Reducing Synchronization to Increase Interest Improves Interpersonal Liking

Inbal Ravreby [iD] [1,2]*, Yoel Shilat [iD] [3,4]*, Yaara Yeshurun [iD] [5,6]

[1]Department of Neurobiology, Weizmann Institute of Science, Rehovot, Israel.

[2]The Azrieli National Institute for Human Brain Imaging and Research, Rehovot, Israel.

[3]Department of Psychology, Ben Gurion University of the Negev, Beer Sheva, Israel.

[4]Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev, Israel.

[5]Sagol School of Neuroscience, Tel-Aviv University, Tel-Aviv, Israel.

[6]School of Psychological Sciences, Tel-Aviv University, Tel-Aviv, Israel.

* These authors contributed equally to this work

Correspondence:

Inbal Ravreby, inbalra5991@gmail.com

Yoel Shilat, yoel.shilat@gmail.com

Yaara Yeshurun, yaaray@tauex.tau.ac.il

Abstract

Synchronization is a critical aspect of social bonding. We use our body to share information and get into sync with others. Predictability facilitates synchronization, which has been suggested as a mechanism for social bonding. This stands in contrast to our striving for interesting, novel, and challenging interactions. In this study we asked 100 dyads to play the mirror game, in which they had to move their hands with as much coordination as possible, and then report how much they liked each other. Using motion energy analysis, we extracted a time-series representing participants' velocity, and showed a positive relationship between liking and the level of synchronization, complexity, and novelty. Moreover, we found that people create novel and challenging interactions, even though they pay a price – being less synchronized. Thus, we propose that balancing between being synchronized and generating novel and challenging interactions, rather than merely maximizing synchronization, optimizes the interaction quality.

Introduction

Sensorimotor communication, which is achieved through modification of individuals' body movements in order to communicate their intentions to others, is integral to human social communication and coordination[1–3]. Moreover, it has been shown that during social interactions, dyadic coordination and synchronization of movements play a key role in successful interaction and achievement of mutual goals[4]. However, sensorimotor communication is a multifaceted process, and it might well be that there are key factors other than synchronization in these processes. In this study, we explore aspects of sensorimotor non-verbal communication that lead to fundamental positive social interactions.

A large body of literature has shown a positive relationship between the quality of social interaction and synchronization[5–10] of movements, defined as the similarity of movements[8], either in the time domain or the frequency domain[10,11], within a dyad or a larger group of people. For example, when individuals interacted with others who mimicked their body language, synchronization of movements was shown to increase liking[6,10], affiliation[10,12], rapport[10,13], trust,[10,14] and collaboration[10,15]. These results are related to a broader concept of synchrony that was offered as a mechanism for social understanding and connectedness[16–18]. Specifically, it was suggested that movement synchronization is a body-based way for instantiating a socioemotional connection with another[16] and creating shared experiences [18]. In coordinated actions, or when mirroring each other, the actions of self and the other overlap, and this facilitates mutual understanding[19]. Remarkably, there is not only a correlation, but also a bidirectional causality between the social interaction quality and synchronization[5,6,20–23]. For instance, when the goal was to affiliate with another person who

touched their own face, there was a tendency to mimic the touching, more than when there was no affiliation goal[6]. This suggests that affiliation causes increased mimicry. In addition, posture sharing may be influential in establishing rapport[5], suggesting that mimicry may lead to better social interaction. Accordingly, synchronization of body movements is related to positive feelings such as connectedness and togetherness[5,12,16,24,25]. The aforementioned studies have established that movement synchronization is rewarding, since it leads to a variety of positive feelings.

Making oneself predictable may be used as a synchronization strategy, which in turn is rewarding. For example, when two acquaintances are approaching one another and want to greet each other using a physical gesture, they have to choose from the various acceptable social gestures. One person may intend a handshake, while the other may intend a hug. If one of the acquaintances starts raising the right hand when approaching the other, the partner would know in advanced to match the movements so they will shake hands successfully. Indeed, research shows that predictable movements facilitate human synchronization during non-verbal interaction[3,26–30]. For example, it was found that when dyads were instructed to synchronize key presses, they reduced the variability of their actions more than when performing the task alone[28]. It is worth mentioning that less variability in their actions resulted in greater interpersonal synchronization. Thus, if individuals make predictable movements, their coordination increases since they can plan how to move properly, and coordinate their movements. Increasing predictability, therefore, may increase the likelihood of a more positive and rewarding social interaction.

Being highly predictable or repetitive facilitates synchronization. Notably, a predictable movement does not have to be repetitive, and vice versa. A movement may be new but simple, or it may be complex but repetitive. Significantly, a highly predictable or repetitive interaction is not necessarily rewarding, as the interaction might feel tedious[31,32] and boring[33]. Boredom may be defined as the aversive experience of wanting, but being unable to engage in a satisfying activity[31], which is also a challenging one[34]. Any dyadic interaction can be conceived of as a dynamic process by which information is exchanged between individuals[35]. Following that, boredom may occur when there is a lack of rich information, making the activity unsatisfying. Such an experience is likely to occur during highly predictable and repetitive interactions. One can avoid boredom by exploring novel stimuli – that is, a change in stimuli conditions from previous experience[36]. Moreover, individuals constantly strive for complexity and novelty[36–38]. Such patterns violate prior expectations[39], and thus may lead to more interesting and challenging interactions. The more patterns are unpredictable (complex) and less repetitive (novel), the more rewarding

the interactions. This notion is consistent with Hasson and Firth[35] who argued that we need to go beyond simple mirror alignment once we start interacting.

Altogether, we suggest that in order to optimize the interaction quality, there should be a subtle balance between being synchronized and generating an interesting and challenging interaction. Accordingly, in this study we set out to test the role of synchronization, complexity, and novelty in generating positive interactions, in the context of sensorimotor dyadic communication. We hypothesized that complex and novel movements will improve the interaction more than mere synchronization. Moreover, we hypothesized that when people are asked to synchronize their movements with each other, they will choose to add complexity and novelty to the interaction, despite greater difficulty in arriving at synchronization.

Results

Participants were assigned to pairs and played the full-body mirror game[40], in which they were asked to move their hands with as much coordination as possible without talking, for two minutes (see Fig. 1a). After each game, participants indicated how much they liked their partner. We filmed the games using a hidden camera and quantified each player's motions using motion energy analysis (MEA)[41]. Finally, the MEA signal was analyzed in order to learn about the quality of the interaction (see Methods section for further details).
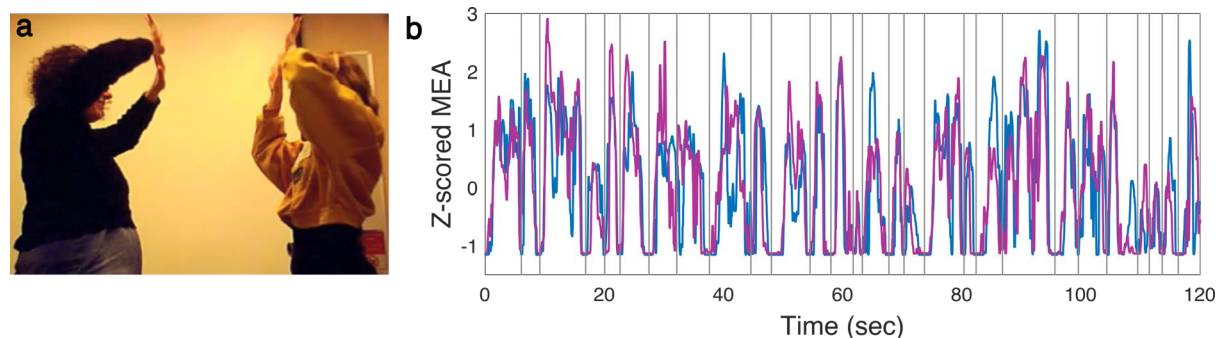

Fig. 1 | The Mirror Game. a, A pair playing the mirror game while a hidden camera alarm clock, that was placed on a table next to the players, is filming the game. **b**, The z-scored MEA signals of two representative participants while playing with each other. The middle and the bottom panels show each player's MEA signal separately. The vertical lines in each panel denote the separation between the movement segments.

Next, to test whether dyads' movement dynamics during the interaction reflect liking, we divided the dyads according to the median into two groups: high-liking half and low-liking half, each comprising 50 dyads, and compared the dynamics of synchronization, complexity, and novelty between the two groups.

Dyads' movement reflected reciprocal relationships. Granger causality analysis (GCA) is a method that uses autoregressive models to measure the causal relationship between two time series[42]. We computed the pairwise-conditional causalities of each participant's movement in the dyad to that of the other participant. Remarkably, the GCA showed that in 95 out of the 100 dyads, each player's movement was significantly causally (Granger caused) determined by the other player's movement, i.e., there was a significant mutual Granger cause. These results suggest that the vast majority of the participants did not consistently play the role of leader or follower, but rather changed roles during the game[43]. Such a symmetric and reciprocal relationship may be more rewarding[44], but may make it harder to be in sync with each other, as movement planning is harder, because the interaction is less predictable. The remaining five dyads exhibited a leader-follower movement pattern, as was shown by the one-way relationship of the Granger causality – in these five dyads one participant Granger-caused the other participant's movement, and there was no reciprocity. Combining these two findings shows that in all the dyads at least one participant Granger-caused the movements of the other, and, therefore, the partner mirrored their movements, suggesting that all dyads followed the instructions and moved in a coordinated manner.

Dyads chose to be novel and complex. Among all 100 dyads, there was not a single dyad in which the participants moved their hands repeatedly throughout the whole mirror game, according to a judge who watched the videos of the mirror game. We also calculated a dyadic novelty score, using the Kolmogorov–Smirnov distance measure (K-S distance)[45], and compared it to a novelty scale we developed (see Methods section for more details). In order to establish a novelty scale, we filmed a volunteer (who was not a part of the Mirror Game cohort) twice: once while repeatedly moving their hands up and down for two minutes, and once while moving their hands in a highly diverse manner for two minutes. We defined these movements as low novelty movements (LN, upper panel of Fig. 2a) and high novelty movements (HN, bottom panel of Fig. 2a), respectively. The results showed that 99% of the dyads moved in a more novel way than just moving the hands up and down repeatedly (LN), even though we had not instructed them to perform novel movements. Furthermore, only 9% of the dyads moved in a more novel manner than when intentionally moving the hands in a highly diverse manner (HN). This result further validates the novelty measure we chose, since our defined low-novelty measure (LN) was at the far-left side of the novelty histogram (0.316, as marked by the blue dashed line in Fig. 2b) and our definition for high-novelty movements (HN) was at the right side of the novelty histogram (0.463, as marked by the magenta dashed line in Fig. 2b). The mean novelty of all dyads = 0.405 ± 0.041 and two-tailed one-sample t-test showed that low-novelty movements, repeated hands movements,

were significantly lower than the average novelty $t(99) = 21.836$, $P < 0.001$, Cohen's $d = 2.184$, 95% CI $= 1.82 \leq d \leq 2.543$, $BF_{10} > 1000$, whereas high-novelty movements, diverse hands movements, were significantly higher than the average novelty $t(99) = 14.051$, $P < 0.001$, Cohen's $d = 1.405$, 95% CI $= 1.68 \leq d \leq 1.126$, $BF_{10} > 1000$. Thus, even though moving hands up and down repeatedly makes it easier to get into sync[28,30] and is in accordance with the instructions, 99% of the dyads preferred moving in a less repetitive, more novel, and more interesting manner.
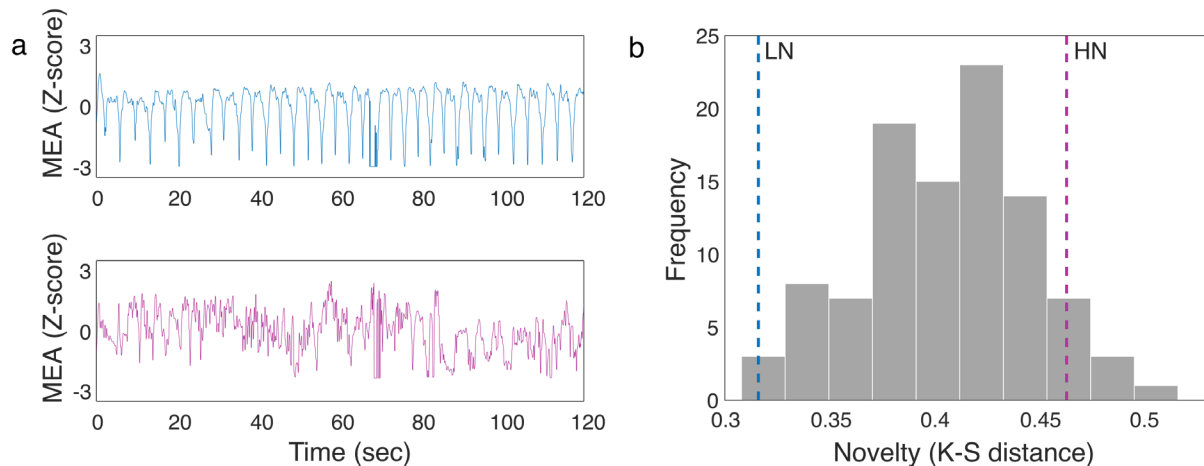

Fig. 2 | Moving in a novel manner. a, The upper panel shows the z-scored MEA of repetitive up and down hand movements (LN). The bottom panel shows the z-scored MEA of diverse and novel hands movements (HN). The hand movements were measured in a setup identical to that of the dyadic mirror games. **b,** A histogram of the novelty of the dyads' movements during the mirror game. The blue dashed line denotes repetitive hand movements up and down (LN). The magenta dashed line denotes diverse movements (HN).

Next, we tested the relationships between the synchronization, complexity, and novelty of the dyads. Synchronization was measured using Pearson correlation; complexity was calculated using Shannon entropy[46], and novelty was measured using K-S distance (see Methods section for more details). We found a significant negative correlation between the synchronization and complexity levels of the dyads, $r = -0.266$, $P = 0.007$, $BF_{10} = 4.252$, and between their synchronization and novelty levels, $r = -0.319$, $P = 0.001$, $BF_{10} = 21.884$ (Fig. 4a-b). This supports the notion that in more complex and novel interactions, it is harder to get into sync. These results suggest that humans do not only seek to be in sync with others, even when they are instructed to do so, but rather they seek to avoid predictable and repetitive interactions. They strive to be synchronized in an interesting, complex, and novel manner. Notably, novelty was found to be significantly positively correlated with complexity, $r = 0.39$, $P < 0.001$, $BF_{10} = 344.208$ (Fig. 4c).
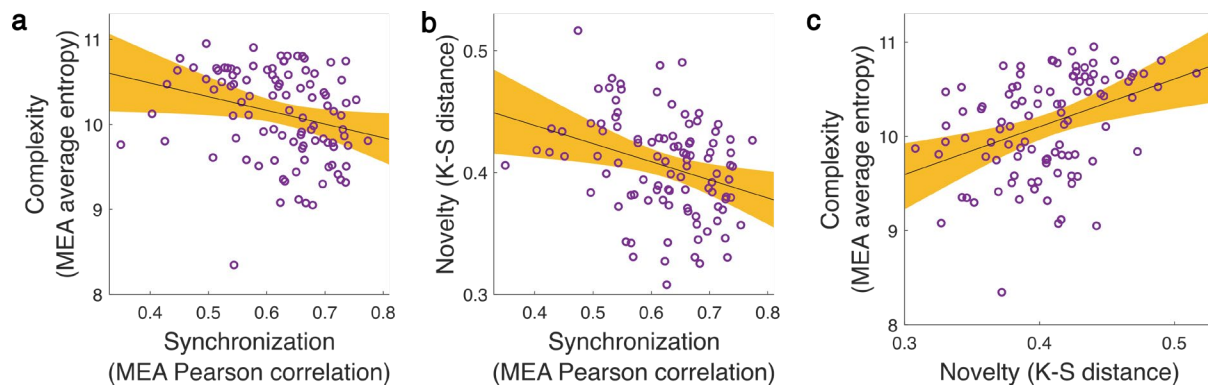
Fig. 3 | A tradeoff between synchronization and being interested. Pearson correlations between the different movement measures. In each panel each circle represents a dyad and the black line is the linear regression line. The orange area marks the confidence interval around the slope of a regression line. **a,** Negative correlation between complexity and synchronization (r = -0.266, P = 0.007, BF_{10} = 4.252) **b**, Negative correlation between novelty and synchronization (r = -0.319, P = 0.001, BF_{10} = 21.884) **c,** Positive correlation between complexity and novelty (r = 0.390, P = 0.00006, BF_{10} = 344.208).

Synchronization and complexity play a role in mutual liking. We used multiple linear regression models as well as Bayesian regression models to predict dyads' mutual liking using synchronization, complexity, and novelty (see Methods section for more details). The mutual liking of dyads was calculated as the average reported liking of the two players (see Methods section for more details). A model that included only the synchronization level predicted 7.8% of variance in liking, β = 0.279, t(98) = 2.878, P = 0.005, R^2 = 0.078, BF_{10} = 7.672 (Fig. 4a). This result is in line with previous studies[6], showing the linkage between synchronization and liking. Including complexity level into the model significantly improved it, explaining almost twice the variance of the former model. Accordingly, the linear model with both synchronization and complexity as predictors, predicted 14.9% of the variance in liking, F(2, 97) = 8.486, P < 0.001, BF_{10} = 66.541, with a positive correlation between synchronization level and liking, β = 0.353, t(97) = 3.629, P < 0.001, $BF_{inclusion}$ = 47.973, and between complexity and liking, β = 0.276, t(97) = 2.844, P = 0.005, $BF_{inclusion}$ = 13.857 (Fig. 4b). Notably, adding complexity level to the model increased the predictive power of synchronization, specifically in its Beta weight. This indicates that adding complexity to the model suppressed the irrelevant variability of synchronization and thus further improved the model. Introducing novelty to the model did not significantly improve it, and predicted an additional variance of 0.05%, P = 0.456, BF_{10} = 0.368. This result suggests that although the average novelty during the game is related to the synchronization level and to the complexity of t interaction, it is not sufficient to create affiliation towards others. Following the comparisons between the models, as demonstrated in Fig. 4b (and in Supplementary Table 1), the best linear model out of the three was:

$$\text{Liking} = -59.33 + 64.73 \times \text{Synchronization} + 8.38 \times \text{Complexity}$$

Notice also that similar results were found using maximal cross-correlation as the synchronization measure (see Supplementary Information for further details). We also conducted a stepwise multiple linear regression on all available independent measures (see Supplementary Information for further details) to evaluate the effect of the order of the variables that were entered to the regression model[47]. This analysis yielded almost identical results, therefore we are presenting here the results of the multiple linear regression, which is a more prominent method of analysis. Taken together, there is a converging evidence that individuals tend to like others when their interactions are more complex and unpredictable, rather than simple and highly predictable.
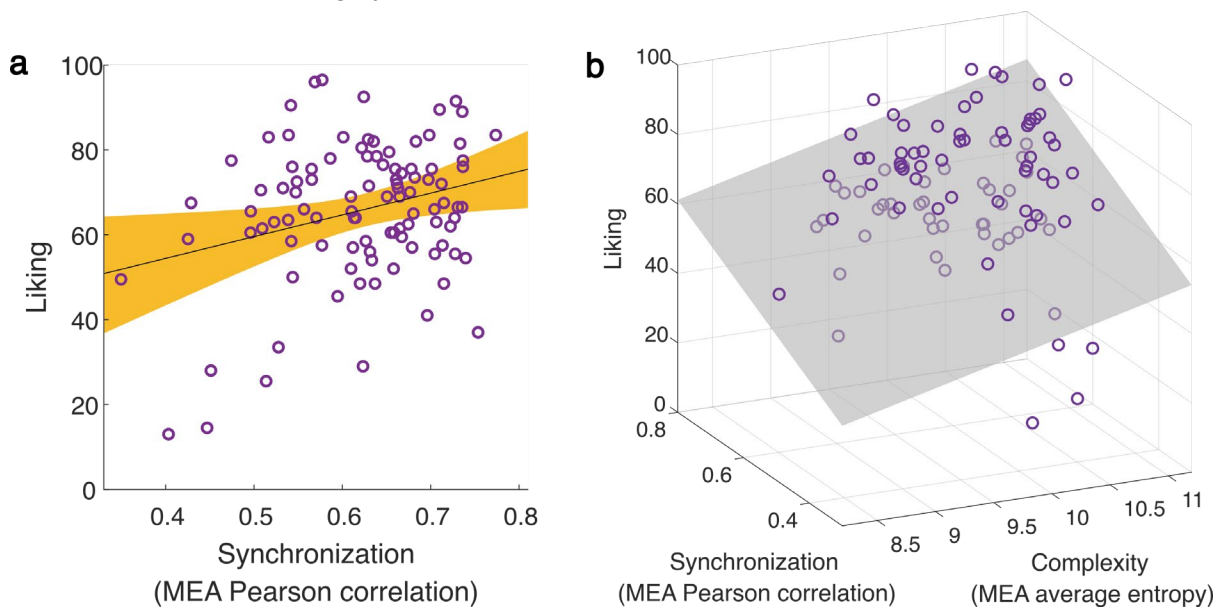

Fig. 4 | Predicting liking by dyadic movement features. a, Synchronization level of the z-scored MEA signals significantly predict liking ($\beta = 0.279$, $t(98) = 2.878$, $P = 0.0049$, $R^2 = 0.078$, $BF_{10} = 7.672$). Each circle represents a dyad, the black line is the linear regression line, and the orange area marks the confidence interval around the slope of a regression line. **b,** Multiple linear regression model including both synchronization and complexity significantly improved the model predictions (this model predicted 14.9% of the variance in liking, $R^2 = 0.149$, $F(2, 97) = 8.486$, $P < 0.001$, $BF_{10} = 66.541$). Each circle represents a dyad in the 3D space and the grey plane marks the regression surface that was fitted by the model.

Dynamics of synchronization, complexity and novelty in dyads with high and low mutual liking. We were interested in testing the relationship between the dynamics of dyads' movements during the interaction and liking. To test this, we compared the dynamics of synchronization, complexity, and novelty between the high-liking and low-liking groups (see Fig. 5), both throughout the entire game and along movement segments[24] (see Methods section for more details). As for synchronization (Fig. 5a), in 55.87% of the total game, the high-liking group moved in a more synchronized manner than the low-liking group.

Binomial sign test shows that this result was significantly above chance level (i.e. 50%), binomial $P < 0.001$. Moreover, the difference between the groups was significant ($P < 0.05$) for 1.2% of the game duration, such that the high-liking group was less synchronized than the low-liking group. Two-tailed Bayesian analysis showed no substantial evidence that the high-liking group is less synchronized than the low-liking group.

Regarding complexity (Fig. 5b), during 79.62% of the game, the movements of the high-liking group were more complex than those of the low-liking group, which is significantly above chance level, as shown by a binomial sign test, $P < 0.001$. Furthermore, the difference between the high and low-liking groups was significant for 15.66% throughout the duration of the game – the high-liking group moved in a more complex manner than the low-liking group. Finally, this was substantially supported by the Bayesian analysis in 4.01% of the mirror game duration.

In terms of novelty (Fig. 5c), unlike in the results of the multiple linear regression model, which did not take into account the time domain, in 90.16% of the game the high-liking group moved in a more novel manner than the low-liking group, binomial sign test $P < 0.001$. Moreover, the difference between the high- and low-liking groups was significant for 10.7% of the game – the high-liking group was more novel than the low-liking group. Using Bayesian analysis, this was substantially supported in 1.94% of the duration of the mirror game.

As shown in Fig. 5c, it seems that novelty increased over time, both in the low and the high-liking groups, but more prominently in the low-liking group. To test this, we performed a post-hoc correlation analysis and found that, indeed, the novelty significantly increased over time in the low-liking group, $r = 0.822$, $P = 0.001$, $BF_{10} > 1000$, and in the high-liking group, $r = 0.671$, $P = 0.001$, $BF_{10} > 1000$. Remarkably, the increase in novelty over time of the low-liking group was significantly larger than that of the high-liking group, $z = 14.059$, $P = 0.001$. This was also demonstrated by the slopes of the fitted linear regression lines: $Novelty_{low-liking} = 6.339 \times 10^{-4} \times Time (s) + 0.3523$, $Novelty_{high-liking} = 3.2934 \times 10^{-4} \times Time (s) + 0.388$. Notably, although the novelty of the high-liking group increased more slowly over time, the level of novelty in this group was relatively high right from the beginning of the mirror game, suggesting that people who like each other tend to create novel interactions from the very beginning, and then gradually increase the novelty level.
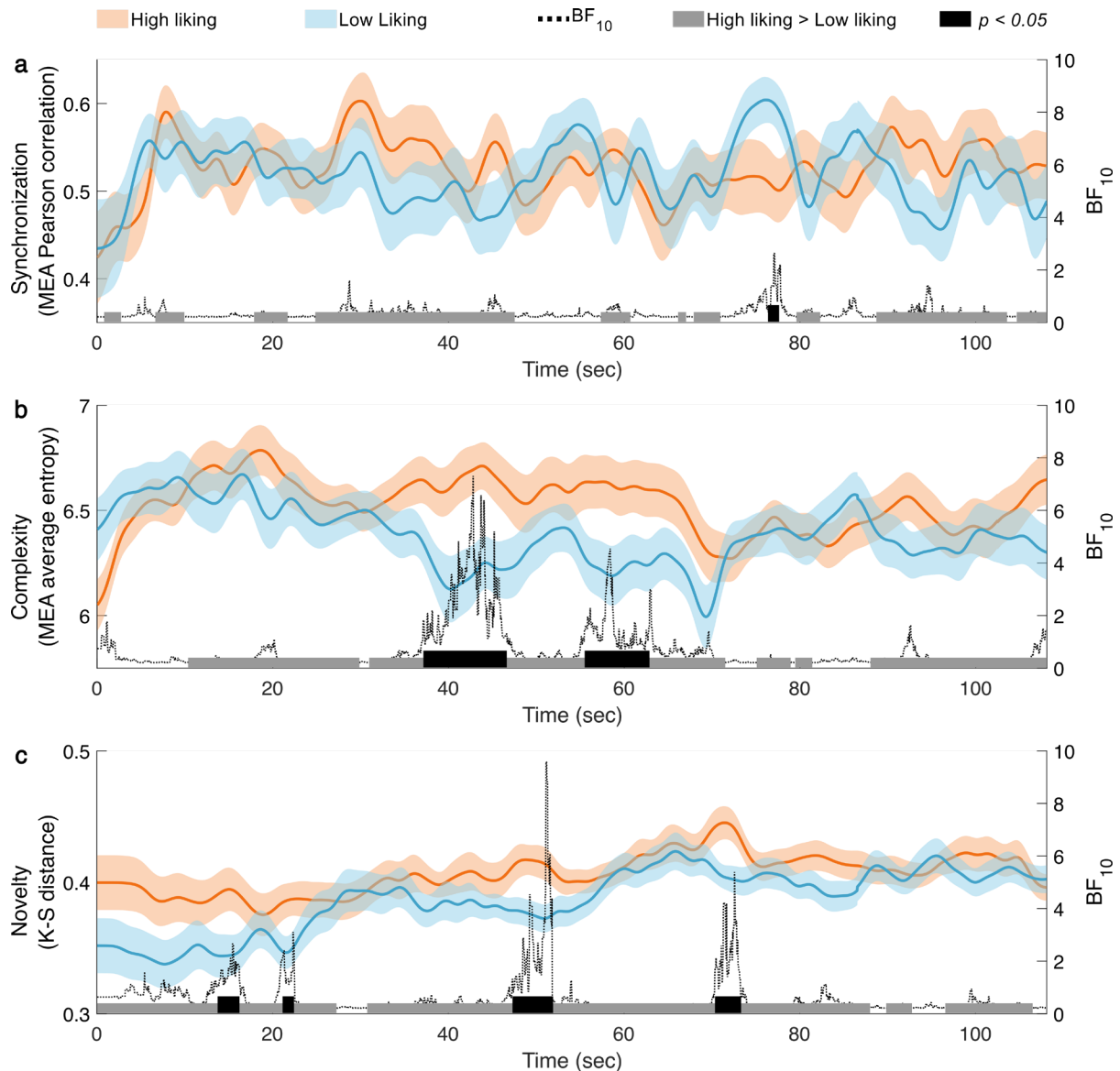
Fig. 5 | The dyadic movement measures along the interaction segments for high and low-liking. The orange and blue lines denote the average value of the high and low-liking groups respectively, along the mirror game time-points. The shaded orange and blue marks denote the *SE*s of the high and low-liking groups, respectively. The gray marks at the bottom of each panel denote time-points in which the high-liking group had a higher value than the low-liking group. The black marks denote time-points in which there was a significant difference between the liking groups. The dashed lines depict two-tailed Bayes factors (BF_{10}). **a,** Synchronization was higher in the high-liking group than the low-liking group for 55.87% of the game duration, Binomial sign test $P < 0.001$. **b,** Complexity was higher in the high-liking group than in the low-liking group for 79.62% out of the game duration, Binomial sign test $P < 0.001$. **c,** Novelty was higher in the high-liking group during 90.16% of the game, binomial sign test $P < 0.001$.

Discussion

In this study we demonstrated that in addition to synchronization, complexity and novelty play a role in generating positive interactions. We also found that when they were synchronized, participants who performed more complex and novel movements while

playing the mirror game liked each other more. Our results suggest that humans seek complexity and novelty, even when getting into sync will be more difficult.

In line with previous studies demonstrating that movement synchronization between individuals increases the positivity of social interactions[10,48,49], we found that elevated synchronization during the mirror game was associated with elevated mutual liking (Fig. 4, 5a). Interpersonal synchrony may signal social proximity or similarity[17] and plays an important role in social cohesion[15,18,50]. It was suggested that in small groups such as dyads, greater attention to the movements of each other, and synchronized movements, or mirroring each other, lead to a blurring between the self and the other[12,51–53]. In turn, this increases the feeling of 'being in the zone' which is also known as togetherness[5,12,16,24,25]. Moreover, it was suggested that being synchronized is rewarding because it is an effective way to understand one's interaction partner[17]. Consequently, such an alignment may facilitate communication[54].

When playing the mirror game, the only instruction the dyads received was "to move their hands with as much coordination as possible, mirroring each other". It is easier to be in sync when the movements are more predictable[3,26–30] and repetitive, and when there is a leader-follower type of interaction, with fixed roles. Although it made it harder for the participants to meet the single requirement of the experiment, in almost all of the mirror games (95% of the interactions), both players influenced each other's motion, as was demonstrated by the GCA results. This occurs when two participants reciprocally adjust their ongoing rhythms as a result of an interaction, serving as a reliable marker for mutual sharing of information[55,56]. This is in contrast to the leader-follower type of interaction, which contains only a one directional information flow. In addition, the dyads chose to perform complex and novel movements, rather than merely performing synchronized movements. Accordingly, the results suggest that participants preferred to decrease their potential synchronization, in order to increase the mutual interest and experience a better, more reciprocal interaction. This may imply that strong relationships between mutual influence and the quality of the interaction [57] and between elevated interest and positive interactions[58] are fundamental for human beings.

Taking into account the whole interaction, we found that the synchronization and complexity of movements predicted liking more accurately than only synchronization of movements (Fig. 4). Adding complexity to the model suppressed the irrelevant variability of synchronization and further improved the prediction of liking. In addition, synchronized and complex movements were negatively correlated (Fig. 3a). This finding implies that liking relies on a tradeoff between the synchronization and the complexity of an interaction. In

other words, the results support the notion that on one hand people seek predictable interaction which facilitates synchronization, and in turn is rewarding[17], but on the other hand, people seek interesting and challenging interactions. Complex interactions are by definition less predictable and comprise a high level of information transformation during communication (as mentioned regarding the definition of entropy). Thus, an optimal balance between the two may maximize the reward and the quality of the interaction.

In contrast to the complexity of movements, when adding the average novelty of the interaction to the model, there was no improvement in predicting liking. Possibly, this is because novelty seeking is a fundamental drive[36–38] and, accordingly, may be a basic need in social interaction. Subsequently, it is plausible that during the mirror game as a whole, the dyads played in a novel manner, regardless of the level of liking. In 99% of the cases, the movements of the dyads were more novel than just repetitively moving their hands up and down, even though there was no requirement to move in a novel manner, which makes it harder to be in sync. Moreover, novelty increased over time, and this trend was even more pronounced in the low-liking group than in the high-liking group, which was relatively novel from the beginning of the game.

Our results showed that the dynamics of synchronization along the mirror game segments, unlike the synchronization of the dyad's movement across the entire game, was only moderately related to liking (Fig. 5a). This discrepancy between the game as a whole and the dynamics on a movement-to-movement basis suggests that, in this case, the whole is greater than its parts, and to identify differences in synchronization, one has to consider the interaction as a whole. During the mirror game, people went in and out of sync, as was previously shown[59]. There were fluctuations in the level of synchronization along the movement segments, but, on the whole, people who liked each other were more synchronized. As Hasson and Firth[35] claimed, interacting individuals are dynamically coupled rather than simply aligned. Interactions are dynamic states which involve continuous mutual adaptation during which there is a development of complementary behavior. Such continuous mutual adaptation along the time domain generates synchrony and, in doing so, promotes shared understanding[60]. We suggest that in order to increase the interaction complexity and novelty, humans are willing to sacrifice synchronization to some extent, and this is done as a part of mutual adaptation. Together, complexity and novelty make an interaction interesting and meaningful – an interaction that one would want, unlike a highly synchronized, but very predictable, repetitive, boring interaction. This notion was supported by the positive relationship between the complexity and novelty of movements along the time domain, to liking. We suggest that when people feel confident enough to allow themselves to

potentially risk losing synchronization, they try to increase the level of complexity and novelty to make the interaction even more satisfying. Then, they restore the synchronization and subsequently balance the two back and forth.

To summarize, in addition to the canonical view that the interaction quality relies on the link between synchronization and prosocial emotions[5,61], we argue that complexity and novelty are crucial and even indispensable factors in human social interactions. Accordingly, we propose a new framework in which optimizing the interaction quality requires a delicate balance between being synchronized and generating challenging and interesting interaction.

Methods

Participants. Twenty-six naïve females participated in this study. Among them 10 have originally participated in another study that is yet to be published. Importantly, its analyses are not related to this study. We recruited only females since the link between movement synchrony and affect has been found to be strongest in female dyads[21]. The experiment took place over three different sessions: the first session included six participants (mean age = 26.83, *SD* = 4.21 years); the second session included ten participants (mean age = 25.6, *SD* = 3.1 years); the third session included ten participants (mean age = 26, *SD* = 3.46 years). Each session included several rounds; in each round participants were randomly assigned partners and played the mirror game (see details below) for about two minutes in a round-robin design, i.e., each participant played the game with all of the other participants in the same session. We excluded one dyad from the analyses, due to lack of movement during the game. Accordingly, a total of 104 dyads were included in the analyses. The duration of the mirror game ranged between 109.81 to 130.56 seconds (*mean* = 119.84, *SD* = 2.5). All participants provided written informed consent and were paid for their time.

Experimental design. In each session, participants were requested to play the full-body Mirror Game[40], in which they were only instructed to move their hands coordinately while keeping their legs in place, with no designated leader or follower (see Fig. 1a). During the game, participants stood at a distance of 50 cm apart, which was marked on the floor. Participants were not allowed to speak with each other during the entire experiment; thus only non-verbal factors influenced the impression formation. After each dyadic interaction, both players indicated on a visual analog scale how much they liked their partner. Throughout the game participants were filmed by a hidden camera alarm clock, which filmed them in 29.97 frames per seconds (FPS) and was set on a table in each of the five rooms used for the experiment, at a distance of 159 cm from where the players stood. After we completed the data collection, we used the video recordings to verify that all participants

followed the instructions and moved during the whole game, mirroring each other without talking. In addition, we used the video recordings to analyze participants' movement.

Motion energy analysis (MEA). We used MEA to quantify each player's motion throughout the mirror game[41]. Motion energy was defined as frame-by-frame differences in pixels color between consecutive video-frames[20,62]. Since, throughout the recordings, both camera position and lighting conditions were kept constant, any frame-by-frame changes indicated body motion of the respective player and not of its surroundings. Following Ramseyer and Tschacher[20], we performed video-noise reduction using automatic detectors for time-series of raw pixel-change. The MEA signal of each player was transformed to z-scores to scale the final values and thus account for differences in the players' height and hand size (Fig. 2). We performed the analyses both at the level of the whole game and along movement segments[24] (see segments' definition below).

Segmentation into movement windows. In order to divide the z-scored MEA vectors of each dyad into movement segments, the signals were smoothed using moving average to eliminate short-term trends and to improve signal to noise ratio. The optimal window for the moving average was heuristically evaluated[63]. Next, we searched for local minima within the signals, i.e., stopping and deceleration points, each having to meet the following conditions: (1) The value was smaller than zero (the average movement velocity); (2) Minimum points must be separated by at least the length of the optimal time window; (3) Two consecutive minimum points must differ by more than 0.1 SDs. After finding the minimum points in the signal of each participant in each dyad, we searched for the minimum points with the smallest time differences between the participants in each dyad and defined them as shared minimum points. Two consecutive minimum points had to be separated by at least the length of the optimal moving average window. To set a starting point and an end point for each movement, we averaged the time indices of minimum points in each dyad's vectors (See Fig. 1b for a representative movement segmentation). The average number of segments was 27.29, *SD* = 13.13. Therefore, the time window analysis was smoothed using a moving average of four seconds, which was the average segment length, to improve signal to noise ratio.

Measuring movement synchronization. In accordance with previous studies, we used Pearson correlation to measure the synchronization level of dyads[5], and thus measured the degree of accelerating or decelerating at the same time.

Measuring movement complexity. We used Shannon entropy – the average level of information – as a measure of the complexity of dyad's movements. Although movement is a

continuous signal, we obtained a sample every 0.033 seconds, so our data were discrete. The entropy of a discrete variable X that can take values in the set A is defined as $H(X) = -\sum_{x \in A} p(x) \log p(x)$. To calculate the entropy of each player's z-scored MEA signal, we first calculated the frequency of each unique MEA value per sample, and then calculated the entropy using the Entropy function[64] in MATLAB[65]. Next, we averaged the entropies of the two participants in each dyad. This was done in order to get a single measure of dyadic entropy, which represents the dyadic average level of movement information. Communication is said to occur when messages (information) flow from one location to another and cause a change in the receiver[46]. Information theory, the theoretical framework underpinning entropy, attributes higher levels of information to more unpredictable distributions. In other words, when an interaction is less predictable it is more complex[26,66–68]. Therefore, unpredictable interactions are more informative and complex than predictable ones, and, therefore, also more interesting.

Measuring movement novelty. We calculated a dyadic novelty score using the K-S distance. We also measured for each dyad how novel (or different) each movement segment was relative to the previous segments. Finally, the novelty scores of all the segments within a dyad were averaged to obtain a single novelty score for each dyad (see details in Supplementary Information). To generate a novelty scale for later comparisons, we recorded two videos of two minutes each, using the exact same setup used in the mirror game experiment (see above). In the first recording, a person was requested to move their hands periodically up and down in a repetitive manner (LN, top panel of Fig. 2a). In the second recording, the request was to move the hands in the most innovative way possible, without repeating any movement patterns (HN, bottom panel of Fig. 2a). We calculated the z-scored MEA of these two videos and then calculated their novelty (using the K-S distance).

In addition to objectively measuring the novelty of the movements, a judge watched each video of the mirror game, and was requested to decide whether the players had moved differently than simply moving their hands up and down repeatedly throughout the whole interaction (or otherwise in a highly repetitive and thus predictive manner, e.g. from side to side or outwards and then inwards).

Measuring liking. To estimate participants' mutual liking, we calculated a dyadic score of likeability per each mirror game, which was defined as the average reported liking of the two players. We wanted to test whether movement synchronization, complexity, and novelty predict how much participants liked each other. To do so, we used multiple linear regression models and calculated the explained variance of liking by synchronization solely, synchronization together with complexity, and synchronization together with complexity and

novelty. A total of three models were tested using JASP software[69]. In addition, we calculated the Pearson correlation between synchronization, complexity, novelty and mutual liking. We excluded four dyads from the analyses, who were farther than 3 SDs from the average of each measure (two were outliers due to their complexity levels, and two due to their liking ratings). In total, the analyses were performed on 100 dyads.

Bayesian Analysis. We have provided a complementary measure to the standard P values[70], using Bayes factors (BF) calculated with the JASP software[69]; priors were set according to default JASP priors[71]. The interpretation of the Bayes factors was according to the following scale: Bayes factors between 3-10 provide substantial evidence against H_0; Bayes factors between 10-100 provide strong evidence against H_0; and Bayes factors above 100 provide decisive evidence against H_0[72,73]. The Bayes factors calculated for the predictors of the regression models (βs' weights) were inclusion Bayes factors, denoting the change in the prior to posterior probability inclusion odds when including the predictor[74]

Code availability

The custom MATLAB scripts used to process and visualize the data collected in this study are available upon request.

Data availability

The data that support the findings in this study are available from the corresponding authors upon request.

References

1. Ansuini, C., Cavallo, A., Bertone, C. & Becchio, C. The visible face of intention: why kinematics matters. *Front. Psychol.* **5**, (2014).

2. Pezzulo, G., Donnarumma, F. & Dindo, H. Human Sensorimotor Communication: A Theory of Signaling in Online Social Interactions. *PLoS ONE* **8**, e79876 (2013).

3. Pezzulo, G. *et al.* The body talks: Sensorimotor communication and its brain and kinematic signatures. *Physics of Life Reviews* **28**, 1–21 (2019).

4. Sebanz, N. & Knoblich, G. Prediction in Joint Action: What, When, and Where. *Topics in Cognitive Science* **1**, 353–367 (2009).

5. LaFrance, M. Nonverbal Synchrony and Rapport: Analysis by the Cross-Lag Panel Technique. *Social Psychology Quarterly* **42**, 66 (1979).

6. Lakin, J. L. & Chartrand, T. L. Using Nonconscious Behavioral Mimicry to Create Affiliation and Rapport. *Psychol Sci* **14**, 334–339 (2003).

7. Lakin, J. L., Jefferis, V. E., Cheng, C. M. & Chartrand, T. L. The Chameleon Effect as Social Glue: Evidence for the Evolutionary Significance of Nonconscious Mimicry. *Journal of Nonverbal Behavior* **27**, 145–162 (2003).

8. Oullier, O., de Guzman, G. C., Jantzen, K. J., Lagarde, J. & Scott Kelso, J. A. Social coordination dynamics: Measuring human bonding. *Social Neuroscience* **3**, 178–192 (2008).

9. Berscheid, E. & Walster, E. H. *Interpersonal attraction*. (Addison-Wesley, 1977).

10. Hale, J. & Hamilton, A. F. de C. Cognitive mechanisms for responding to mimicry from others. *Neuroscience & Biobehavioral Reviews* **63**, 106–123 (2016).

11. Hale, J., Ward, J. A., Buccheri, F., Oliver, D. & Hamilton, A. F. de C. Are You on My Wavelength? Interpersonal Coordination in Dyadic Conversations. *J Nonverbal Behav* **44**, 63–83 (2020).

12. Hove, M. J. & Risen, J. L. It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition* **27**, 949–961 (2009).

13. Vacharkulksemsuk, T. & Fredrickson, B. L. Strangers in sync: Achieving embodied rapport through shared movements. *Journal of Experimental Social Psychology* **48**, 399–402 (2012).

14. Cornejo, C. *et al.* Dynamics of Simultaneous and Imitative Bodily Coordination in Trust and Distrust. *Front. Psychol.* **9**, (2018).

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

16. Marsh, K. L., Richardson, M. J. & Schmidt, R. C. Social connection through joint action and interpersonal coordination. *Top Cogn Sci* **1**, 320–339 (2009).

17. Wheatley, T., Kang, O., Parkinson, C. & Looser, C. E. From Mind Perception to Mental Connection: Synchrony as a Mechanism for Social Understanding: Mind Perception and Mental Connection. *Social and Personality Psychology Compass* **6**, 589–606 (2012).

18. Cheong, J. H., Molani, Z., Sadhukha, S. & Chang, L. J. *Synchronized affect in shared experiences strengthens social connection*. https://osf.io/bd9wn (2020) doi:10.31234/osf.io/bd9wn.

19. Wilson, M. & Knoblich, G. The Case for Motor Involvement in Perceiving Conspecifics. *Psychological Bulletin* **131**, 460–473 (2005).

20. Ramseyer, F. & Tschacher, W. Nonverbal synchrony in psychotherapy: Coordinated body movement reflects relationship quality and outcome. *Journal of Consulting and Clinical Psychology* **79**, 284–295 (2011).

21. Tschacher, W., Rees, G. M. & Ramseyer, F. Nonverbal synchrony and affect in dyadic interactions. *Front. Psychol.* **5**, (2014).

22. Bernieri, F. J. Coordinated movement and rapport in teacher-student interactions. *J Nonverbal Behav* **12**, 120–138 (1988).

23. Miles, L. K., Nind, L. K. & Macrae, C. N. The rhythm of rapport: Interpersonal synchrony and social perception. *Journal of Experimental Social Psychology* **45**, 585–589 (2009).

24. Noy, L., Dekel, E. & Alon, U. The mirror game as a paradigm for studying the dynamics of two people improvising motion together. *PNAS* **108**, 20947–20952 (2011).

25. Noy, L., Levit-Binun, N. & Golland, Y. Being in the zone: physiological markers of togetherness in joint improvisation. *Front. Hum. Neurosci.* **9**, (2015).

26. Konvalinka, I. *et al.* Synchronized arousal between performers and related spectators in a fire-walking ritual. *Proceedings of the National Academy of Sciences* **108**, 8514–8519 (2011).

27. Thornton, M. A., Weaverdyck, M. E. & Tamir, D. I. The Social Brain Automatically Predicts Others' Future Mental States. *J. Neurosci.* **39**, 140–148 (2019).

28. Vesper, C., van der Wel, R. P. R. D., Knoblich, G. & Sebanz, N. Making oneself predictable: reduced temporal variability facilitates joint action coordination. *Exp Brain Res* **211**, 517–530 (2011).

29. Koban, L., Ramamoorthy, A. & Konvalinka, I. Why do we fall into sync with others? Interpersonal synchronization and the brain's optimization principle. *Social Neuroscience* **14**, 1–9 (2019).

30. Konvalinka, I., Vuust, P., Roepstorff, A. & Frith, C. D. Follow you, Follow me: Continuous Mutual Prediction and Adaptation in Joint Tapping. *Quarterly Journal of Experimental Psychology* **63**, 2220–2230 (2010).

31. Eastwood, J. D., Frischen, A., Fenske, M. J. & Smilek, D. The Unengaged Mind: Defining Boredom in Terms of Attention. *Perspect Psychol Sci* **7**, 482–495 (2012).

32. Zuckerman, M. Sensation Seeking and Risk Taking. in *Emotions in Personality and Psychopathology* (ed. Izard, C. E.) 161–197 (Springer US, 1979). doi:10.1007/978-1-4613-2892-6_7.

33. O'Hanlon, J. F. Boredom: Practical consequences and a theory. *Acta Psychologica* **49**, 53–82 (1981).

34. van Tilburg, W. A. P. & Igou, E. R. On boredom: Lack of challenge and meaning as distinct boredom experiences. *Motiv Emot* **36**, 181–194 (2012).

35. Hasson, U. & Frith, C. D. Mirroring and beyond: coupled dynamics as a generalized framework for modelling social interactions. *Philosophical Transactions of the Royal Society B: Biological Sciences* **371**, 20150366 (2016).

36. Costa, V. D., Tran, V. L., Turchi, J. & Averbeck, B. B. Dopamine modulates novelty seeking behavior during decision making. *Behavioral Neuroscience* **128**, 556–566 (2014).

37. Zuckerman, M. Sensation Seeking. in *The Corsini Encyclopedia of Psychology* 1–4 (American Cancer Society, 2010). doi:10.1002/9780470479216.corpsy0843.

38. Bevins, R. A., Klebaur, J. E. & Bardo, M. T. Individual differences in response to novelty, amphetamine-induced activity and drug discrimination in rats. *Behav Pharmacol* **8**, 113–123 (1997).

39. Berns, G. S., Cohen, J. D. & Mintun, M. A. Brain Regions Responsive to Novelty in the Absence of Awareness. *Science* **276**, 1272–1275 (1997).

40. Feniger-Schaal, R., Hart, Y., Lotan, N., Koren-Karie, N. & Noy, L. The Body Speaks: Using the Mirror Game to Link Attachment and Non-verbal Behavior. *Front Psychol* **9**, (2018).

41. Feniger-Schaal, R., Schönherr, D., Altmann, U. & Strauss, B. Movement Synchrony in the Mirror Game. *J Nonverbal Behav* **45**, 107–126 (2021).

42. Granger, C. W. J. Investigating Causal Relations by Econometric Models and Cross-spectral Methods. *Econometrica* **37**, 424 (1969).

43. Jiang, J. *et al.* Leader emergence through interpersonal neural synchronization. *Proc Natl Acad Sci USA* **112**, 4274–4279 (2015).

44. Hart, Y. *et al.* Automated Video Analysis of Non-verbal Communication in a Medical Setting. *Frontiers in Psychology* **7**, (2016).

45. Massey, F. J. The Kolmogorov-Smirnov Test for Goodness of Fit. *Journal of the American Statistical Association* **46**, 68–78 (1951).

46. Shannon, C. E. A Mathematical Theory of Communication. *Bell System Technical Journal* **27**, 623–656 (1948).

47. Lewis, M. Stepwise versus Hierarchical Regression: Pros and Cons. 30 (2007).

48. Wiltermuth, S. S. & Heath, C. Synchrony and Cooperation. *Psychol Sci* **20**, 1–5 (2009).

49. Fessler, D. M. T. & Holbrook, C. Marching into battle: synchronized walking diminishes the conceptualized formidability of an antagonist in men. *Biol. Lett.* **10**, 20140592 (2014).

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

51. Tarr, B., Launay, J. & Dunbar, R. I. M. Silent disco: dancing in synchrony leads to elevated pain thresholds and social closeness. *Evolution and Human Behavior* **37**, 343–349 (2016).

52. Tarr, B., Launay, J. & Dunbar, R. I. M. Music and social bonding: "self-other" merging and neurohormonal mechanisms. *Front. Psychol.* **5**, (2014).

53. Hove, M. J. Shared circuits, shared time, and interpersonal synchrony. *Behav Brain Sci* **31**, 29–30 (2008).

54. Nummenmaa, L. *et al.* Emotions promote social interaction by synchronizing brain activity across individuals. *Proceedings of the National Academy of Sciences* **109**, 9599–9604 (2012).

55. Burgess, A. P. On the interpretation of synchronization in EEG hyperscanning studies: a cautionary note. *Front. Hum. Neurosci.* **7**, (2013).

56. Rosenblum, M., Pikovsky, A., Kurths, J., Schäfer, C. & Tass, P. A. Chapter 9 Phase synchronization: From theory to data analysis. in *Handbook of Biological Physics* vol. 4 279–321 (Elsevier, 2001).

57. Miller, L. C. Intimacy and liking: Mutual influence and the role of unique relationships. *Journal of Personality and Social Psychology* **59**, 50–60 (1990).

58. Sansone, C. & Thoman, D. B. Interest as the Missing Motivator in Self-Regulation. *European Psychologist* **10**, 175–186 (2005).

59. Dahan, A., Noy, L., Hart, Y., Mayo, A. & Alon, U. Exit from Synchrony in Joint Improvised Motion. *PLoS One* **11**, (2016).

60. Fogel, A. *Developing through relationships: origins of communication, self, and culture*. (Harvester Wheatsheaf, 1993).

61. Charny, J. E. Psychosomatic Manifestations of Rapport in Psychotherapy: *Psychosomatic Medicine* **28**, 305–315 (1966).

62. Grammer, K., Honda, M., Juette, A. & Schmitt, A. Fuzziness of nonverbal courtship communication unblurred by motion energy detection. *Journal of Personality and Social Psychology* **77**, 487–508 (1999).

63. Pearl, J. Intelligent Search Strategies for Computer Problem Solving. /paper/Intelligent-Search-Strategies-for-Computer-Problem-Pearl/2a2d5c2532cd2d1cf2b612a50baa2bb2fe1b5735 (1984).

64. Dwinnell, W. *Entropy*. (2020).

65. *MATLAB (Version 2020a)*. (The MathWorks Inc., 2020).

66. Varni, G., Hupont, I., Clavel, C. & Chetouani, M. Computational Study of Primitive Emotional Contagion in Dyadic Interactions. *IEEE Transactions on Affective Computing* **11**, 258–271 (2020).

67. Davidson, R. J. One of a Kind: The Neurobiology of Individuality. *Cerebrum* **2014**, (2014).

68. Butler, E. A. Temporal Interpersonal Emotion Systems: The "TIES" That Form Relationships. *Pers Soc Psychol Rev* **15**, 367–393 (2011).

69. JASP Team. *JASP (Version 0.14.1)*. (2020).

70. Keysers, C., Gazzola, V. & Wagenmakers, E.-J. Using Bayes factor hypothesis testing in neuroscience to establish evidence of absence. *Nat Neurosci* **23**, 788–799 (2020).

71. Goss-Sampson, M. *Bayesian Inference in JASP: a guide for students*. (2020).

72. Kass, R. E. & Raftery, A. E. Bayes Factors. *Journal of the American Statistical Association* **90**, 773–795 (1995).

73. Wasserman, L. Bayesian Model Selection and Model Averaging. *Journal of Mathematical Psychology* **44**, 92–107 (2000).

74. van den Bergh, D. *et al. A Tutorial on Bayesian Multi-Model Linear Regression with BAS and JASP*. https://osf.io/pqju6 (2020) doi:10.31234/osf.io/pqju6.

Acknowledgements:

Author Contributions:

Conceived the idea: IR; YS. Designed experiments: IR. Ran experiments: IR. Analyzed data: IR; YS. Wrote first draft: IR, YS. Edited final draft: IR; YS; YY. Supervision: YY.

Competing interests

The authors declare no competing interests.

Correspondence and requests for materials should be addressed to I.R., Y.S. or Y.Y.