The choreography of human attraction: physiological synchrony in a blind date setting

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Abstract

Humans are social animals whose well-being is shaped by the ability to attract one another and connect with each other. To determine what drives attraction, we measured the physiological dynamics between people during real-life dating interactions outside the laboratory, where it 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 females were more expressive than males, while males looked longer at females. Crucially, visible signals that can be controlled, such as facial expressions or gaze, did not predict attraction. Instead, attraction was predicted by synchrony in heart rate and skin conductance between partners, which is unconscious and difficult to regulate. Our findings suggest that shared emotionality is vital for mutual attraction. Moreover, physiological synchrony may provide a medium for translating visible expressions into embodied emotions, which can turn into intentions via somatosensory simulation.

Introduction

In the past decade, we have witnessed rapid changes in the modern dating culture. With more than 50 million people dating online, of whom 80% are looking for a serious relationship, and more than 1.5 million Tinder dates per week[1], online dating has become a cultural force that shapes the way our generation interacts with and relates to each other[2]. In consequence, three main vicissitudes have occurred: First, in contrast to previous generations, dates are happening largely between strangers. Second, dating decisions are made upon short interactions. Third, the access to many potential partners upsurges the difficulty to choose one partner. In the social realm, this global phenomenon can be placed in the context of an even broader fundamental puzzle: In the world of vast dating possibilities, *what defines attraction and true connection between people?* We took a data-driven approach to answer this question. In this blind date experiment, we used state of the art technology including eye-tracking glasses linked to physiological measures combined with machine learning[3,4] and windowed cross-correlation techniques[5] to track a whole choreography of movements, subtle expressions and physiological reactions to predict sexual attraction between people.

Physical attractiveness is often valued as one of the most important characteristics of a potential partner[6]. Yet, research demonstrates that judging a potential romantic partner based on a photo does not predict how attractive this person will be rated after a social interaction[7]. In a social situation, apart from verbal information, a variety of dynamic features such as changes in pupil size, gaze directionality, facial expressions, and gesticulations are continually exchanged between individuals, shaping their perception over time. For instance, both smiling and laughing have been reported to reflect the degree of attraction to the other person, and subsequently cause the other to be attracted to the person expressing the smiles and laughter[8–10]. Similarly, head nods and open body postures are associated with more self-reported feelings of love among newly met and long-term committed relationship partners[11–13]. In addition, dominant body posture, direct eye contact[8,14,15], increased skin conductance and heart rate responses have all been linked to the perception of more attractive, opposite-sex targets[16–18].

Intriguingly, people are often unaware of being influenced by other's affective displays. This is evident from studies showing that friends and lovers implicitly mimic each other's nonverbal behavior, such as gaze and facial expressions[19–21]. Remarkably, a series of recent studies demonstrated that committed romantic partners synchronize their heart rate and skin conductance and that the level of synchrony was positively associated with the quality of relationship emotional ties, such as the amount of time spent together and the ability to identify the emotions of one's partner[22–24]. Contemporary theories propose that behavioral and physiological synchrony results from the biologically mediated tendency to adapt to incoming social information[25–27]. Specifically, during an interaction individuals continuously exchange information via verbal and non-verbal routes. During this process, the sensory receptors convert vibrational energy from the partner's face and body to electrical impulses that the brain then uses to acquire social and emotional information[27,28]. A recent fMRI study showed that the human brain possesses a neural mechanism, which attracts individuals to partners whose affective nonverbal behavior they can easily understand[29]. From this point of view, emotional expressions that people display do not only communicate emotions – they embody human feelings, build social bonds and promote attraction.

Given the strong link between the human body and attraction, from a theoretical[30] and empirical perspective[14,31,32], it should be possible to decode attraction purely by behavioral and biological means. Specifically, certain behavioral and physiological patterns may predict sexual attraction between people. To test this hypothesis, we built a dating lab outside of the regular laboratory setting, at different social events, where meeting a new person is most natural (Fig. 1a). Males and females (N = 140), 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 was 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. At the end of the experiment, participants could decide whether they wanted to go on another date with their partner and also indicate whether they thought their partner wanted to date them. Furthermore, throughout the date, we tracked subjects' expressions and the durations of gaze fixations with eye-tracking glasses and measured their heart rate and skin conductance with electrodes.

A dating experiment provides an excellent scenario to test how people infer other's internal states. This is because during dating interactions, people are likely to exchange a broad variety of facial expressions and gestures, in order to make inferences about a partner's romantic intentions. The first aim of this study was to test how accurate people are at predicting whether or not a partner wants to date them. The second aim was to define which behavioral or physiological displays predict attraction. While the first and the second aims focus on how to detect attraction on the individual level, we mainly hypothesized that attraction might be a matter of synchrony *between* individuals. Although both behavioral and physiological synchrony have been linked to emotional alignment, the mechanistic evidence linking these processes is still missing. Thus, the third aim was to study attraction as a dynamic construct that emerges from behavioral and/or physiological synchrony.

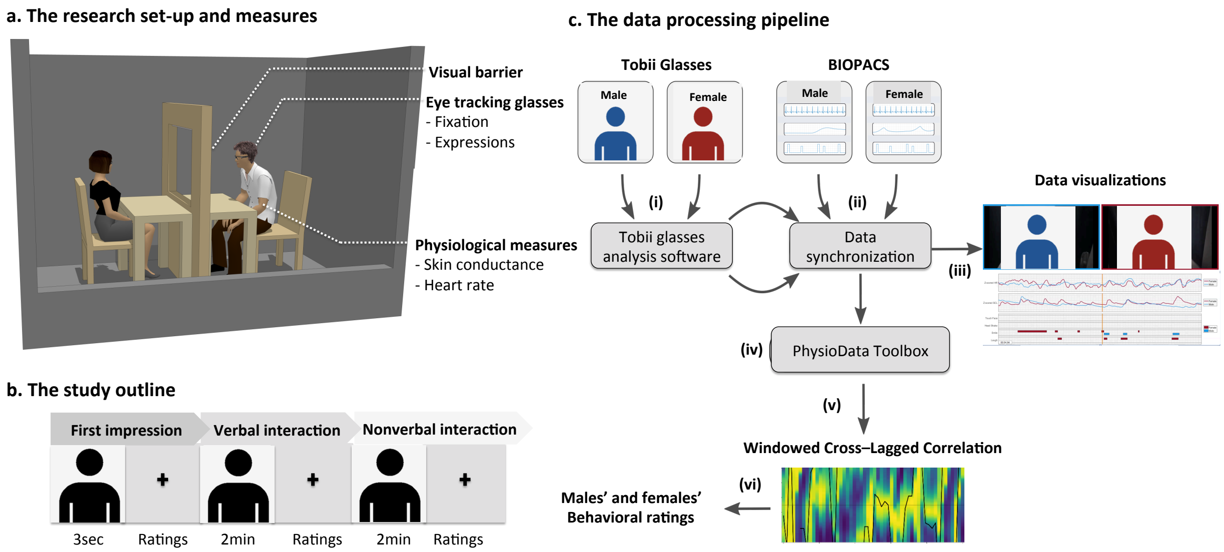

Figure 1. (a) The experimental set-up was situated in a habitable container. Inside the cabin, there was a table with two chairs on opposite sides. A white barrier with a fixation cross was placed in the middle of the table, preventing the dyad from seeing each other and controlling the dating interaction 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 0 – 9 point scales regarding attraction and liking (see methods). Two additional interactions followed, each preceded by a 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 0 – 9-point 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 [33] and down-sampled to 100 ms windows for further (v) Windowed Cross-Lagged Correlation analyses [5] before they were (vi) regressed with attraction ratings.

Results

How accurate are people at predicting their partner's romantic interest?

To test participants' ability to predict partners' romantic interest, we asked subjects at the end of the experiment whether they thought their partner wanted to date them again (yes/ no). Surprisingly, only about half of the subjects (54%) correctly predicted their partner's answers, which means participants' accuracy was at chance level ($\chi^2(1) = 1.06$, $p = 0.30$, females: 56%, male: 51%, Fig. 2a). We further tested whether participants' impression of being liked relates to their attraction towards their partner. Specifically, we asked participants two questions: How attractive is your partner? How much do you think your partner likes you? The results of a Multilevel mixed effect model with gender and partner's attraction as predictors revealed that the more males and females were attracted to their partner, the more likely they were to think that their partner was more attracted to them ($F(1, 402) = 64.55$, $p < 0.0001$, Fig. 2b and Supplementary Table 1). Yet, in reality, there was no association between how much participants were attracted to their partner and how much the other was attracted to them ($F(1, 402) = 0.135$, $p = 0.71$, Fig. 2c). These data imply that, contrary to common belief, people are in fact not very accurate at reading a partner's romantic intentions. Moreover, participants' impressions of being liked seemed to be biased by participants' attraction to their partner (and vice versa). In the next analyses we therefore tested whether participants' facial expressions, eye fixations and physiological responses are more reliable predictors of interpersonal attraction than participants' judgment.

Is there a specific behavioral or physiological pattern that predicts attraction?

The results obtained from a Multivariate generalized linear mixed model (see Supplementary Table 2) revealed gender differences in naturally occurring expressions, eye fixations and physiological responses ($F (11, 98) = 4.06$, $p < 0.0001$; Pillai's Trace = 0.34, Partial Eta = 0.34). Figure 2d shows that females were significantly more expressive than males: females smiled, nodded and touched their face more frequently than males did (all *p*s < 0.01). Males, on the other hand, stared at their female partner more; they fixated at the female's head and eyes significantly longer than females looked at them (all *p*s < 0.01, Fig. 2e). In a control analysis we found that females had a tendency to look around and fixate longer at the background than males did ($p = 0.025$, Supplementary Fig. 1). This suggests that, during dating interactions, females are more expressive than males, while males gaze at females more firmly. Moreover, females' heart rate ($F (1, 108) = 5.39$, $p = 0.002$) and skin conductance responses ($F (1, 108) = 9.68$, $p < 0.0001$) were higher than males' (Fig. 2f). In line with this observation, throughout the date, females reported to feel more "aroused" and less self-confident than men (all *p*s < 0.01; Supplementary Table 3-4). In summary, females tended to be more expressive than males, while males stared at women more. Furthermore, females were more physiologically and cognitively aroused while men reported to be more self-confident.

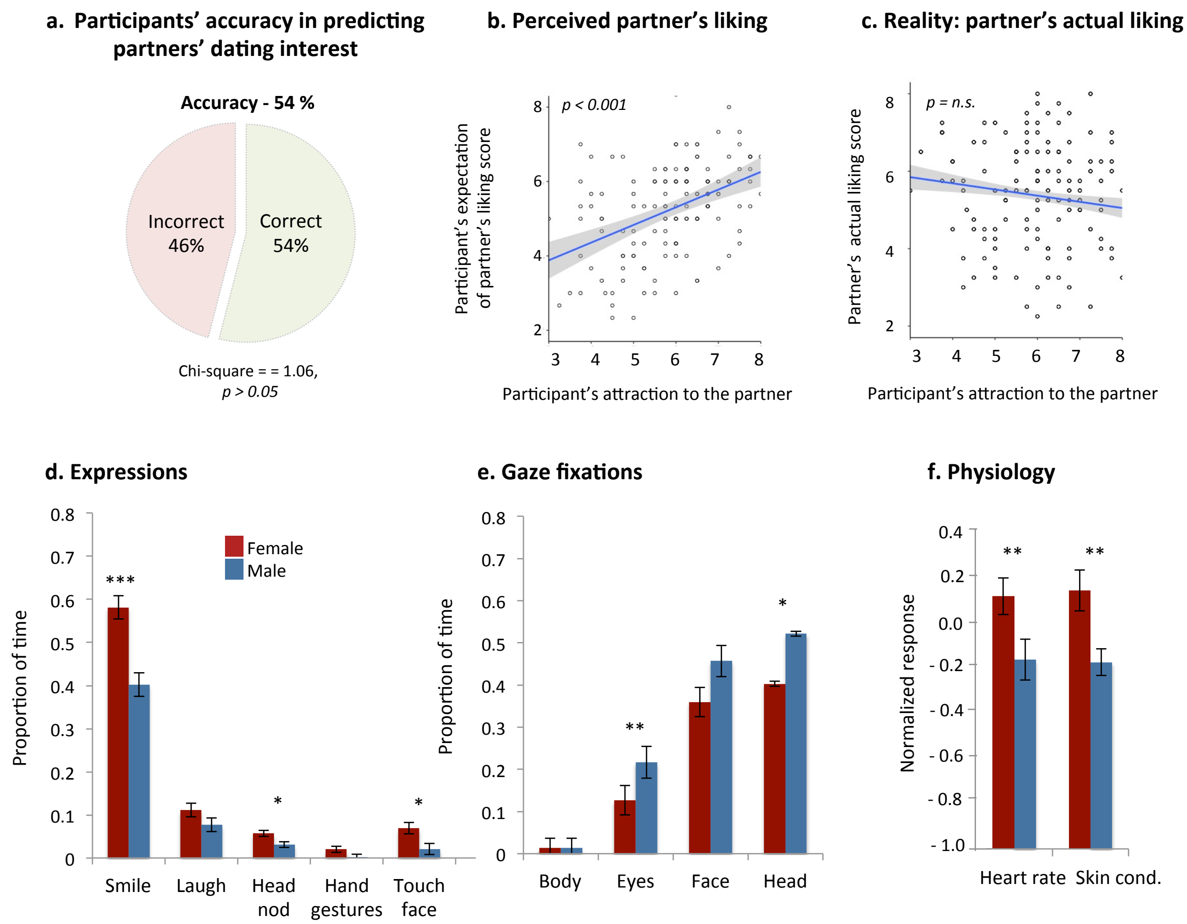

Figure 2. Behavioral and physiological results. (a) Pie chart shows the percentage of participants' accuracy in predicting whether their partner wants to date them or not (binary decision, N = 138 couples): 74 people were accurate (54.4%), 62 people were inaccurate (45.6%); four people chose not to report. **(b)** Scatter plots show that the more participants were attracted to their partner, the more likely they were to think that their partner was more attracted to them (ratings are averaged across all three interaction types (β =0.45, p <0.0001). **(c)** In reality, there was no association between how much participants were attracted to their partner and how much the other was attracted to them (β = -0.16, p =0.135). Shaded areas represent 95% confidence intervals. Bar graphs represent gender differences in the proportion of time males and females displayed specific **(d)** expressions, **(e)** gazed at specific areas of interest and **(f)** average heart rate (HR) and skin conductance responses (SCR) across the three interaction types; physiological responses were normalized by baseline correction and z-transformation. All $**p <$ 0.01, $***p < 0.001$, N = 54 couples, error bars: ± SE.

Attraction could be reflected in a combination of these measures. To test this, we split the data across genders and used machine-learning techniques to predict attraction. The major advantage of machine learning is that these methods can handle many predictors at the same time and by using 10-fold cross-validation to validate our model there is no concern for overfitting and collinearity[34]. In this data-driven approach, we used participants' expressions (i.e., frequency of smiling, laughing, hand gestures, head nods), eye fixations (e.g. duration of eye contact, face contact) and physiological responses (skin conductance, heart rate) as well as two-way interactions between all those features to predict males' and females' self-reported attraction scores during verbal and nonverbal interactions. Due to the high amount of predictors, we utilized a cross-validated Lasso model[4] to penalize non-predicted features (see methods). Neither of our observed R^2s were significantly better than the permuted null distributions, men verbal ($R^2 = -0.36$, $p = 0.96$), men non-verbal ($R^2 = -0.13$, $p = 0.48$), women verbal ($R^2 = -1.51$, $p = 0.92$), women non-verbal ($R^2 = -0.36$, $p = 0.96$). In other words, males and females who reported to be more attracted to their partner did not differ from those who were less attracted to their partner in their expressions, gaze fixations and physiological patterns.

Together, these data imply that neither males nor females behaved in a specific way when they were attracted to their partners. In consequence, similarly to our subjects (Fig. 2a), we were not able to accurately predict attraction between participants on the individual level. However, what if we zoom out from one individual, and look at the couple as a whole?

Does synchrony promote attraction?

First of all, a series of Spearman's rank – order correlations with FDR correction showed evidence for behavioral mimicry. Within the couples, we found correlations between the number of partners' smiles ($\rho = 0.31$, $p < 0.001$), laughs ($\rho = 0.66$, $p < 0.001$), head nods ($\rho = 0.31$, $p < 0.001$), hand gestures ($\rho = 0.87$, $p < 0.001$) and face touching ($\rho = 0.28$, $p < 0.001$). In other words, the more expressive one person in the couple was, the more expressions the other person displayed. Fig. 3a shows that participants also reciprocated each other's gaze fixations as demonstrated by significant correlations between the duration that individuals looked eye-to-eye and head-to-head (all $\rho > 0.22$, $p < 0.001$). Finally, within the couples, we observed correlations in partners' (baseline-corrected) average heart rates ($\rho = 0.32$, $p < 0.001$) and skin conductance levels ($\rho = 0.36$, $p < 0.001$). These data demonstrate that there were associations between partners' expressions, eye fixation and physiology. In a control analysis, we paired each female with a random male who did not belong to the real couple. In contrast to real couples, we did not find significant correlations between randomly coupled participants (Supplementary Fig. 2). The control analysis (see methods) confirmed that in the real dyads the correlations between males' and females' smiles, laughs, head nods and hand gestures were significantly higher than the correlations in the shuffled dyads (all Fisher's $z > 0.2$, $p < 0.05$, Supplementary Table 8).

In the next analysis, we investigated the impact of synchrony of different measures including participants' expressions (i.e., frequency of smiling, laughing, hand gestures, head nods), eye fixations (e.g. duration of eye contact, face contact) and physiological responses (skin conductance, heart rate) on changes in partners' attraction. Intriguingly, the results of the Generalized linear mixed model showed that physiological synchrony predicted attraction increase. The more couples' skin conductance levels synchronized ($F(9, 314) = 8.87$, $p = 0.002$) and the more heart rate responses synchronized during the verbal interaction (heart rate * interaction type: $F(9, 314) = 6.21$, $p = 0.013$), the more attracted couples' became to each other over the course of the date (Fig. 3b-c, Supplementary Table 9). These data imply that people physiologically couple to their partners and that the strength of this coupling influences attraction. Crucially, we did not find this association in visible synchrony; expressions mimicry (smiling, laughing, head shaking, hand gestures, face touching), or alignment in gaze fixations (looking at partners' head, eyes, face, body) did not predict attraction (all ps > 0.05). This suggests that physiological synchrony could potentially explain more than visible mimicry can capture.

To show an example of what physiological synchrony looks like, we included a video of one couple (see Supplementary 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 here>

Video 1. An example of physiological synchrony. The video shows a nonverbal interaction where participants were instructed not to talk. At 00:04:00, 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 (top two rows). Again, at 00:18:24, the female laughs; in response the male smiles and we again observe synchrony in heart rate and skin conductance. Importantly, not all smiles and laughs were paired with physiological synchrony, but in the case of this couple, they did. Thus, the purpose of the video is to explain how synchrony can occur. Further examination of these empirical visualizations suggested that physiological synchrony is more closely linked to "genuine" emotional exchange such as contagious smiles or uncontrolled laughter, as opposed to overt expressions used during polite communication (grins or nods).

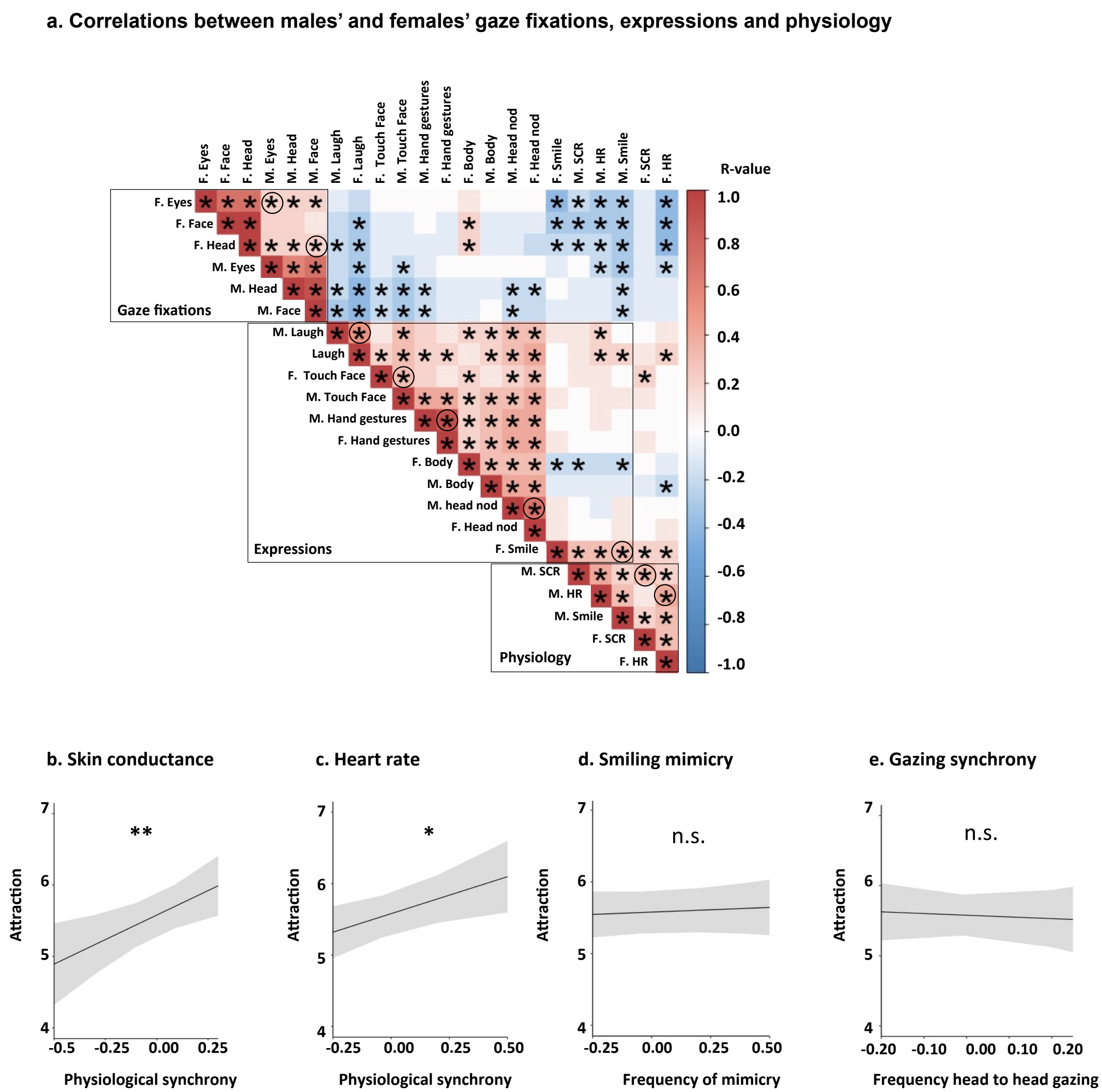

Figure 3. Synchrony and mimicry results. (a) Correlation table summarizes associations between males' and females' frequency of expressions, gaze fixations and mean baseline corrected physiological responses for three interaction types ($N = 162$). F = females, M = males. The columns of the correlation matrix are placed according to the hierarchical clustering with similar values near each other. The black boxes framed around naturally occurring clusters demonstrate that synchrony occurred on all three levels of expressions; the circles represent significant mimicry between males' and females' eye-to-eye gaze, and head-to-head gaze. The circles in the physiology cluster highlight the significant relationship between males' and females' mean heart rate and skin conductance responses. The expressions' circles signify mimicry between males' and females' smiling, hand gestures, head nods and laughter. The significance is adjusted according to FDR Benjamini-Hochberg's *p*-value[35]: *$p < 0.05$. **(b)** Predictions about attraction from physiological synchrony. Attraction increase based on the synchrony of skin conductance levels [$\beta = 3.044$, SE = 0.95, CI (1.16, 4.93), $p = 0.002$] and **(c)** Attraction increase following heart rate synchrony during verbal interaction [$\beta = 2.51$, SE = 1.01, CI (0.52, 4.48), $p = 0.013$]. * $p < 0.05$, ** $p < 0.01$**. (d - e)** The frequency of smiling mimicry and

gazing synchrony did not significantly affect attraction. The shaded areas represent 95% confidence intervals. All predictors were centered. HR = heart rate, SCR = skin conductance response.

Discussion

In the online world of mobile applications, single people can find a potential partner within a second before they even meet face-to-face. Thanks to this, dating has become a fast and more controllable process. Nevertheless, this rather consumeristic way of finding a partner may have its shortcomings[2]. Previous theories proposed that attraction emerges from the dynamic exchange of verbal and nonverbal signals[8,12–14,36], yet the necessary empirical and analytic tools to directly address these hypotheses were not available at the time. In consequence, the direct link between nonverbal behavior, physiology and attraction has been missing. Thanks to the combination of multiple measures we were able to acquire a new point of view, providing a more holistic understanding of nonverbal signals that drive social interactions.

First of all, we observed that people are not accurate at predicting their partner's romantic intentions, as at the end of the date only half of the participants were correct in their predictions. We further show that participants who perceived their partner as highly attractive predicted that their partner liked them more than participants who rated their partner as less attractive. Yet, in reality, there was no correlation between partners' perceived attraction and partners' actual liking scores. These results complement previous findings showing that during dating interactions people tend to mix their own feelings with partners' feelings[37]. At the same time, this result contradicts the notion that people excel in their 'mindreading' capacities[38]. Instead, we found that similarly to economic predictions[39], people are not very good "emotional statisticians".

Furthermore, in terms of nonverbal visible signals, we show that females were more expressive during the date, which corresponds to previous research[40]. Males, on the other hand, hold their eye gaze more steadily focused on their partner than females. Furthermore, we observed mimicry on all three levels of expression (expressions, eye gaze and physiology). Importantly, here we clarified that attraction was not directly reflected in any of the measured nonverbal signals (eye gaze, expression or physiology), nor was promoted by expression mimicry (e.g., smiling, laughing, etc.) or eye gaze synchrony (e.g., eye-to-eye contact). Instead, we found that attraction was promoted by physiological synchrony between partners, which is unconscious and difficult to regulate. Specifically, the level of skin conductance synchrony promoted attraction during both verbal and nonverbal interaction, and the level of heart rate synchrony promoted attraction during verbal interaction. We propose that a possible explanation of why physiological synchrony predicts attraction and visible mimicry did not is because physiological synchrony captures 'genuine emotional exchange'. While people might be smiling and mimicking each other on a superficial level, these expressions are not always aligned to people's physiology. However, when they are, that is when the deeper emotional transfer happens and attraction is promoted.

Previous research has shown that people make up their minds about others' after seeing their picture for a fraction of a second[41]. Although these quick judgments are often inaccurate, they can lead to important decisions (e.g. vote in elections)[42]. In addition to facial morphology biases, the current finding opens up a new debate regarding the putative link between *emotion* and *expression*. From the perspective of basic emotion theories[43–45], behaviors such as smiling, eye contact and mimicry are expressed to communicate romantic attraction. Thus, these behaviors should be more evident when an individual is romantically/sexually motivated. In contradiction, here we show that visible signals or even their mimicry did not accurately predict the feeling of attraction. We propose that this is because visible signals largely play a communicative function

- people do not always act according to their feelings[37]. On the other hand, recent literature has begun to uncover that peripheral physiological changes can trigger feelings via interoception[46,47]. Specifically, as information arrives from distinct sensory channels (seeing, hearing, smelling, touching), these exteroceptive signals interact with afferent signaling and neural representation of bodily changes (transferred via the spinal and cranial nerves). In consequence, we propose that when people align on the autonomic level, these physiological changes can trigger feelings of attraction via body-to-brain signaling. Although we acknowledge that our findings are correlational and therefore need to be both replicated and experimentally tested, our results begin to shed light on the contagious spread of emotional information that stimulates attraction during real-life interactions.

In this study, we used state of the art technology to lay down a foundation for the processes that underlie human attraction during real-life interactions, outside the laboratory setting. In the field of social neuroscience, researchers have been mainly focusing on controllable expressions such as facial expression, body postures and eye gaze; our research suggests that these signals and even their mimicry do not accurately predict interpersonal attraction. Instead, our current and previous work[48] demonstrate that social perception is shaped by unconscious physiological synchrony between people. With regards to this evidence, we propose that physiological synchrony may provide a medium for rendering social signals into embodied emotions. We further conclude that in order to truly understand a social phenomenon such as attraction, we need to study it in its natural habitat, with real people, and during real-life interactions.

Methods

Participants

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). Our sample size was motivated by those used in previous studies[22,49,50]. To participate in the experiment, participants had to be single, between 18 and 37 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 due to a technical error; meaning 69 dyads were included in the behavioral analysis. For the physiological analysis an additional 15 dyads were excluded due to artifacts or missing physiological data, meaning 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, Happen) both males and females were looking for a committed relationship (see Supplementary Table 10). At the end of the study, 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%). 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 reciprocated. 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 11). 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 the University of Amsterdam. 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 control 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) 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 the 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 email and go for 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 have 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, we included the Liebowitz Social Anxiety Scale[51], Positive and Negative Affect Schedule[52] and Sexual Desire Inventory[53].

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 70%); 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 glasses recordings conducted under dynamic situations. Same as with 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 pre-processing. Using the PhysioData Toolbox, the raw skin conductance signal was visually inspected and short-duration artifacts were removed and replaced using linear interpolation. 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. Sections missing more 50% percent of the IBIs were excluded.

Analysis

Analysis 1. At the final ratings, we asked participants whether they thought their partner wanted to date them or not (yes =1/ no=2). We subtracted these answers from partners' actual response (partner really wants to date: yes =1/ no=2). This resulted in either accurate (0), false negative

(1) or false positive (-1) answers. We then binarized the accuracy variable (correct/incorrect (pooling 1 and -1)) to test for significance above chance level with Chi-square test (alpha = 0.05).

Analysis 2. Apart from categorical answers (date or not), we asked participants to rate how attractive is their partner and how much do they think partner likes them? We asked these questions to investigate whether participants' impression of being liked relates to their attraction towards their partner. We used a Multilevel linear mixed model with 3 level structure: dyad (Level 3), participant (Level 2) and time (Level 1). In this model, participants' impression of being liked was used as the target variable predicted by participant's attraction towards their partner. We further included gender and the interaction between gender and attraction to control for gender differences (see Table S1).

Analysis 3. We tested whether females' and males' differ in frequency of their naturally occurring expressions, eye fixations, and physiological responses. To do so, for each interaction type (first impression, verbal interaction and nonverbal interaction) and each participant we calculated the proportion of time (min = 0, max = 1) that participants were (i) smiling, (ii) laughing, (iii) head shaking, (iv) making hand gestures, (v) touching their face or fixating on partners' (vi) body, (vii) eyes, (viii) face, (ix) head. Physiological levels: (x) skin conductance and (xi) heart rate responses were baseline corrected (30 seconds prior to every interaction) and then z-scored. This resulted in eleven averaged values for each subject and interaction. We used a 3 x 2 Multivariate Generalized Linear Mixed model to test for gender differences using the within subject factor interaction type (first impression, verbal and nonverbal interaction), gender (male, female) as between subject factor. To control for multiple comparisons we employed a false discovery rate (FDR) in all following models[35]. To check whether females look longer at the background than males do, we conducted a Generalized Linear Mixed Model. In this model, the data were nested in each subject and the individual intercept was random. The average time (in seconds) looking at the background was used as a dependent variable and gender, interaction type (first impression, verbal, nonverbal), gender * interaction type were used as fixed effects (see Supplementary Fig.1).

Analysis 4. Apart from physiological arousal, we investigated whether males and females differ in their cognitive arousal by conducting Multivariate Generalized Linear Mixed model testing for gender differences on mood grids: (i) arousal (ii) valence, self-ratings reporting the level of (ii) shyness and (v) self-confidence.

Analysis 5. Furthermore, we tested whether males and females behave in a specific way when they feel attracted to their partner. To account for within subject and dyad dependencies, we conducted a series of Multilevel mixed effects models with following structure: three time points (Level 1) nested in participants (Level 2), nested in dyads (Level 3). In each model, expression, gaze fixations frequencies and baseline corrected physiological responses were used as predictors of participant's attraction scores (scale 0 – 9). Gender and genders * expression/fixation interaction were used as additional predictors of attraction. Due to the multicollinear nature of the data, we carried out a model for each expression, gaze fixations frequencies and physiological response independently (11 mixed effects models). The Multilevel mixed effects models were conducted such that the intercept terms were allowed to vary across dyads and participants, we further used an AR1 covariance matrix to account for time dependencies. We defined significance using an FDR < 0.05.

Analysis 6. We used machine-learning techniques to detect a specific behavioral and physiological pattern that would predict participant's attraction level. Using a 10-fold cross-validated lasso regression model (alpha = 0.5) implemented in Sci-kit learn in python 3.6[3], we aimed to predict attraction directly following either the verbal or non-verbal interaction, separately for men and women. In our model, we included all the predictors including participants' frequency of smiling, laughing, hand gestures, fixations duration on partner's eyes, face, head, body and physiological responses (skin conductance, heart rate) as well as 2-way interactions between all those features (91 predictors in total) to predict males' and females' self-reported attraction scores. All predictors were z-scored. To evaluate the performance of our models we performed a permutation test with 3000 permutations, shuffling the attraction levels across participants and testing that our observed non-shuffled R^2 was larger than 95% of the randomly shuffled R^2.

Analysis 7. 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 control analysis, each female was paired with a random male. To test for significance, we directly contrasted the (FDR corrected) correlations coefficients between true couples and randomly matched couples with cocor package in R studio [54] using gender an independent group, two sided test with alpha set to 0.05.

Quantifying expressive mimicry and eye fixation synchrony. We quantified mimicry for each dyad and interaction by calculating the proportion of time both participants' directly reciprocated expressions (smiling, laughing, head nod, hand gestures, face touching) and gaze fixations (looking at partners' head, eyes, face, body).

Quantifying synchrony. We quantified synchrony with windowed cross-lagged correlational analyses[5]. This method has the advantage that it takes into account the non-stationarity of the time series and the dynamical nature of the interaction. This is important as the level of synchrony may fluctuate during the experiment. The first step in the analysis was to determine the parameters (window size, window increment, maximum lag, lag increment). We did that following an extensive process by comparing previous studies using similar statistical methods, looking at what is physiologically plausible given the time course of the physiological signals and by employing a data-driven bottom-up approach where we investigated how changing the parameters affected the outcomes using a different dataset. As expected, the absolute values of the synchrony measures varied depending on the parameters (e.g., the window size, the lag size), but as supported by McAssey, Helm, Hsieh, Sbarra, and Ferrer[55], the relative results were not affected (e.g. a dyadic manifesting relatively high synchrony showed such tendency for the different parameters). Based on these three factors, we set the parameters as follows: the window size was 8 seconds, the window increment was 2 seconds, the maximum lag was 4 seconds and the lag increment was 100ms. Then the peak picking algorithm was applied[5]. This algorithm allows detecting the maximum cross-correlation across the lags for each time segment. Both the windowed cross-correlations and the peak picking algorithm are conducted 6 times per dyad, once for the heart rate responses and once for the skin conductance responses for each condition (the first impression, verbal and nonverbal interaction) resulting in N dyads * 6 result and peak picking matrices. Finally, the mean and standard deviation of the peak cross-correlations of all window segments and the mean of the absolute values of corresponding time lags are calculated for both physiological measures for each condition per dyad.

Analysis 8. We test whether attraction can be predicted by synchrony. In this model, we used synchrony in expressions (smiling, laughing, head nod, hand gestures, face touching) and gaze fixations (looking at partners' body, head, eyes, face) and physiology (skin conductance, heart rate) as predictors of participant's attraction. In addition, gender, interaction type (verbal, nonverbal), the order of interaction (verbal/nonverbal first) were used as additional predictors in the model. To allow for differences between dyads, the intercept terms were allowed to vary across dyads and we included a first-order autoregressive AR(1) residuals structure to account for time dependencies. The final model was selected with a backward stepwise selection of fixed effects in a generalized linear mixed-effects model. This method first tests interaction terms, and then drops interactions one by one to test for main effects. Main effects that are part of interaction terms were retained, regardless of their significance as main effects (full model summarized in Supplementary Table 9).

Data and code availability: All data, code, and materials that are associated with this paper and used to conduct the analyses will be uploaded and accessible on the Leiden University archiving platform DataverseNL when published.

References

1. Mansoor Iqbal. *Business of Apps* (2019). Available at: https://www.businessofapps.com/data/tinder-statistics/. (Accessed: 20th June 2019)

2. Heino, R. D., Ellison, N. B. & Gibbs, J. L. Relationshopping: Investigating the market

metaphor in online dating. *J. Soc. Pers. Relat.* **27,** 427–447 (2010).

3. Pedregosa, F. *et al.* Scikit-learn: Machine learning in Python. *J. Mach. Learn. Res.* **12,** 2825–2830 (2012).

4. Tibshirani, R. Regression shrinkage and selection via the lasso. *J. R. Stat. Soc. Ser. B* **58,** 267–288 (1996).

5. Boker, S. M., Xu, M., Rotondo, J. L. & King, K. Windowed cross-correlation and peak picking for the analysis of variability in the association between behavioral time series. *Psychol. Methods* **7,** 338–55 (2002).

6. Walster, E., Aronson, V., Abrahams, D. & Rottman, L. Importance of physical attractiveness in dating behavior. *J. Pers. Soc. Psychol.* **4,** 508–516 (1966).

7. Eastwick, P. W. & Finkel, E. J. Sex differences in mate preferences revisited: Do people know what they initially desire in a romantic partner? *J. Pers. Soc. Psychol.* **94,** 245–264 (2008).

8. Hall, J. A. & Xing, C. The verbal and nonverbal correlates of the five flirting styles. *J. Nonverbal Behav.* **39,** 41–68 (2015).

9. Moore, M. M. Nonverbal courtship patterns in women. Context and consequences. *Ethol. Sociobiol.* **6,** 237–247 (1985).

10. Tickle-Degnen, L. & Rosenthal, R. The nature of rapport and its nonverbal correlates. *Psychol. Inq.* **1,** 285–293 (1990).

11. Gonzaga, G. C., Keltner, D., Londahl, E. A. & Smith, M. D. Love and the commitment problem in romantic relations and friendship. *J. Pers. Soc. Psychol.* **81,** 247–262 (2001).

12. Gonzaga, G. C., Turner, R. A., Keltner, D., Campos, B. & Altemus, M. Romantic love and sexual desire in close relationships. *Emotion* **6,** 163–179 (2006).

13. Vacharkulksemsuk, T. *et al.* Dominant, open nonverbal displays are attractive at zero-

acquaintance. *Proc. Natl. Acad. Sci.* **113,** 4009–4014 (2016).

14. Givens, D. B. The nonverbal basis of attraction: Flirtation, courtship, and seduction. *Psychiatry* **41,** 346–359 (1978).
15. Montoya, R. M., Kershaw, C. & Prosser, J. L. A meta-analytic investigation of the relation between interpersonal attraction and enacted behavior. *Psychol. Bull.* **144,** 673–709 (2018).
16. Hughes, S. M., Farley, S. D. & Rhodes, B. C. Vocal and physiological changes in response to the physical attractiveness of conversational partners. *J. Nonverbal Behav.* **34,** 155–167 (2010).
17. Foster, C. A., Witcher, B. S., Campbell, W. K. & Green, J. D. Arousal and attraction: Evidence for automatic and controlled processes. *J. Pers. Soc. Psychol.* **74,** 86–101 (2005).
18. Zuckerman, M. Physiological measures of sexual arousal in the human. *Psychol. Bull.* **75,** 297–329 (1971).
19. Farley, S. D. Nonverbal reactions to an attractive stranger: The role of mimicry in communicating preferred social distance. *J. Nonverbal Behav.* **38,** 195–208 (2014).
20. Stel, M. & Vonk, R. Mimicry in social interaction: Benefits for mimickers, mimickees, and their interaction. *Br. J. Psychol.* **101,** 311–323 (2010).
21. Chartrand, T. L. & van Baaren, R. Human mimicry. *Advances in Experimental Social Psychology* **41,** 219–274 (2009).
22. Levenson, R. W. & Gottman, J. M. Marital interaction- Physiological linkage and affective exchange. *J. Pers. Soc. Psychol.* **45,** 587–597 (1983).
23. Palumbo, R. V. *et al.* Interpersonal autonomic physiology: A systematic review of the literature. *Personal. Soc. Psychol. Rev.* **21,** 99–141 (2017).

24. Timmons, A. C., Margolin, G. & Saxbe, D. E. Physiological linkage in couples and its implications for individual and interpersonal functioning: A literature review. *J. Fam. Psychol.* **29,** 720–731 (2015).

25. Gallotti, M. & Frith, C. D. Social cognition in the we-mode. *Trends in Cognitive Sciences* **17,** 160–165 (2013).

26. Hari, R., Himberg, T., Nummenmaa, L., Hämäläinen, M. & Parkkonen, L. Synchrony of brains and bodies during implicit interpersonal interaction. *Trends in Cognitive Sciences* **17,** 105–106 (2013).

27. Hasson, U., Ghazanfar, A. A., Galantucci, B., Garrod, S. & Keysers, C. Brain-to-brain coupling: a mechanism for creating and sharing a social world. *Trends Cogn. Sci.* **16,** 1–8 (2012).

28. Prochazkova, E. & Kret, M. E. Connecting minds and sharing emotions through mimicry: A neurocognitive model of emotional contagion. *Neuroscience and Biobehavioral Reviews* **80,** 99–114 (2017).

29. Anders, S., de Jong, R., Beck, C., Haynes, J.-D. & Ethofer, T. A neural link between affective understanding and interpersonal attraction. *Proc. Natl. Acad. Sci.* **113,** E2248–E2257 (2016).

30. Niedenthal, P. M. Embodying emotion. *Science* **316,** 1002–1005 (2007).

31. Ekman, P., Levenson, R. W. & Friesen, W. V. Autonomic nervous system activity distinguishes among emotions. *Science* **221,** 1208–10 (1983).

32. Ekman, P., Freisen, W. V. & Ancoli, S. Facial signs of emotional experience. *J. Pers. Soc. Psychol.* **39,** 1125–1134 (1980).

33. Elío Sjak-Shie. PhysioData Toolbox (Version 0.4) [Computer software]. (2018).

34. Kohavi, R. A study of cross-validation and bootstrap for accuracy estimation and model

selection. *Proc. 14th Int. Jt. Conf. Artif. Intell. - Vol. 2* **2,** 1137–1143 (1995).

35. Benjamini, Y. & Hochberg, Y. Controlling the ralse discovery rate: A practical and powerful approach to multiple testing. *J. R. Stat. Soc. Ser. B* **57,** 289–300 (1995).

36. Friedman, H. S., Riggio, R. E. & Casella, D. F. Nonverbal skill, personal charisma, and initial attraction. *Personal. Soc. Psychol. Bull.* **14,** 203–211 (2007).

37. Back, M. D. *et al.* Why mate choices are not as reciprocal as we assume: The role of personality, flirting and physical attractiveness. *Eur. J. Pers.* **25,** 120–132 (2011).

38. Gallese, V. Embodied simulation: From neurons to phenomenal experience. *Phenomenol. Cogn. Sci.* **4,** 23–48 (2005).

39. Kahneman, D. & Tversky, A. On the psychology of prediction. *Psychol. Rev.* **80,** 237–251 (1973).

40. Grammer, K. Strangers meet: Laughter and nonverbal signs of interest in opposite-sex encounters. *J. Nonverbal Behav.* **14,** 209–236 (1990).

41. Willis, J. & Todorov, A. First impressions: Making up your mind after a 100-ms exposure to a face. *Psychol. Sci.* **17,** 592–598 (2006).

42. Todorov, A., Mandisodza, A. N., Goren, A. & Hall, C. C. Psychology: Inferences of competence from faces predict election outcomes. *Science (80-.).* **308,** 1623–1626 (2005).

43. Izard, C. E. Innate and universal facial expressions: Evidence from developmental and cross-cultural research. *Psychol. Bull.* **115,** 288–299 (2005).

44. Ekman, P. An argument for basic emotions. *Cogn. Emot.* **6,** 169–200 (1992).

45. Panksepp, J. & Watt, D. What is basic about basic emotions? Lasting lessons from affective neuroscience. *Emot. Rev.* **3,** 387–396 (2011).

46. Pace-Schott, E. F. *et al.* Physiological feelings. *Neurosci. Biobehav. Rev.* **103,** 267–304 (2019).

47. Critchley, H. D. & Harrison, N. A. Visceral influences on brain and behavior. *Neuron* **77,** 624–638 (2013).

48. Prochazkova, E. *et al.* Pupil mimicry promotes trust through the theory-of-mind network. *Proc. Natl. Acad. Sci.* **115,** E7265–E7274 (2018).

49. Reed, R. G., Randall, A. K., Post, J. H. & Butler, E. A. Partner influence and in-phase versus anti-phase physiological linkage in romantic couples. *Int. J. Psychophysiol.* **88,** 309–316 (2013).

50. Thomsen, D. G. & Gilbert, D. G. Factors characterizing marital conflict states and traits: Physiological, affective, behavioral and neurotic variable contributions to marital conflict and satisfaction. *Pers. Individ. Dif.* **25,** 833–855 (1998).

51. Liebowitz, M. R. *Social phobia*. *Modern Problems of Pharmacopsychiatry* (Guilford Publications, 1987). doi:http://dx.doi.org/10.1159/000414022

52. Watson, D., Clark, L. A. & Tellegen, A. Development and Validation of Brief Measures of Positive and Negative Affect: The PANAS Scales. *J. Pers. Soc. Psychol.* **54,** 1063–1070 (1988).

53. Spector, I. P., Carey, M. P. & Steinberg, L. The sexual desire inventory: Development, factor structure, and evidence of reliability. *J. Sex Marital Ther.* **22,** 175–190 (1996).

54. Diedenhofen, B. & Musch, J. Cocor: A comprehensive solution for the statistical comparison of correlations. *PLoS One* **10,** e0121945 (2015).

55. McAssey, M. P., Helm, J., Hsieh, F., Sbarra, D. A. & Ferrer, E. Methodological advances for detecting physiological synchrony during dyadic interactions. *Methodology* **9,** 41–53 (2013).

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