Connecting minds and sharing emotions through human mimicry
Prochazkova, E.

Author: Prochazkova, E.
Title: Connecting minds and sharing emotions through human mimicry
Issue Date: 2021-03-04

Chapter 5

Physiological synchrony predicts attraction in a blind date setting

Based on: Procházková, E., Sjak-Shie, E. E., Behrens, F., Lindh, D., & Kret, M. E. (2019). The choreography of human attraction: physiological synchrony in a blind date setting. *bioRxiv*, 748707.

Also: Procházková, E., Sjak-Shie, E. E., Behrens, F., Lindh, D., & Kret, M. E. (under review). The choreography of human attraction: physiological synchrony in a blind date setting. *Nature human behavior*.

All data, code, and materials that are associated with this paper and used to conduct the analyses are accessible on the Leiden University archiving platform DataverseNL.

Abstract

Humans are social animals whose well-being is shaped by the ability to attract one another and connect with each other. In a dating world in which success can be determined by brief interactions, apart from physical features, there is a choreography of movements, physical reactions, and subtle expressions that promote attraction. To determine what drives attraction between people, we measured the physiological dynamics between couples during real-life dating interactions outside the laboratory, where dating is most relevant. Participants wore eye-tracking glasses with embedded cameras, and devices to measure physiological signals including heart rate and skin conductance. We demonstrate that overt signals such as smiles, laughter, eye contact, or the mimicry of those signals, did not predict attraction. Instead, attraction was predicted by synchrony in heart rate and skin conductance between partners. Our findings suggest that when interacting partners' subconscious arousal levels rise and fall in synchrony, mutual attraction emerges. We conclude that physiological synchrony possibly provides a medium which translates subtle visible expressions into embodied emotions that influence attraction via somatosensory simulation.

Keywords: physiological linkage, nonverbal communication, mimicry, emotion, interpersonal coupling

Introduction

In our modern world where millions of people meet online before interacting face-to-face, the question "what defines attraction" has never been more relevant. Physical attractiveness is often valued as one of the most important characteristics of a potential partner (Walster et al., 1966). Yet, research demonstrates that judging a potential romantic partner based on written or visual stimuli (e.g., personal ads, photos) does not predict attraction during a first date (Eastwick and Finkel, 2008). This is because during a social situation, aside from static facial features and the conversation, nonverbal dynamics such as eye gaze, facial expression, and body posture play a key role. Importantly, research has begun to acknowledge that what people really seek in a partner is a "gut feeling of connection" expressed as a sensation in the body (Tahhan, 2013; Wheatley et al., 2012). This type of attraction is difficult to regulate, fake, or put in words, yet seems to be a major force that often overrides rational decisions when it comes to partner selection. Despite its importance, what sparks this feeling between people remains one of the unsolved mysteries of science. To understand how this romantic spark between people develops, we developed a blind date experiment utilizing state of the art technology including eye-tracking glasses linked to physiological measures in order to elucidate the nonverbal and physiological signals that predict attraction between strangers.

Early-stage romantic attraction is sometimes referred to as passionate love (Berscheid and Wastler, 1974). A first date provides an excellent scenario in which to test how attraction develops. This is because during dating interactions people are likely to exchange a broad variety of facial expressions and gestures, and during this process, their attraction towards a partner also transforms (Eastwick and Finkel, 2008; Grammer, 1990). For instance, both smiling and laughing have been reported to reflect the degree of attraction one person feels for another, and furthermore to lead to reciprocal attraction (Givens, 1978; Hall and Xing, 2015; Moore, 1985; Tickle-Degnen and Rosenthal, 1990). Similarly, friends and lovers implicitly mimic each other's nonverbal behavior such as eye gaze and facial expressions, and this type of matching behavior has been proposed to be a key ingredient fostering liking and attraction (Chartrand and Bargh, 1999; Chartrand and van Baaren, 2009; Farley, 2014; Guéguen, 2009; Lakin and Chartrand, 2003; Stel and Vonk, 2010; Van Baaren et al., 2009). Nevertheless, while smiling is considered to signal affiliation, it *can* have different meanings. Research demonstrates that people smile to show subordination (Hecht and LaFrance, 1998), to gain approval (Cashdan, 1998), or to express embarrassment (Goldenthal et al., 1981). Likewise, prolonged gazing (Givens, 1978; Hall and Xing, 2015; Montoya et al., 2018) or the tendency to look away has both been reported as signs of affection (Goffman, 1977). Perhaps this is why research has been unable to reliably detect non-verbal signals of attraction (for review see Montoya et al., 2018). Nevertheless, if a “gut feeling of connection” truly exists (beyond perceiver’s projection of infatuation by perceiver onto the other), there must be a physical manifestation of interpersonal attraction in the real world of behavior.

One possibility is that the feeling of attraction between people is achieved on a physiological level not easily observed or detected. According to the Somatic Marker Hypothesis, emotional reactions have strong somatic components (Damasio, 1996). These somatic components mark the occurrence of important events through a parallel somatic/visceral response. In return, bodily information provides feedback perceived as a “gut feeling” that shapes a perceiver’s cognition and behavior. In this way, physiological responses can potentially contribute to social perception and provide input for romantic decisions. In line with this hypothesis, recent advances in methodologies have begun to uncover that during social encounters, partners tend to synchronize on physiological levels (Palumbo et al., 2017; Reed et al., 2013). This type of subconscious synchrony is reflected in the correlation between people's continuous measures of autonomic nervous system such as heart rate and skin conductance (Palumbo et al., 2017). Crucially, in established couples the level of synchrony has been associated with the amount of time couples have spent together (Papp et al., 2013), the ability to identify the emotions of one's partner (Levenson and Ruef, 1992), and their romantic satisfaction (Helm, Sbarra, & Ferrer, 2014; J. Helm, Sbarra, & Ferrer, 2012; Levenson & Gottman, 1983). The *function* of physiological synchrony is not well understood, but similar to motor mimicry (e.g. facial expression mimicry), it may help people to emotionally align (de Waal and Preston, 2017; Procházková and Kret, 2017). Specifically, physiological synchrony might be a result of the biologically mediated tendency to adapt to incoming social information (Hasson et al., 2012; Procházková and Kret, 2017). Through subtle changes in the face and body, changes in physiological arousal can become visible to others, allowing physiological synchrony to emerge. Physiological synchrony also seems to increase with familiarity and during intimate moments such as direct eye contact (McAssey et al., 2013) and touch (Chatel-Goldman et al., 2014). Taken together, prior literature agrees that physiological synchrony might be a precursor to deeper emotional understanding (Chatel-Goldman et al., 2014; Levenson and Ruef, 1992). Yet, what does physiological synchrony really predict? Is it that couples who feel closer to each other synchronize more? Or does synchrony predict moment-by-moment affective exchanges that are predictive of the quality of that interaction? We elaborate on this theory further and hypothesize that this type of affective alignment might be particularly meaningful for early romantic development.

Taken together, the current literature suggests that attraction emerges from the dynamic exchange of verbal and nonverbal signals (Givens, 1978; Gonzaga et al., 2001; Hall and Xing, 2015), yet the necessary empirical and analytic tools to directly address this hypothesis were not available until recently. Consequently, a direct link between nonverbal behavior, physiology, and attraction has never been directly verified. To define what drives the feeling of attraction, we built a dating lab outside of the regular laboratory setting, at different social events, where meeting a new person is most natural (Fig. 1). Males and females (140 participants), who had never met before, entered the dating cabin and sat at a table. A visual barrier initially occluded their view of each other, but then opened for three seconds, allowing them to form a *first impression* of their partner. The barrier then closed and subjects rated their partner on attraction (0 – 9-point scale). This baseline measure of initial attraction was then followed by one *verbal* and one *nonverbal* interaction of 2 minutes each (the order of which was counterbalanced). After each interaction, the barrier closed and subjects rated their partner on the same scales again. At the end of the experiment, participants could decide whether they wanted to go on another date with their partner.

The benefit of a blind date is that we can observe how attraction between newly introduced partners develops over time and therefore study the relationship between attraction and synchrony in a controlled way. We anticipated *(a)* that dating partners would synchronize on multiple levels of expression including motor movements (facial expressions, nodding, gestures), gaze (face-to-face contact and eye-contact), and physiology (synchrony in heart rate and skin conductance). Although each of these modalities has different characteristics and the literature uses a variety of terms to describe them (“mimicry”, “physiological linkage”, “gaze reciprocity”), for consistency we will refer to the various forms of mirroring as *“synchrony”*. We further hypothesized *(b)* that the strength of heart rate synchrony and skin conductance synchrony would be predictive of attraction over the course of the date. This carefully designed set-up had several other advantages: First, a blind date setting is a stressful context that likely induces strong physiological reactions, which is a desirable state for physiological synchrony measures. Furthermore, introducing verbal and nonverbal conditions allowed us to separate the influence of nonverbal expressions from verbal expressions on attraction. Finally, thanks to the combination of multiple measures and the longitudinal aspect of our study, we could go beyond investigating the putative link between synchrony and attraction (i.e., a between-dyadic effect). Specifically, we were able to investigate whether dyads that increased in synchrony over the course of their date became more attracted to each other (i.e., within-dyad effect predicting attraction over time). To our knowledge this is the the first time that attraction has been studied as a dynamic construct that emerges from behavioral and/or physiological synchrony. For an overview of the collected measures, see Figure S1.

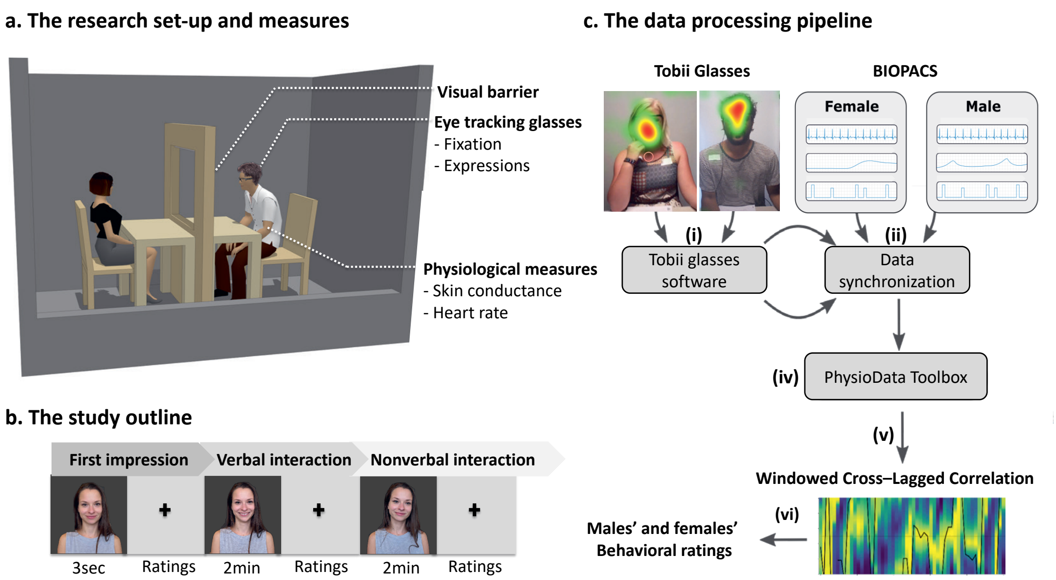


Figure 1. (a) The experimental set-up was situated in a habitable container. Inside the cabin, there was a table with two chairs on opposite sides. A white barrier with a fixation cross was placed in the middle of the table, preventing the dyad from seeing each other and controlling the dating interaction types. Participants were instructed to remain silent until they heard pre-recorded instructions via a speaker. Throughout the experiment, Tobii eye-tracking glasses measured subjects' gaze fixations and expressions while participants' physiology was recorded with two BIOPACs. **(b) Experimental outline.** To collect baseline physiological measures, participants looked at the fixation cross on the closed barrier for 30 seconds. The barrier opened for three seconds and participants saw each other for the first time (first impression). After that, the barrier closed and post-first impression physiological measures were collected during another 30 second fixation period. Subsequently, participants rated their partner on attraction. Two additional interactions followed, each preceded by 30 seconds closed barrier baseline (the barrier closed). During verbal interaction: the visual barrier opened and participants were instructed to talk freely with their partner for 2 minutes. During nonverbal interaction: participants were instructed to look at each other without talking for 2 minutes. After each interaction, the barrier closed and subjects rated their partner on the same scales. The order of verbal and nonverbal interaction was counterbalanced **(c) Pre-processing pipeline.** (i) Two groups of independent coders rated behavioral expressions, and mapped eye gaze fixations on pre-selected areas of interest. (ii) Gaze fixations and expressions were time locked and synchronized with physiological measures (heart rate, skin conductance) using customized scripts. (iii) Video visualizations were created. (iv) The physiological data were further pre-processed with our PhysioData Toolbox (Elío Sjak-Shie, 2018) and down-sampled to 100 ms windows for further (v) Windowed Cross-Lagged Correlation analyses (Boker et al., 2002) before they were (vi) regressed with attraction ratings.

Results

Hypothesis 1: Is there evidence for synchrony?

The first hypothesis predicted that dating partners would synchronize on multiple levels of expression including motor movements, gaze, and physiology. Specifically, we expected that if one of the individuals often shows one type of behavior (e.g., look long into a partner's eyes, smiles, or displays an increase in physiological arousal), his/her partner would also show the same behavioral responses. In the first analysis, we tested for evidence of associations between partners' expressions with a series of Spearman's rank–order correlations in which we included all females' motor movements (frequency of facial expressions, nodding, gestures), duration of eye gaze (i.e., looking at partner's eyes, face or body), and physiological responses (heart rate and skin conductance), and correlated them with expression measures of their male partners. This resulted in a correlation matrix (Figure 2). The circled cells in Figure 2 highlight the synchrony types between male and female partners, which were the main focus of this analysis. The additional cells are other between-partner associations (for the full matrix see Supplementary Figure 1a). Considering that individuals differ in their level of expressiveness, there is a certain baseline chance that partner's expressions are correlated by chance. To test for the significance of associations above random chance, in a subsequent control analysis, we paired each female with a random male whom they had not interacted with but whom had dated another female (see Supplementary Table 1 and Supplementary Figure 1b). We here focus on the results of the different synchrony types (circled cells in Figure 2) and show that for seven out of ten, the correlations between real dyads were significantly higher than the correlations in the randomly shuffled dyads (all Fisher's $z > 2.3$, $p < 0.05$). Specifically, we found evidence for synchrony of (i) smiles, (ii) laughs, (iii) head nods, (iv) hand gestures, (v) face-to-face gaze, (vi) heart rate, and (vii) skin conductance. For eye contact, gaze at partner's body and face touching, the associations were similar across real and randomly shuffled dyads (Fisher's $z < 0.1$, $p > 0.05$). Thus, these three synchrony types were excluded from subsequent analyses. To predict attraction, in the next model we zoom in on the seven significant synchrony types that we observed.

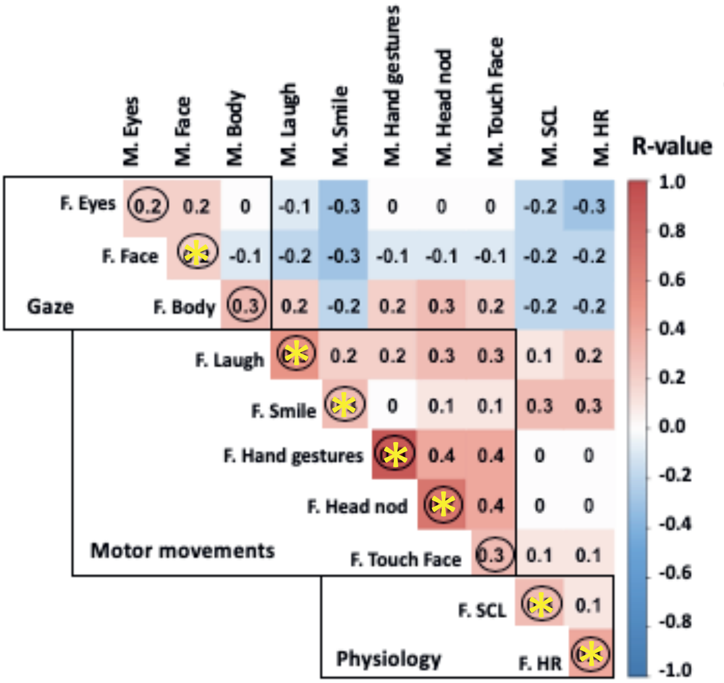


Figure 2. Correlation table summarizes the associations between real dyad's expressions, eye gaze, and physiology across three interaction time periods (based on Spearman's rank–order correlations, N = 162). The circled cells depict synchrony types between two interacting partners and other cells are other between-partner associations. The asterixis show 7 synchrony types that were significantly higher for real couples versus randomly shuffled dyads. The redder the color, the more positively correlated these variables were. The black boxes framed around naturally occurring clusters demonstrate that associations occurred on all three levels of expression including males' and females' gaze, motor movements, and physiology. F = females, M = males. HR = heart rate, SCL = skin conductance level.

Hypothesis 2: Does synchrony strength predict attraction?

As expected, attraction was not a stable construct as participants' feelings of attraction changed substantially over the course of the date. While some individuals became more attracted to their partners, others became less attracted (Supplementary Fig. 2). At the end of the date, almost half of the participants (44%) wanted to go on another date with their partner (34% females, 53% males), which is a substantial rate considering that couples were paired randomly. However, only 17% of the couples matched and had a mutual wish to date each other again.

Having confirmed our first hypothesis that people synchronized their expressions with each other across multiple levels including motor movements, gaze and physiology, our next analysis investigated whether the strength of different interpersonal synchrony types predicts attraction. To transform synchrony into binary variables (e.g., smiling or not), we calculated the proportion of time both participants' reciprocated expressions for motor movements (smiling, laughing, head nods, hand gestures) and gaze fixations (looking at partners' face). To calculate the strength of synchrony between continuous physiological signals (heart rate and skin conductance level), we used windowed cross-correlation analyses (Boker et al., 2002) (for details see Methods)**.** This resulted in seven synchrony values (synchrony in smiles, laughs, head nods, hand gestures, face-to-face gaze, heart rate, and skin conductance level) for each dyad and time-block (first impression, first interaction, second interaction). These seven synchrony types were used as predictors of attraction in a Multilevel linear mixed model. The multilevel model had the following structure: three time points (Level 1), nested in participants (Level 2). As both the attraction ratings and the synchrony measures were Level 1 (repeated-measures) predictors, the longitudinal design of the study implies that we predict the evolution of attraction by the evolution in synchrony over the course of the three-time intervals. To account for the dependency of measures within subjects, we included a random intercept effect (across participants) and a random slope for time to account for the different trajectories in attraction scores (as outlined above). Apart from different synchrony measures, to account for other variables that may influence attraction, the full model included factors of gender, a dummy variable for interaction type (verbal = 1, nonverbal = 0), a dummy variable for interaction order (verbal first: yes = 1, no = 0), and two-way interactions between interaction type * and each type of synchrony. The final model was selected with a backward stepwise selection of fixed effects. The VIF values of the full and final models were all smaller than 4, suggesting that multicollinearity did not influence our results (Gould, 2010) (for the final and full models see Supplementary Table 2 – 3)**.**

The final model showed a main effect of gender (F (1, 298) = 8.38 p = 0.004), revealing that males were more attracted to females than females were to males. Importantly, we further found that attraction was predicted by physiological synchrony between partners. Specifically, the more couples' skin conductance and heart rates synchronized, the more attracted participants were to their partner (skin conductance level: F (1, 298) = 7.33, p = 0.007; heart rate: F (1, 298) = 5.49, p = 0.020) (Fig. 3b-c). Interestingly, we did not find this association with synchrony in smiles, laughs, head nods, hand gestures, or face-to-face gaze (all Fs < 1.50, ps > 0.05; Fig. 3b-c). Moreover, the lack of an interaction between physiological synchrony and interaction type (p > 0.05) implied that physiological synchrony had a positive effect on attraction during both verbal and nonverbal interactions. In sum, these data suggest that physiological synchrony explains more variance in attraction than the synchrony of explicit expressions such as smiles, laughs, head nods, hand gestures, or face-to-face gaze.

5

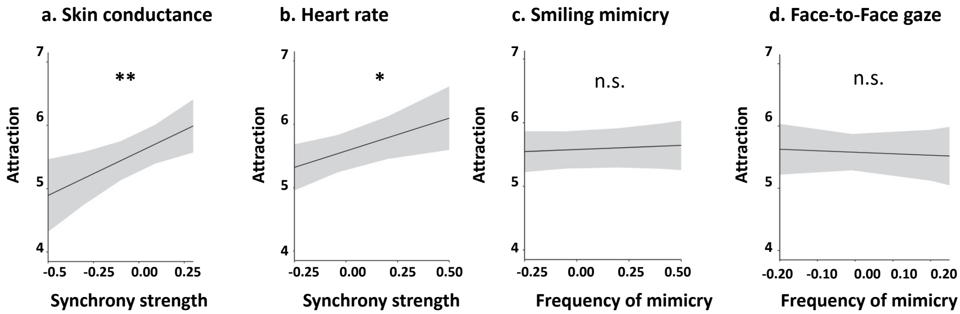
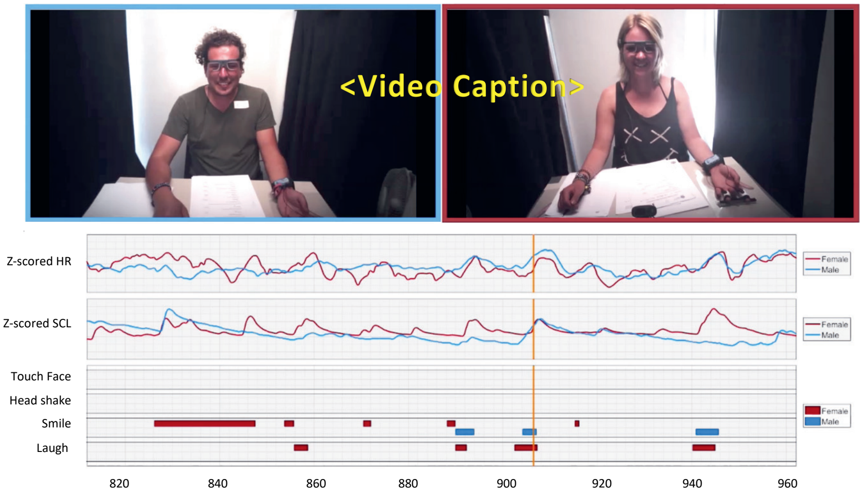


Figure 3. The line graphs represent slopes extracted from our Multilevel linear mixed model **(a)** Attraction based on the synchrony of skin conductance level [β = 1.44, SE = 0.53, CI (0.39, 2.49), p = 0.007] and **(b)** heart rate synchrony [β = 0.99, SE = 0.42, CI (0.16, 1.83), p = 0.020] **(c - d)** The frequency of smile synchrony and face-to-face gaze did not significantly affect attraction (both p > 0.05). The shaded areas represent 95% confidence intervals.

To show an example of what physiological synchrony looks like, we included a video of one couple (see Video 1). We selected this video because these two people first met without exchanging any words and, during this non-verbal interaction, their mean attraction score increased.



Video 1. An example of measures. The video shows a nonverbal interaction where participants were instructed not to talk (825 – 945 seconds). Female's and males' z-scored skin conductance and heart rate (top two rows). In four rows below selection of measured expressions is depicted (Touch face, Head shake, Smile, Laugh). In addition, gaze fixations were collected (not depicted). Notice the contagious spread of emotional information; at 886 second, the female will smile and the male partner reciprocates with a smile back. During this moment, we observe an increase in female's and males' skin conductance and heart rate. Again, at 903 second, the female laughs; in response the male smiles and we again observe synchrony in heart rate and skin conductance (highlighted by orange cursor). Although nonverbal, during this 2-minute interaction couples' physiological synchrony and attraction increased.

Additional Control Analyses

Does within or between dyad physiological synchrony predict attraction?

For a more precise examination of the effect of physiological synchrony on attraction, we conducted three control analyses. First, in the previously described model, the variables for heart rate and skin conductance level synchrony included within and between-dyad level variation in synchrony. It is therefore unclear whether couples that were highly attracted to each other synchronized more than those that were not (i.e., between-dyad effect), or whether changes in physiological synchrony over time predicts attraction changes (i.e., within-dyad effect). To disentangle the two types of variations, we computed two variables: (1) Between-dyad SCL synchrony: the averaged synchrony level across time points per dyad, and (2) Within-dyad SCL synchrony: the deviation in synchrony level (per time point) from the dyad's averaged synchrony level (within-dyad centering). Both variables were included in a Multilevel linear mixed model with a two-level structure (three-time points (Level 1), nested in participants (Level 2). We also included a random intercept effect (across participants) and a random slope for time.

5

Results clearly showed that the change in synchrony influenced the change in attraction at the within-dyad level (for both synchrony variables; heart rate: (F (1, 296) = 4.67 p = 0.031); skin conductance: (F (1, 296) = 6.23 p = 0.013), but there was no effect at between-dyad levels (Supplementary Table 4). Thus, dyads with more overall synchrony were not significantly more attracted to each other. However, it is worth noting that the effect, although non-significant, was in the predicted direction. A possible confound in this analysis is an asymmetry in variance between and within dyads, with between-dyad synchrony exhibiting greater variance than within-dyad synchrony (Supplementary Figure 4). Nevertheless, the two main effects for within-dyad SCL and HR synchrony demonstrate that the more couples became synchronized over the course of the date, the more their attraction increased. This finding is consistent with the hypothesis that moment-to-moment physiological synchrony correlates with moment-to-moment affective dynamics that are predictive of the quality of that interaction.

Does arousal predict attraction?

The fact that arousal has been linked to attraction invites the possibility that an increase in synchrony of physiological signals is required for attraction to occur. For example, increases in the level of skin conductance and heart rate may yield similar attraction changes without the need for synchrony. If true, this would mean that participants' arousal level alone may promote attraction irrespective of interindividual synchrony. To test this, in an additional control analysis we used the same Multilevel linear mixed model with the same structures as in the second analyses, but instead of heart rate and skin conductance synchrony measures, we used participants' average (baseline corrected) heart rate and skin conductance for each interaction as predictors of attraction (see Supplementary Table 5 for the model summary and more details). The results showed that attraction was not significantly explained by individuals' independent heart rates (F (1, 298) = 0.01, p = 0.955) or skin conductance levels (F (1, 298) = 0.04, p = 0.850). This result further confirms that attraction could not be solely predicted by the arousal responses of the two individuals, but by the synchrony of arousal between individuals.

Is attraction a valid outcome variable?

One may wonder whether we really measured attraction in this study or some other phenomenon. To control for this possibility, throughout the experiment we also collected other ratings including trust, liking, feeling of connection, and "click". We also asked whether subjects felt awkward or anxious. These scores were then compared with attraction ratings and participants choice to go on another date (yes/no) with the partner. The results of a principal components analysis (PCA) showed that attraction was closely correlated with positive factors (e.g. liking and connection) and negatively linked with feelings of being shy, awkwardness and low self-esteem (Supplementary Table 6-7). Importantly, among all collected ratings, the feeling of attraction was the strongest predictor of the decision made at the end of the date to date the partner again (F (1, 317) = 6.33, p = 0.012, see Supplementary Table 5 for details).

Discussion

Multiple studies have suggested that synchrony on the emotional level promotes connection and affiliation (Mogan et al., 2017), yet the mechanisms mediating the link between attraction and nonverbal communication remain unknown. In this blind date experiment, we measured a whole choreography of movements, gestures, and physiological reactions in order to understand how romantic attraction between people develops. In line with the existing literature (Chartrand and van Baaren, 2009; Palumbo et al., 2017; Procházková and Kret, 2017), we observed that people spontaneously synchronized on multiple levels of expression including: motor movements, eye gaze, and physiological responses. We further demonstrated that attraction was predicted by physiological synchrony between partners; an effect which persists regardless of whether couples were allowed to speak or were forced to remain silent. Since attraction was *not* predicted by visible expressions such as smiling, laughing, or direct eye contact, these results highlight the importance of subconscious physiological coupling in the development of romantic attraction. The current findings are particularly relevant from the perspective of our modern romantic landscape where affective exchange is reduced to quick encounters between strangers.

The finding that physiological synchrony promotes attraction between strangers supports existing theory implicating unconscious synchrony in the development of human connection (Tahhan, 2013; Wheatley et al., 2012). There are several theoretical and methodological reasons for why physiological synchrony is more strongly coupled to levels of attraction than visible mimicry or arousal level. Mimicry in a form of pure motor imitation has been found to increase liking and rapport between individuals (Chartrand and Bargh, 1999). However, especially at the early stages of dating, humans do not disclose their interest in the opposite sex too overtly (Goffman, 1977). Whereas straightforward information exchange would be more evident, research suggests that humans make handy use of a 'backdoor', which offers an option of escape when things do not progress as hoped (Grammer, 1990). For instance, while smiling and prolonged gazing has been proposed to be a sign of affection (Givens, 1978; Hall and Xing, 2015; Montoya et al., 2018), ignoring partner's gaze and looking away is often also a sign of affection (Goffman, 1977). These behavioral inconsistencies likely relate to the lack of visible synchrony effects on attraction found in this and others' experiments (for review see Montoya et al., 2018). In contrast to visible synchrony (e.g., direct copying of overtly perceived behaviors), physiological synchrony requires both partners' autonomic nervous systems to become simultaneously activated. Considering that such a response is difficult to regulate, we propose that physiological synchrony potentially captures more 'genuine emotional exchange'. In support of this theory, our data demonstrate that couples were often smiling and mimicking each other on a superficial level, yet these types of visible signals did not predict attraction (for the analysis of individual expressions see Supplementary Table 8). However, when participants' physiological signals aligned during these interactions, attraction increased (Fig. 3).

Our data revealed that attraction is not predicted by partners' frequency of expression or eye fixation duration, nor is it linearly related to participant's autonomic nervous system activity. This result suggests that synchrony shapes attraction beyond individuals' nonverbal expressions and autonomic arousal. The fact that arousal plays a role in sexual attraction has been well established (Berscheid and Wastler, 1974; Bryant and Miron, 2003). For instance, it has been found that couples who had been watching a high arousal movie engaged in more affiliative behaviors than did couples who had watched a low-arousal movie (Cohen et al., 1989). Similarly, people who just got off a roller-coaster ride perceived a photograph of an opposite-sex individual as more attractive than people who had been waiting for the roller-coaster ride (Meston and Frohlich, 2003). However, while most contemporary theories suggest that attraction is heightened by the level arousal (e.g., excitation-transfer theory (Zillmann, 1971)), the current study shows that skin conductance and heart rate baseline during dating interactions were no sufficient predictors of interpersonal attraction while the increased synchrony of these signals was. These results imply that attraction is not as much of an arousal response as the ability of two people to put each other in a similar physiological state (ease/or excitement). Indeed, while many social interactions require effort to reach mutual understanding, when we experience the feeling of a "click" or "mental connection" with someone, it often feels effortless.

One thing that merits discussion is the role of synchrony in romantic relationships. Although at this stage, the direction between physiological synchrony and attraction is unclear (synchrony may cause attraction or vice versa), we propose that the ability to synchronize with others allows humans to embody the affective experiences of others. This proposal is in line with the emotional contagion theory (Hatfield et al., 1993) and the Somatic Marker Hypothesis (Damasio, 1996). The underlying mechanism of physiological synchrony is not fully understood but it has been suggested that large spindle shaped neurons located in the fronto-insular region of the brain (present in humans and great apes) may be involved in processes that are underlying complex social interactions (Allman et al., 2010). Through sympathetic and parasympathetic innervations, the insular (INS) and anterior cingulate cortex (ACC) mediate emotion-related motivation, which is often perceived as a bodily sensation (Mayer, 2011). The concept of embodied emotions is closely related to the 'somatic marker' hypothesis (Damasio, 1996) or to the concept of interoceptive memories (Critchley, & Garfinkel, 2018). As people perceive another person's smile, blush, or pupil dilation, their homeostatic reflexes at the level of INS and ACC can be triggered while viewing affects expressed by another individual. This way, people can emotionally and physiologically align. Therefore, ones' 'gut feeling' about others can be defined as the rapid assessment of the probability of a favorable or unfavorable outcome based on somatic experiences (Damasio, 1996). However, since the assessment of others' behavior is dependent on previous experiences rather than on serial processes of inductive/deductive reasoning (Mayer, 2011), a social signal that is perceived as pleasant by one person may trigger unpleasant feelings in another person.

In support of this theory, seminal studies with married couples measured physiological synchrony while couples argued (negative affect). In these experiments, physiological linkage was associated with lower marital satisfaction and higher chance of a divorce (Levenson and Gottman, 1985, 1983). In contrast, in the current study, couples were voluntary on a date, which is generally a positive experience. Consequently, physiological synchrony was predictive of positive affect – attraction. This result aligns with prior research suggesting that physiological linkage can be either good or bad, depending on the environmental context (Helm et al., 2014). Moreover, from a methodological perspective, the reason why physiological synchrony might be a better predictor of interpersonal attraction than physiological arousal is that interindividual metrics might be better suited to capture/normalize physiological patterns. Recently, research has begun to demonstrate that the unified nature of conscious experience consists of temporally interleaved and highly selective activations in the central nervous system (Hasson, Nir, Levy, Fuhrmann, & Malach, 2004). While skin conductance level and heart rate responses lack specificity (high arousal can be both pleasant or unpleasant), by tracking the stream of physiological signals between two interacting partners, physiological synchrony incorporates information regarding affective reciprocity. In this way, physiological synchrony provides deeper insights into human interactions than the level of arousal alone. These findings are particularly relevant if we consider the rapid change in our modern dating culture. With the rise of online dating, the pool of potential partners has substantially grown (50 million people date online today, (Iqbal, 2019)), and dating has become a fast and controllable process. We propose that future studies could use modern divides (wireless watches collecting physiology, mobile apps) to assess this nonverbal form of communication. Further understanding of these processes may shed light on the mechanisms by which humans relate to each other during real life interaction in their everyday natural environments.

In sum, thanks to the unique combination of measures (videos, eye-tracking, and physiological measures), we were able to visualize the contagious spread of emotional information that already emerges during first encounters. Our findings suggest that when interacting partners' subconscious arousal levels rise and fall in synchrony, mutual attraction emerges. Crucially, our findings imply that, on the dyad's levels, the interacting partners' physiological states sync into mutual alignment on a moment-by-moment basis. During these moments, a joint mental state potentially facilitates the feeling of a "click" and attraction. By knowing that physiological synchrony is involved in early romantic development, these data reveal a fundamental mechanism by which an individual's emotional displays trigger neurophysiological responses in others.

Methods

Participants

Our sample size was motivated by those used in previous studies (Levenson and Gottman, 1983; Reed et al., 2013; Thomsen and Gilbert, 1998). In total, 140 participants were recruited (70 opposite-sex dyads). Participants' age ranged from 18 to 37 years old (Male: M = 25.71, SD = 4.639; Female: M = 23.45, SD = 4.265). Participants were recruited at three different yearly events in the Netherlands: during Lowlands (a music festival that takes place in the city of Biddinghuizen), The Night of Arts and Science (a festival that brings art and science together in Leiden), and during InScience (a science film festival in Nijmegen). To participate in the experiment, participants had to be single, between 18 and 38 years old, had to have normal vision or vision corrected by contact lenses (normal glasses could not be worn underneath the eye tracking glasses). Furthermore, participants could not have or have had any psychological illness, use medication, or be undergoing psychological treatment.

Using a digital 1PC alcohol tester we made sure to only include participants who did not exceed a blood alcohol content of 220 micrograms of alcohol per liter of exhaled breath (Dutch driving limit). For the behavioral analysis, one dyad was excluded because they were part of camera crew and their interaction was recorded, in another dyad the male left the experiment prematurely; leaving 69 dyads included in the behavioral analysis. For the physiological analysis an additional 15 dyads were excluded due to artifacts or missing physiological data, meaning that 54 dyads were included in the physiological analysis. Participants were mostly Dutch (92%), highly educated, seventy-three percent of the subjects used dating applications (e.g., Tinder, Bumble, Happn) both males and females were looking for a committed relationship (see Supplementary Table 9). At the end of the study, out of 138 people, in total 58 people (44%) wanted to date their partner at the end of the date (34% females, 53% males) from which eleven couples matched (17%), five people did not report. Furthermore, twenty couples (31%) mutually agreed on not being a good match for each other and in half of the couples (52%) one partner wanted to date their partner but the other did not reciprocate. There were no significant differences between males and females in their level of social anxiety, positive/negative affect, or score on the social desire scale (Supplementary Table 10). The experimental procedures were in accordance with the Declaration of Helsinki and approved by the Ethical Committee of the Faculty of Behavioral and Social Sciences of Leiden University (Number: CEP16 - 0726/258). All participants provided informed consent.

Procedure

Baseline measures. Participants were screened for exclusion criteria, received information about the study and gave informed written consent. Subjects were then asked to fill out some questionnaires to control for psychological factors that could influence a person's ratings of their partner or the general behavior during social interactions (see Materials). In addition, participants filled out baseline ratings reporting on participants' expectations and standards (e.g. how attractive, intelligent, trustworthy and funny their potential romantic partner should be). Subjects also rated themselves on the same items on the 10-point scales. Two researchers (one for male, one for female participants) attached electrodes measuring heart rate (HR) and skin conductance (SC) to participants' skin. They also helped participants to put on the eye-tracking glasses, which were calibrated afterward. Without seeing their partner, participants were led to the dating cabin, females first and after calibration of her equipment, the male partner followed. Upon eye-tracking and skin conductance calibration, participants were instructed to look at the fixation cross (at the closed barrier), while their baseline (30 seconds) physiological measures were collected. Cameras in the glasses recorded video and sound over the whole period of the dating experiment. Participants were instructed to remain silent until they heard instructions via a speaker.

First impression. The screen then opened shortly (3 seconds), giving participants a first impression of their partner. After the first impression, participants looked at the fixation cross for 30 seconds to collect post-first impression physiological measures after which they rated their partner on the same (0 – 9) scales as they rated their imaginary or potential romantic partner during baseline. In addition, participants were asked to rate how much they liked their partner and how much they thought their partner liked them. Other questions included how similar they thought their partner was in terms of personality and how much connection, 'click', and sexual attraction they felt between them. After the first impression, two additional interactions would take place (the order of which was counterbalanced).

Verbal interaction. The visual barrier opened and participants were instructed to talk freely with their partner for 2 minutes. After this interaction, the participant was asked to fill in the same scales as during the first impression, plus rate their impression of the verbal interaction.

Nonverbal Interaction. The visual barrier opened and participants were instructed to look at their partner and not speak for 2 minutes. Afterward, the barrier closed and subjects rated their partner on the same 0 – 9 point scales. Whether participants began with verbal or nonverbal interactions was counterbalanced (Fig. 1b). During the final ratings, participants indicated how much they thought the other person liked them and whether they wanted the experimenters to exchange their email addresses. The pairs were also asked to predict whether they thought their partner wanted to exchange their email addresses and go on another date. Finally, subjects were asked to indicate whether their video recordings could be used for follow-up experiments.

Follow-up. For ethical reasons, participants' decisions to date their partner again or not were not revealed until the festival was over. Only if both of them agreed to exchange contact information, one week after the study they received an email with their partner's email address. They were asked if we could contact them again later to ask if they were still in contact with their partner.

Measures

Ratings. Participants filled in ratings before the experiment, after the first impression and after both the verbal and nonverbal interactions. All questionnaires included the same questions about the partner (or during baseline about a potential partner) in which the participant rated: attraction, funniness, intelligence, trustworthiness, the similarity in personality, connection, sexual attraction, and click, on scales ranging from 1 (not at all) to 9 (very). Additionally, during baseline, participants had to indicate how attractive, funny, intelligent and trustworthy they thought they themselves were (0 – 9 scales). Every questionnaire also contained a mood grid, in which participants had to indicate their level of arousal and valence of their affect. Subjects also rated how shy, awkward, and self-confident they were feeling. Furthermore, every questionnaire (except during baseline), included a question asking how much they liked the partner, and how much they thought their partner liked them. Finally, during the first impression and during their last interaction, participants indicated whether they wanted to see their partner again and whether they thought their partner wanted to see them again. As additional control measures for mood and sexual desire, we included the Liebowitz Social Anxiety Scale (Liebowitz, 1987), Positive and Negative Affect Schedule (Watson et al., 1988) and Sexual Desire Inventory (Spector et al., 1996) (see Supplementary Table 10).

Pre-processing

Behavioral expressions coding. The eye-tracking glasses automatically detected eye-fixations and videotaped participants' behavior. Four independent raters (two raters for males and two for females) rated participants' expressions (smiling, laughing, head nod, hand gestures, face touching) using the Tobii Pro Lab (Version 1.5, 5884). The tapes were coded without sound and coders were blind to participants' ratings. The facial expressions were coded per tenths of seconds and the frequency of each expression was then averaged per interaction (lasting between 3 seconds – 120 seconds). The reliability then was calculated as percentage of agreement between recoded observations. All coders had successfully completed training and reached an agreement ratio of at least .70 for all behaviors, except for the open versus closed body position (agreement was less than 0.7); thus, this particular behavior was dropped from all analyses.

Eye gaze fixations classification. Eye fixations were recorded using Tobii Pro Glasses 2. We defined areas of interest (AOI) including the head, face, eyes, nose, mouth, body, right arm, left arm and background. AOIs were drawn on snapshot images of participants taken at the start of each interaction (size in pixels: 1079 x 605). Eye gaze fixations were then automatically mapped onto the areas of interest (partner's face and body) using the Fixation Classification Method implemented in Tobii Pro Lab (Version 1.5, 5884). The I-VT (Attention) filter (Velocity-Threshold Identification Gaze Filter) was selected to handle eye-tracking data from the glasses recordings conducted under dynamic situations. Same as with facial expressions, the fixations were collected per tenths of seconds for each AOI. This resulted in AOI visit duration (0 excluded). Prior to each interaction, we checked whether the eye-tracker needed recalibration or not. To do so, we asked participants to focus on the fixation point at the barrier. In case the eye fixation did not overlay the fixation cross, we re-calibrated. In the post-experiment pre-processing stage, we calculated the remaining small differences in the x and y coordinates between the glasses' fixation and the fixation cross. The AOI masks were moved with the small differences on the respective x and y coordinates.

Physiological measures. For each participant, ECG and EDA data were collected using BIOPAC's ECG2-R and PPGED-R modules, respectively, and an MP-150 system operated using AcqKnowledge software version 3.2 (BIOPAC, Goleta, CA). All raw signals were recorded at 1000 Hz.

Skin conductance level pre-processing. Two electrodes were attached on the intermediate phalanges of the index and ring finger of the non-dominant hand. Using the PhysioData Toolbox, the raw skin conductance signal was visually inspected and short-duration artifacts were removed and replaced using linear interpolation (maximum interpolation duration was 2 seconds). Longer invalid sections of data were excluded. The skin conductance signal (SC) was then low-pass filtered at 2 Hz to remove high-frequency noise, and for each section of interest, down-sampled to 10 Hz for further analysis.

Heart rate pre-processing. Similarly, the PhysioData Toolbox was used to extract 10 Hz continuous instantaneous heartrate (IHR) signals from the raw ECG signal. This involved bandpass-filtering the raw signal at 1 to 50 Hz, performing peak detection to find the R-peaks, and calculating the interbeat intervals (IBIs). Both the R-peaks and resulting IBIs were visually reviewed, and erroneously derived instances of any of the two were removed. The IHR signal, in BPM, was then generated from the remaining IBIs using piece-wise cubic interpolation (maximum interpolation duration was 2 seconds). Trials (participants' interaction segments) with less than 30% coverage of the sum of the IBIs relative to the duration of the time signal were excluded**.** Participants missing more 50% percent of the IBIs were excluded.

Analysis

Analysis 1. We ran a correlation between all measures. This resulted in a large correlation table showing associations between male's and female's expressions eye fixations and physiological measures as well as associations between female's-female's, male's-male's showing how nonverbal behaviors and physiological responses relate to each other within participants. Then in a control analysis, each female was paired with a random male. To test for significance, we compared correlations coefficients between true couples and randomly matched couples with the cocor package in R studio (Diedenhofen and Musch, 2015) using gender as an independent group, two-sided test with alpha set to 0.05.

Quantifying expressive mimicry and eye fixation synchrony. Mimicry is defined broadly as 'doing what others are doing'. While some studies are very loose on their definition of mimicry (for instance, mimicry might be defined as any movement following the other person's movement (Fujiwara and Daibo, 2016; Tschacher et al., 2014)), we adopt a stricter definition of mimicry where mimicry occurs when person A (directly or within a short time window) shows the same expression as person B. We quantified mimicry for each dyad and interaction by calculating the proportion of time both participants' directly reciprocated expressions (smiling, laughing, head nods, hand gestures, face touching) and gaze fixations (looking at partners' head, eyes, face, body). The proportion of mimicry was calculated for each condition (the first impression, verbal and nonverbal interaction) resulting in N dyads * 3 results * for mimicry in smiles, laughs, head nods, hand gestures, eye-to-eye fixations.

Quantifying physiological synchrony. We conducted a lagged windowed cross correlation analysis to quantify physiological synchrony for the heart rate and skin conductance level measures separately (Boker et al., 2002). The objective of this analysis was to calculate the strength of association between two time series while taking into account the non-stationarity of the signals and the lag between responses, that is, to consider the dynamics of a dyadic interaction. Non-stationarity is accounted for by breaking down the time series into smaller segments and calculating the cross-correlation of these segments, allowing the correlation to change throughout the time series. A more detailed description of the analysis can be found in the Supplementary Material ("Quantification of physiological synchrony"). Based on this analysis, we obtained a measure of the strength of synchrony for each interaction per dyad.

*Analysis 2***.** We here investigate whether attraction can be predicted by synchrony. In this analysis, we used Multilevel linear mixed model to investigate how different types of interpersonal synchronies impact on participant's attraction ratings (0-9). The multilevel model had the following structure: three time points (Level 1) nested in participants (Level 2). Note that we did not consider dyad as a separate third level, as we found little variation in attraction at the dyad level. We also included a random intercept effect (across participants) and a random slope for time, but not allowing a correlation between both random effects. The time variable was specified on continuous scale (as participants displayed (more or less) linear trajectories over time in attraction. The slope for time indicated the evolution of attraction over time. In the model, we included all 7 synchrony predictors including synchrony in (i) smiles, (ii) laughs, (iii) head nods, (iv) hand gestures, (v) face-to-face gaze, (vi) heart rate, and (vii) skin conductance. The full model further included factors of gender, the type of interaction (verbal, nonverbal), the order of interaction (verbal/nonverbal first), and two-way interactions between type of interaction * all synchrony types (smiles, laughs, head nods, hand gestures, face-to-face gaze, heart rate, and skin conductance). The final model was selected with a backward stepwise selection of fixed effects. This method first tests interaction terms, and then drops interactions one by one to test for main effects. All predictors were centered. To check that multicollinearity would not confound our results, we calculated the variance inflation factor (Kohavi, 1995).

For details regarding control analyses see Supplementary Materials.