01$, ***$p \leq .00$

Table 2 Frequency of synchrony and comparison of participant-led and experimenter-led synchrony (average and standard deviation)

	Total frequency of synchrony	Participant-led synchrony	Experimenter-led synchrony	Comparison of participant versus experimenter
Stage 1	53.71 (13.46)	42.68 (13.98)	10.76 (4.11)	$t = 11.63$, $p < .01$, $d = 3.25$
Stage 2	45.43 (9.39)	9.56 (3.46)	34.62 (9.17)	$t = -13.98$, $p < .01$, $d = -3.70$
Stage 3	34.55 (13.88)	18.79 (8.68)	14.64 (6.41)	$t = 2.99$, $p = .01$, $d = .53$

In stage 1, the participant is instructed to lead the interaction; in stage 2, the participant should follow the movements of experimenter; and in stage 3, there is no designated leader

of synchrony). According to our hypothesis, consistent with task instructions, the results show that participant-led synchrony was found to be significantly higher in stage 1 than was experimenter-led synchrony. In stage 2, experimenter-led synchrony was found to be significantly higher than participant-led synchrony. In stage 3, participant-led synchrony was still higher than experimenter-led synchrony. Results show that our algorithm can differentiate quite accurately between the various stages (the participant leading in stage 1, and the experimenter leading in stage 2, as expected).

The ANOVA for repeated measurements showed a significant difference between the different stages for participant-led synchrony ($F = 115.38$, $df = 2$, $p < .001$, *partial* $\eta^2 = .79$) and the experimenter-led synchrony ($F = 119.43$, $df = 2$, $p < .001$, *partial* $\eta^2 = .79$). Applying contrast within the generalized linear model (GLM) showed that for participant-led synchrony, stages 1 and 2 (contrast = .33, $p < .001$), stages 2 and 3 (contrast = −.10, $p < .001$), and stages 1 and 3 (contrast = .24, $p < .001$) differ substantially. Contrasts for experimenter-led synchrony showed substantial differences in the comparison of synchrony during stages 1 and 2 (contrast = −.24, $p < .001$), stages 2 and 3 (contrast = .20, $p < .001$), and stages 1 and 3 (contrast = −.04, $p < .001$). The results show that our algorithm can differentiate quite accurately between the different stages. In accordance with the instructions provided to participants and experimenters, the synchrony values indicated that participants led in stage 1 and experimenters in stage 2.

Next, we examined the correlations between the human-rated scales and the computerized detection of synchrony. In the first step, we examined the correlation between the scales of affect and of social relatedness and synchrony, based on our hypothesis. As shown in Table 3, the results indicate that frequent synchronized movements are linked with high levels of *shared affect*, *reference to the other*, and *having fun* (marginally significant), and with lower levels of *negative affect*. In the next step, we examined the correlation between all the rest of the MGSs and computerized detection of synchrony. Most of the other MGSs, which are not concerned directly with affect expression or minding the other person, showed no correlation with synchrony.

For the dichotomous scale of unusual behavior, we found a significant difference in the amount of synchrony, with participants showing unusual behavior ($M = .40$, $SD = .15$) having a significantly lower amount of synchronized movement than participant who did not show unusual behavior ($M = .55$, $SD = .13$), $t\,(30) = -2.15$, $p = .04$.

Table 3 Pearson product-moment correlations (two-tailed) between synchrony and human ratings scales of the mirror-game behavior

Mirror game scale	*r*	*p*
Affect		
Negative affect	− .38*	.03
Having fun	.33*	.06
Tension	− .16	.37
Minding the other		
Reference to the other	.37*	.04
Shared affect	.33*	06
The greeting	.19	.29
Gaze aversion	− .17	.36
Eye contact	*.03*	.87
Other scales		
Distance	*.35**	.05
Pace	− .12	.51
Breaks	− .16	.37
Competitiveness	.05	.80
Arching	− .12	.50
Exploration	− .1	.59
Body parts	− .00	.98
Movement directions	.13	.47
Leader–follower[a]	− .22	.24

[a]This scale was compared to the amount of synchrony in the third stage of the game

*$p \leq .05$, **$p \leq .01$, ***$p \leq .005$

Discussion

The study tested the MG and different methods of looking at the data it produces, using both computerized and human-rated methods. In this two-phase study we examined first the applicability of a computerized assessment to detect synchrony and role taking in the MG paradigm, and second, the correlation between human rating and the computer assessment. In doing so, we are hoping to set the stage for the use of the MG in further clinical studies. As expected, the results show the possibility for automated detection of movement synchrony and of leading/following in the MG, and provide evidence of the convergent validity of computerized assessment of synchrony and human rating of prosocial expression.

Using Computerized Detection of Synchrony in the MG

The validation study of Schoenherr et al. (2019a) showed the use of different computer algorithms to detect movement synchrony in a naturalistic (psychotherapy) setting. The present study extends the validation of the algorithm to a different setting, with more movements and synchrony. The results show that the computerized method of WCLC, in combination with a peak-picking algorithm, was able to capture synchrony in the MG and identify the different levels of movement shown by the participant and the experimenter. Thus, in stage 1, synchrony is led by the participant, in stage 2 by the experimenter, and in stage 3 more by the participant, but to a lesser extent. The results show that the WCLC method with a peak-picking algorithm is valid for assessing differences in leading patterns and confirms the possibility of use an automated method to identify the different stages.

Results showing the identification of the various roles in the MG have been reported in a previous study by Noy et al. (2011). In that study, participants used a special device to play the MG, which enabled easy detection and quantification of synchrony at various stages of a one-dimensional movement MG. The contribution of our results is that we were able to quantify the MG interaction (with respect to synchrony and role-taking) in a full-body expression, without a special device. This opens the possibility of wider research and clinical applications of the MG paradigm. Different role-taking is part of almost any relationship or encounter. Thus, the possibility of identifying not only synchrony but also different roles in the MG is of interest for future research. The MG paradigm can be easily used to explore turn-taking, role changing, and synchrony with different clinical populations. Some studies have already shown the role played by leading as opposed to following in synchrony, in psychotherapeutic settings (Altman et al. 2019; Ramseyer and Tschacher 2011). Use of the MG with computerized detection of synchrony and role-taking can help explore the correlation between different psychological characteristics and the possibility of leading versus following in synchronized dyadic movement. For example, looking at the third stage of the game, when there is no designated leader (similarly to a psychotherapy session), it is possible to examine to what degree one is able to take the lead or to be the follower, the amount of synchrony produced together, and the link to various psychopathologies.

Synchrony and Positive Affect

As previous studies showed, synchronous motion correlates with positive affect and a sense of connection between participants (Lakin et al. 2003; Van Baaren et al. 2004; Wiltermuth and Heath 2009). As mentioned earlier, most studies on synchrony investigated the correlators of synchrony in a deliberate and constant synchrony setting, like tapping together (Hove and Risen 2009). Our study tested the link between affect and synchrony in a "free" movement task, and found that the greater the synchrony, the higher the levels of positive affect and interpersonal relatedness. Similar results, with similar correlation coefficients, are reported in meta-analyses by Vicaria and Dickens (2016) and Mogan et al. (2017) regarding synchrony and prosocial parameters.

Our results suggest that the prosocial consequences can also be found during a standardized "free" movement task, and therefore the results show that our setting is valid for replicating similar findings from other studies. The MG may, therefore, be an optimal option for investigating nonverbal synchrony because it is not as artificial as tapping experiments, and not as stationary and "naturalistic" as interactions during psychotherapy.

The Connection Between Human Ratings and Automated Detection

Our results show some connections between automatedly measured synchrony and human rating of prosocial expression. These results join several other studies that emphasize the notion of synchrony using information from both machine and human sources. For example, Hart et al. (2014a, b) measured synchrony during patient-doctor interaction in a medical setting, using computerized video analysis, and found a correlation between the type of speech the doctor used during the interaction, and patient-doctor synchrony; so that more attentive, warm, and friendly speech correlated with higher synchrony. The computer analysis of movement synchrony was associated with the behavior of the doctor, and a correlation was found between the human and computerized sources of information. Another example can be found in a recent study (Sharon-David et al. 2018) that demonstrated a link between automated measurement of synchrony while pedaling on a bike and self-report regarding the feeling of intimacy while pedaling. In the present study, we found that synchrony causes third parties (human) to perceive interactions as fun, shared, and showing high reference to the other. Our results join the evidence regarding the meaning of synchrony in human interaction, and its positive outcome is validated by the congruence of the computerized synchrony measure and the human-reported measure of affect and social relatedness.

Some of our human-rated MGSs showed no correlation with synchrony, whereas others showed unexpected significant correlation (for example, the scale *distance*, which capture the participants' flexibility in using the interpersonal distance). The MGSs captured the richness of the non-verbal expression, although not all these expressions were necessarily linked to interpersonal synchrony. For example, the amount of eye contact showed no correlation with synchrony. It is reasonable to assume that maintaining eye contact is a necessary requirement for synchronized movement. Our results, however, support the findings of Rabinowitch and Meltzoff (2017), who reported that children's synchronized movement showed no significant connection with the amount of eye contact the children made with each other. *Reference to the other*, a scale that assess the amount of cooperation and engagement of the partner in the MG, was found to be connected to synchrony, perhaps because it is a more robust measure of connectedness to the other than eye contact is.

Another example of a bodily expression that showed no correlation with synchrony is the use of central or peripheral parts of the body, which were found in a previous study to correlate highly with attachment classification (Feniger-Schaal and Lotan 2017). Our results, however, showed no correlation between the use of body parts and the computerized detection of synchrony. Only a few studies examined interpersonal synchrony in a full-body movement task. Future studies should further investigate the nuances and qualities of interpersonal, synchronized movement to expand our knowledge about human interactions.

Setting the Stage for Using the MG in Psychotherapy Research

The third aim of our study was to serve as a pilot, preparing for future use of the MG as an assessment measure. There is growing interest in the field of psychotherapy research in developing movement synchrony measures as a way to assess nonverbal interpersonal behavior (Paulick et al. 2018a; Schoenherr et al. 2019a, b). To date, the use of synchrony measures in psychotherapy was assessed in a naturalistic setting—usually, two people facing each other. This type of measurement emphasized the context-dependence of synchrony. For example, nonverbal behavior and its synchronization depend on the content of the conversation (e.g., talking about organizational issues versus about alliance rupture).

Empirical evidence shows that the quality of nonverbal synchrony can be a marker for different psychiatric pathologies, such as social anxiety (Varlet et al. 2014) or depression (Paulick et al. 2018b). Additionally, the MG has already been found to be associated with interpersonal constructs (Feniger-Schaal et al. 2018) and with psychiatric conditions (e.g., schizophrenia; Słowinski et al. 2017). Therefore, changes in the diagnosis or in the ability for interpersonal connectedness may be captured using the nonverbal, embodied task of the MG. The benefit of MG is that it is free of conversational content, and the tasks of leading and following can be changed by instruction to allow the investigation of different roles. The MG can be used as a standardized setting for repeated measures, for example, at the beginning, middle, and end of psychotherapy, to track interpersonal changes, as expressed in nonverbal interaction (Feniger-Schaal et al. 2018; McGarry and Russo 2011).

Limitations

A limitation of the study is the small sample size, which may explain the marginally significant and some of the non-significant results. Despite the small sample size, however, the correlation coefficients were similar to the average coefficients in the meta-analyses conducted by Vicaria and Dickens (2016) and Mogan et al. (2017).

When individuals changed places during the game, motion energy time series were treated as missing values. As a result, our method did not allow us to capture some moments in synchrony because MEA requires marking individuals independently in a video, showing no overlaps. Therefore, even if individuals were synchronous when changing places (e.g., running in a circle), this synchrony was not captured by the computerized method, resulting in the underestimation of synchrony for some dyads. Additionally, the computerized method produced global movement indices in which gestures and other types of body movements are aggregated. The general amount of movement may not be the only critical issue, and it is possible that the type of movement is also an important indicator of psychological variables such as social anxiety (Kreyenbrink et al. 2017).

In addition to the overlapping of movements, we excluded participants if technical problems occurred during their game, for example, when a window that appeared in the recording caused a reflection. Future studies should replicate the results with a larger sample, paying special attention to technical issues to minimize the exclusion of participants from the sample. For example, red lines can be marked on the floor, and participants can be instructed not to cross the lines, so that they don't switch places.

Implications

The MG can be used as a structured movement task before, during, and after psychotherapy, to measure changes in synchrony and other interpersonal abilities, such as taking turns in leadership. The simple movement interaction of the MG can offer an assessment measure that bypasses verbal accounts and can be used with populations that have cognitive limitations or whose verbal account cannot express their mental state sufficiently well. It can enrich the verbal report of patients by providing additional ways of expressing interpersonal abilities.

Acknowledgements This research received no grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Altmann, U. (2011). Investigation of movement synchrony using windowed crosslagged regression. In A. Esposito, A. Vinciarelli, K. Vicsi, C. Pelachaud, & A. Nijholt (Eds.), *Analysis of verbal and nonverbal communication and enactment: The processing issue* (pp. 344–354). Berlin: Springer. https://doi.org/10.1007/978-3-642-25775-9_31.

Altmann, U. (2013). *Synchronisation nonverbalen Verhaltens: Weiterentwicklung und Anwendung zeitreihenanalytischer Identifikationsverfahren. [Synchronization of nonverbal behavior: Development and Application of time series analysis methods]*. Berlin: Springer.

Altmann, U., Schoenherr, D., Paulick, J., Deisenhofer, A. K., Schwartz, B., Rubel, J. A., & Strauss, B. (2019). Associations between movement synchrony and outcome in patients with social anxiety disorder: Evidence for treatment specific effects. *Psychotherapy Research*, 1–17.

Bente, G., Donaghy, W. C., & Suwelack, D. (1998). Sex differences in body movement and visual attention: An integrated analysis of movement and gaze in mixed-sex dyads. *Journal of Nonverbal Behavior, 22*(1), 31–58.

Berliner, P. F. (2009). *Thinking in jazz: The infinite art of improvisation*. Chicago: University of Chicago Press.

Bernieri, F. J., Reznick, J. S., & Rosenthal, R. (1988). Synchrony, pseudosynchrony, and dissynchrony: Measuring the entrainment process in mother-infant interactions. *Journal of Personality and Social Psychology, 54*(2), 243–253.

Boal, A. (2013). *The rainbow of desire: The Boal method of theatre and therapy*. Abingdon: Routledge.

Boker, S. M., Rotondo, J. L., Xu, M., & King, K. (2002). Windowed cross-correlation and peak picking for the analysis of variability in the association between behavioral time series. *Psychological Methods, 7*(3), 338–355. https://doi.org/10.1037/1082-989x.7.3.338.

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.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale: Erlbaum Associates.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155.

Feldman, R. (2007). Parent–infant synchrony and the construction of shared timing; physiological precursors, developmental outcomes, and risk conditions. *Journal of Child Psychology and Psychiatry, 48*(3–4), 329–354.

Feniger-Schaal, R., Hart, Y., Lotan, N., Koren-Karie, N., & Noy, L. (2018). The body speaks: Using the mirror game to link attachment and non-verbal behavior. *Frontiers in Psychology, 9,* 1560.

Feniger-Schaal, R., & Lotan, N. (2017). The embodiment of attachment: Directional and shaping movements in adults' mirror game. *The Arts in Psychotherapy, 53,* 55–63.

Ramseyer, F., & Tschacher, W. (2010). Nonverbal synchrony or random coincidence? How to tell the difference. In C. N. A. Esposito, C. Vogel, A. Hussain, & A. Nijholt (Eds.), *Development of multimodal interfaces: Active listening and synchrony* (Vol. 5967, pp. 182–196). Berlin: Springer.

Gaggioli, A., Falletta, E. M., Ferrise, F., Graziosi, S., Gallace, A., D'Ausilio, A., et al. (2019). Effects of interpersonal sensorimotor synchronization on dyadic creativity: Gender matters. *Frontiers in psychology, 9,* 2604.

Gaziv, G., Noy, L., Liron, Y., & Alon, U. (2017). A reduced-dimensionality approach to uncovering dyadic modes of body motion in conversations. *PLoS ONE, 12*(1), e0170786.

Grammer, K., Honda, M., Juette, A., & Schmitt, A. (1999). Fuzziness of nonverbal courtship communication unblurred by motion energy detection. *Journal of Personality and Social Psychology, 77*(3), 487–508. https://doi.org/10.1037/0022-3514.77.3.487.

Gueugnon, M., Salesse, R. N., Coste, A., Zhao, Z., Bardy, B. G., & Marin, L. (2016). The acquisition of socio-motor improvisation in the mirror game. *Human Movement Science, 46,* 117–128.

Harrigan, J., Rosenthal, R., Scherer, K. R., & Scherer, K. (Eds.). (2008). *New handbook of methods in nonverbal behavior research*. Oxford: Oxford University Press.

Harrist, A. W., Pettit, G. S., Dodge, K. A., & Bates, J. E. (1994). Dyadic synchrony in mother-child interaction: Relation with children's subsequent kindergarten adjustment. *Family Relations*, 417–424.

Hart, Y., Noy, L., Feniger-Schaal, R., Mayo, A. E., & Alon, U. (2014a). Individuality and togetherness in joint improvised motion. *PLoS ONE, 9,* e87213. https://doi.org/10.1371/journal.pone.0087213.

Hart, Y., Noy, L., Feniger-Schaal, R., Mayo, A. E., & Alon, U. (2014b). Individuality and togetherness in joint improvised motion. *PLoS ONE, 9*(2), e87213.

Himberg, T., Laroche, J., Bigé, R., Buchkowski, M., & Bachrach, A. (2018). Coordinated interpersonal behavior in collective dance improvisation: The aesthetics of kinaesthetic togetherness. *Behavioral sciences, 8*(2), 23. https://doi.org/10.3390/bs8020023.

Hove, M. J., & Risen, J. L. (2009). It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition, 27*(6), 949–960.

Isabella, R. A., & Belsky, J. (1991). Interactional synchrony and the origins of infant-mother attachment: A replication study. *Child Development, 62*(2), 373–384.

Julien, D., Brault, M., Chartrand, É., & Bégin, J. (2000). Immediacy behaviours and synchrony in satisfied and dissatisfied couples. *Canadian Journal of Behavioural Science/Revue canadienne des sciences du comportement, 32*(2), 84.
Koole, S. L., & Tschacher, W. (2016). Synchrony in psychotherapy: A review and an integrative framework for the therapeutic alliance. *Frontiers in Psychology, 7,* 862. https://doi.org/10.3389/fpsyg.2016.00862.
Kreyenbrink, I., Joraschky, P., Konstantinidis, I., Neumann, N., & Lausberg, H. (2017). Nonverbales Verhalten von Patienten mit sozialen Phobien und ihren Therapeuten in psychodynamischen Psychotherapien (Teilprojekt SOPHO-NET). *Zeitschrift für Psychosomatische Medizin und Psychotherapie, 63*(3), 297–313.
Lakin, J. L., Jefferis, V. E., Rebing, 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.
Leander, N. P., Chartrand, T. L., & Bargh, J. A. (2012). You give me the chills: Embodied reactions to inappropriate amounts of behavioral mimicry. *Psychological Science, 23*(7), 772–779.
Lindsey, E. W., Colwell, M. J., Frabutt, J. M., Chambers, J. C., & MacKinnon-Lewis, C. (2008). Mother-child dyadic synchrony in European American and African American families during early adolescence: Relations with self-esteem and prosocial behavior. *Merrill-Palmer Quarterly, 54*(3), 289–315.
Lindsey, E. W., Cremeens, P. R., & Caldera, Y. M. (2010). Mother–child and father–child mutuality in two contexts: Consequences for young children's peer relationships. *Infant and Child Development, 19*(2), 142–160.
Lindsey, E. W., Cremeens, P. R., Colwell, M. J., & Caldera, Y. M. (2009). The structure of parent–child dyadic synchrony in toddlerhood and children's communication competence and Self-control. *Social Development, 18*(2), 375–396.
McDowall, J. J. (1978). Interactional synchrony: A reappraisal. *Journal of Personality and Social Psychology, 36*(9), 963–975.
McGarry, L. M., & Russo, F. A. (2011). Mirroring in dance/movement therapy: Potential mechanisms behind empathy enhancement. *The Arts in Psychotherapy, 38*(3), 178–184.
Mogan, R., Fischer, R., & Bulbulia, J. A. (2017). To be in synchrony or not? A meta-analysis of synchrony's effects on behavior, perception, cognition and affect. *Journal of Experimental Social Psychology, 72,* 13–20.
Noy, L., Dekel, E., & Alon, U. (2011). The mirror game as a paradigm for studying the dynamics of two people improvising motion together. *Proceedings of the National Academy of Sciences, 108*(52), 20947–20952.
Noy, L., Levit-Binun, N., & Golland, Y. (2015). Being in the zone: physiological markers of togetherness in joint improvisation. *Frontiers in Human Neuroscience, 9,* 187.
Paulick, J., Deisenhofer, A.-K., Ramseyer, F., Tschacher, W., Boyle, K., Rubel, J., et al. (2018a). Nonverbal synchrony: A new approach to better understand psychotherapeutic processes and drop-out. *Journal of Psychotherapy Integration, 28*(3), 367–384. https://doi.org/10.1037/int0000099.
Paulick, J., Rubel, J. A., Deisenhofer, A. K., Schwartz, B., Thielemann, D., Altmann, U., et al. (2018b). Diagnostic features of nonverbal synchrony in psychotherapy: Comparing depression and anxiety. *Cognitive Therapy and Research, 42*(5), 539–551.
Paxton, A., & Dale, R. (2013). Argument disrupts interpersonal synchrony. *The Quarterly Journal of Experimental Psychology, 66*(11), 2092–2102. https://doi.org/10.1080/17470218.2013.853089.
Rabinowitch, T. C., & Meltzoff, A. N. (2017). Synchronized movement experience enhances peer cooperation in preschool children. *Journal of Experimental Child Psychology, 160,* 21–32.
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), 284–295. https://doi.org/10.1037/a0023419.
Reddish, P., Fischer, R., & Bulbulia, J. (2013). Let's dance together: Synchrony, shared intentionality and cooperation. *PLoS ONE, 8*(8), e71182. https://doi.org/10.1371/journal.pone.0071182.
Rennung, M., & Göritz, A. S. (2016). Prosocial consequences of interpersonal synchrony. *Zeitschrift für Psychologie, 224*(3), 168–189.
Repp, B. H. (2005). Sensorimotor synchronization: A review of the tapping literature. *Psychonomic Bulletin & Review, 12*(6), 969–992.
Schechner, R. (1994). *Environmental theater*. Wisconsin: Hal Leonard Corporation.
Schoenherr, D., Paulick, J., Strauss, B. M., Deisenhofer, A. K., Schwartz, B., Rubel, J. A., et al. (2019a). Identification of movement synchrony: Validation of windowed cross-lagged correlation and-regression with peak-picking algorithm. *PLoS ONE, 14*(2), e0211494.

Schoenherr, D., Paulick, J., Strauss, B., Deisenhofer, A.-K., Schwartz, B., Rubel, J., Altmann, U. (2019b). Nonverbal synchrony predicts premature termination of psychotherapy for social phobic patients. *Psychotherapy (Chicago, III.)*, Advance online publication. https://doi.org/10.1037/pst0000216.

Seham, A. E. (2001). *Whose improv is it anyway? Beyond Second City*. Mississippi: Univ. Press of Mississippi.

Sharon-David, H., Mizrahi, M., Rinott, M., Golland, Y., & Birnbaum, G. E. (2018). Being on the same wavelength: Behavioral synchrony between partners and its influence on the experience of intimacy. *Journal of Social and Personal Relationships*, 1–26.

Słowiński, P., Alderisio, F., Zhai, C., Shen, Y., Tino, P., Bortolon, C., et al. (2017). Unravelling socio-motor biomarkers in schizophrenia. *Schizophrenia, 3*(1), 8.

Spolin, V. (1999). *Improvisation for the theater*. Evanston: Northwestern University Press.

Sroufe, L. A., & Fleeson, J. (1986). Attachment and the construction of relationships. *Relationships and development, 51,* 72.

Tschacher, W., Rees, G., & Ramseyer, F. (2014). Nonverbal synchrony and affect in dyadic interactions. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2014.01323.

Valdesolo, P., & DeSteno, D. (2011). Synchrony and the social tuning of compassion. *Emotion, 11*(2), 262–266.

Valdesolo, P., Ouyang, J., & DeSteno, D. (2010). The rhythm of joint action: Synchrony promotes cooperative ability. *Journal of Experimental Social Psychology, 46*(4), 693–695.

Van Baaren, R. B., Holland, R. W., Kawakami, K., & Van Knippenberg, A. (2004). Mimicry and prosocial behavior. *Psychological Science, 15*(1), 71–74.

Varlet, M., Marin, L., Capdevielle, D., Del-Monte, J., Schmidt, R., Salesse, R., et al. (2014). Difficulty leading interpersonal coordination: towards an embodied signature of social anxiety disorder. *Frontiers in Behavioral Neuroscience, 8,* 29.

Vicaria, I. M., & Dickens, L. (2016). Meta-analyses of the intra-and interpersonal outcomes of interpersonal coordination. *Journal of Nonverbal Behavior, 40*(4), 335–361.

Watanabe, T. (1983). A study of motion-voice synchronization. *Bulletin of JSME, 26*(222), 2244–2250.

Wiltermuth, S. S., & Heath, C. (2009). Synchrony and cooperation. *Psychological Science, 20*(1), 1–5.

Zhai, C., Alderisio, F., Tsaneva-Atanasova, K., and di Bernardo, M. (2014). A novel cognitive architecture for a human-like virtual player in the mirror game. In *2014 IEEE International Conference on Systems, Man and Cybernetics (SMC)*. San Diego, CA (pp. 754–759). https://doi.org/10.1109/smc.2014.6974001.