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Article

Strangers, Friends, and Lovers Show Specific Physiological Synchronies In Different Emotional Contexts

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Abstract: The mere co-presence of another person synchronizes physiological signals, but no study has systematically investigated effects of type of emotional context and type of relationship in eliciting dyadic physiological synchrony. In this study, we investigated the synchrony of pairs of strangers, companions, and romantic partners while watching a series of video clips designed to elicit different emotions. Maximal cross-correlation of heart rate variability (HRV) was used to quantify dyadic synchrony. The findings suggest that an existing social relationship might reduce the predisposition to conform one's autonomic responses to a friend or romantic partner during social situations that do not require direct interaction.

Keywords: heart rate variability; dyads; physiological synchrony; relationship; emotion

1. Introduction

As social mammals, humans need to affiliate and be able to form social bonds with others in order to foster and maintain social relationships. Individuals find themselves differentially affiliated to several others within social pair-bonds. During the establishment of these selective attachments, a bio-behavioral reorganization is thought to occur in which multiple biological, behavioral, and cognitive processes between partners come to coincide [1]. Through repeated interactions, partners become increasingly sensitized to one another's unique rhythms and cues, which, over time, become ingrained and reflected at a physiological level. Although first manifest within the context of the mother-infant relationship [1], the concept of synchrony, defined as the "dynamic and reciprocal adaptation of the temporal structure of behaviors and shared affect between interactive partners" [2], is increasingly applied to investigate social attachments between diverse individuals in diverse social contexts.

The exchange of emotions at a dyadic level is facilitated by the constant influence of behavioral reciprocity (e.g. facial expressions, gaze patterns) on automatic physiological synchrony (e.g. heart rate pattern) [3,4]. This reciprocity may influence cognition and behavior through emotional contagion [3]. In a recent study, [5] showed that imitation of facial expressions (i.e. behavioral) increased the synchrony of heart rate patterns (i.e. physiological) in both members of a dyad. Instances of synchrony have been demonstrated in adult dyads, such as between strangers and romantic couples, using various physiological parameters. In romantic pairs, within-couple hormonal associations have been shown to predict levels of empathy [6] and connectedness [7]. Physiological synchrony has also been

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observed in pairs of strangers, wherein synchrony was correlated with an enhanced ability to complete collaborative tasks [5,8]. Synchrony of skin conductance at the group level has been shown to correlate with a team's ability to work together cooperatively [9], which feeds back into the performance level of the team [8] and increases cohesion [9].

It may seem intuitive that synchrony is indicative of rapport and becomes pronounced in positive emotional situations [1,10–13], but contradictory findings challenge the generality of this principle. For instance, negative events, such as couple conflict, have been found to synchronize heart rate variability and predict elevation of inflammatory compounds [14]. Similarly, synchrony of electrodermal activity (EDA), the difference in electrical potential between different areas of the skin, between romantic partners was enhanced during negative rather than positive interactions [15]. Within a group setting, incompatible results between heart rate variability (HRV) and skin conductance have been noted, in which team cohesion was only significantly linked to synchrony measured by skin conductance but not HRV. These results raise questions regarding what inferences can be drawn from measures of physiological synchrony across different emotional conditions and types of social affiliations.

The present study sought to systematically investigate how the co-presence partners from different relational categories (i.e. strangers (Strangers), companions (Friends), and romantic partners (Lovers)) and the emotional context (i.e. embarrassment, sadness, fear, calmness, romance, and pride) influence physiological synchrony during a minimal social setup that did not require face-to-face communication. To this aim, we measured HRV indices, which reflect the extent of autonomic arousal. A previous study, [16] demonstrated that direct communication was not necessary to signal emotional states. That study also found that degrees of synchrony of HRV and EDA signals were correlated with the extent of convergence of emotional responses. With respect to its two novel components of categories of persons and contexts, the present study has two sets of hypotheses. First, we expected to observe the effect of mere co-presence on synchrony amongst Strangers as shown by [16], where synchrony was evident between strangers, and we expected a positive correlation between closeness and synchrony so that Lovers should exhibit the highest level of physiological synchrony, followed by Friends and Strangers. Second, we expected Strangers to exhibit synchrony in fearful and embarrassing contexts, similar to the findings by [16], whereas we anticipated that Friends and Lovers would synchronize only to specific to positive emotional contexts, namely romance, pride and calmness.

2. Results

2.1. Emotional Embedding

To assess whether the different videos elicited different emotional contexts, we investigated the values of the EE from the PCA analysis (see Figure 1 and Table 1 for Means and SDs of the EE for all the emotional contexts).

We conducted a two-way Analysis of Variance (ANOVA) to compare the effects of the type of emotional context, relationship, and gender, and their interaction on the EE. The only significant effect was the type of emotional context ($F(5, 742) = 39.9$, $p < 0.001$) and the interaction of the type of emotional context and gender ($F(5, 743) = 3.7$, $p < 0.003$).

In the post-hoc analysis, we performed a pairwise Wilcoxon signed-rank test to compare the distributions of the EE between the different emotional context. Results (see Table 2) showed that the first three emotional contexts are statistically different. CALMNESS resulted non statistically different from EMBARRASS, and ROMANCE non statistically different from PRIDE. The statistical difference between EMBARRASS and ROMANCE, EMBARRASS and PRIDE and CALMNESS and PRIDE could not survive the Bonferroni's correction.

We then applied a two-way ANOVA to investigate the effects of the relationship and gender on the EE for each emotional context. Results indicate that there is a significant effect of the Gender for FEAR ($F(1, 122) = 20,7$, $p < 0.001$; Females: M = 0.445, SD = 0.276; Males: M = 0.213, SD = 0.294) and ROMANCE ($F(1, 122)$, $p = 0.045$; Females: M = -0.239, SD = 0.447; Males: M = -0.087, SD = 0.388).

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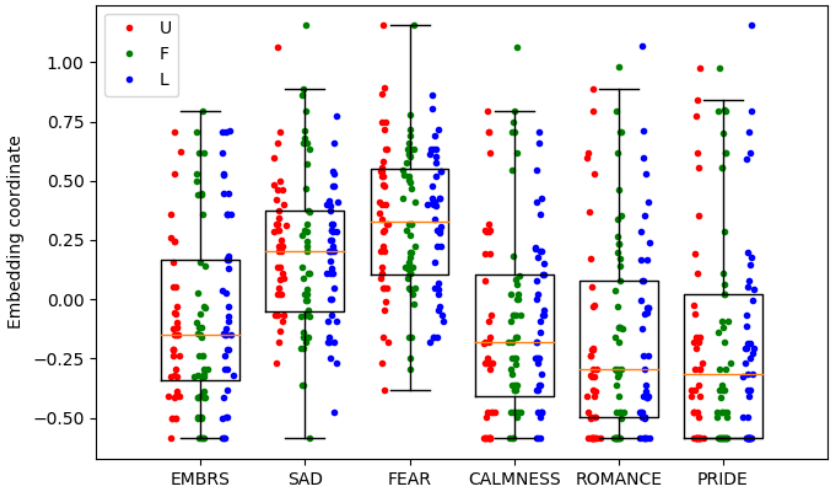

Figure 1. Distribution of the EE values for each emotional context and type of relationship.

Table 1. Means and SDs of the EE for each emotional context (Emot.), relationship group (Relat.): Strangers (S), Friends (F), Lovers (L); and gender: Females (F), Males (M).

Emot.	Relat.	Gender	N	Mean	SD	Emot.	Relat.	Gender	N	Mean	SD
Emb.	S	F	20	-0.099	0.344	Calm.	S	F	20	-0.106	0.412
		M	20	-0.148	0.289			M	20	-0.207	0.427
	F	F	23	-0.19	0.386		F	F	23	-0.076	0.396
		M	23	-0.02	0.395			M	23	-0.108	0.436
	L	F	21	-0.023	0.363		L	F	21	-0.103	0.364
		M	21	0.039	0.417			M	21	-0.06	0.338
	Total	F	64	-0.107	0.367		Total	F	64	-0.094	0.385
		M	64	-0.041	0.375			M	64	-0.123	0.402
		All	128	-0.074	0.371			All	128	-0.109	0.392
Sad	S	F	20	0.289	0.256	Romance	S	F	20	-0.3	0.465
		M	20	0.181	0.273			M	20	-0.161	0.368
	F	F	23	0.161	0.415		F	F	23	-0.22	0.412
		M	23	0.196	0.351			M	23	-0.015	0.449
	L	F	21	0.187	0.302		L	F	21	-0.201	0.482
		M	21	0.17	0.24			M	21	-0.097	0.337
	Total	F	64	0.209	0.335		Total	F	64	-0.239	0.447
		M	64	0.183	0.289			M	64	-0.087	0.388
		All	128	0.196	0.312			All	128	-0.163	0.424
Fear	S	F	20	0.481	0.28	Pride	S	F	20	-0.181	0.445
		M	20	0.208	0.335			M	20	-0.245	0.441
	F	F	23	0.448	0.286		F	F	23	-0.174	0.525
		M	23	0.194	0.269			M	23	-0.127	0.454
	L	F	21	0.407	0.268		L	F	21	-0.12	0.469
		M	21	0.238	0.293			M	21	-0.239	0.401
	Total	F	64	0.445	0.276		Total	F	64	-0.158	0.476
		M	64	0.213	0.294			M	64	-0.2	0.43
		All	128	0.329	0.307			All	128	-0.179	0.452

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Table 2. Results of the Wilcoxon signed-rank tests to compare the EE of the different emotional contexts.

	Wilcoxon signed-rank test				
Emotion	SAD	FEAR	CALMNESS	ROMANCE	PRIDE
EMBARASS	Z=7.36, p<0.001	Z=7.96, p<0.001	Z=0.72, p=0.47	Z=2.67, p<0.008	Z=2.68, p<0.008
SAD	-	Z=4.01, p<0.001	Z=7.53, p<0.001	Z=8.36, p<0.001	Z=8.15, p<0.001
FEAR	-	-	Z=8.29, p<0.001	Z=8.28, p<0.001	Z=8.27, p<0.001
CALMNESS	-	-	-	Z=1.89, p=0.059	Z=2.46, p<0.02
ROMANCE	-	-	-	-	Z=0.17, p=0.86

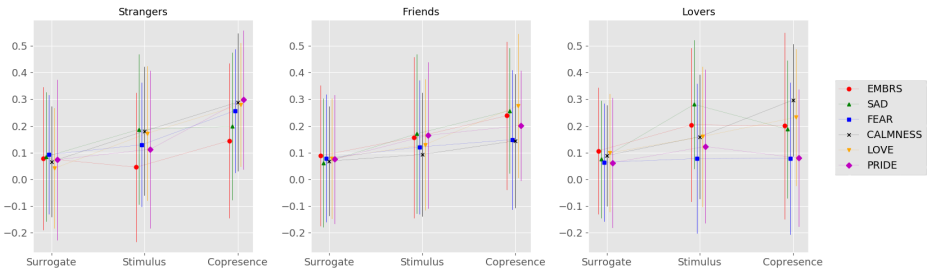

Figure 2. Mean and SD of the three types of physiological synchrony for each group of relationship and stimulus.

No other effects were observed, neither due to the type of relationship nor to the interaction between gender and type of relationship.

2.2. Effects of Relationship, Emotion and Gender on the Physiological Response

In the second part of the analysis, we investigated the effects of the type of relationship, emotional context and gender on the physiological response, measured in terms of average IBI during the stimulus (see Table 3).

For each video, we performed a two-way ANOVA to investigate the effects of gender and type of relationship on the physiological response. Results (see Table 4) showed an effect of gender for all emotional contexts, with the exception of CALMNESS ($F(1,116) = 3.77$, $p = 0.055$; Females: $M = 0.798$, $SD = 0.102$; Males: $M = 0.840$, $SD = 0.130$) and PRIDE ($F(1,116) = 3.43$, $p = 0.066$; Females: $M = 0.776$, $SD = 0.104$; Males: $M = 0.816$, $SD = 0.129$). No significant effect of type of relationship or of the interaction between type of relationship and gender was found. The differences due to gender are expected and can be explained by physiological differences in emotional responses found between men and women in general [17]. The non-significant differences between the relationship types indicate that individual physiological responses do not depend on the social category of the dyad.

2.3. Effects of Relationship, Emotion and Gender on the Physiological Synchrony

Results from the analyses of the EE and of the average IBI ensured that the stimuli are appropriate to elicit different emotions and that the type of relationship and gender have no effect on the perceived emotion and on the physiological response. We focused then on the investigation of the physiological synchrony between the dyads, and in particular on the effects of the different type of relationships on the synchrony associated to the stimulus and to the co-presence (see Table 5) and Figure 2).

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Table 3. Means and SDs of the Average IBI for each emotional context (Emot.), relationship group (Relat.): Strangers (S), Friends (F), Lovers (L); and gender: Females (F), Males (M). Values are reported in seconds.

Emot.	Relat.	Gender	N	Mean	SD	Emot.	Relat.	Gender	N	Mean	SD
Emb.	S	F	19	0.778	0.086	Calm.	S	F	19	0.813	0.092
		M	19	0.815	0.127			M	19	0.825	0.112
	F	F	23	0.768	0.111		F	F	23	0.795	0.108
		M	23	0.831	0.152			M	23	0.848	0.137
	L	F	19	0.774	0.115		L	F	19	0.787	0.108
		M	19	0.857	0.16			M	19	0.844	0.144
	Total	F	61	0.773	0.103		Total	F	61	0.798	0.102
		M	61	0.834	0.146			M	61	0.84	0.13
		All	122	0.803	0.129			All	122	0.819	0.119
Sad	S	F	19	0.804	0.092	Romance	S	F	19	0.823	0.092
		M	19	0.833	0.129			M	19	0.84	0.109
	F	F	23	0.779	0.116		F	F	23	0.804	0.119
		M	23	0.85	0.135			M	23	0.858	0.143
	L	F	19	0.775	0.115		L	F	19	0.791	0.109
		M	19	0.861	0.156			M	19	0.858	0.151
	Total	F	61	0.785	0.108		Total	F	61	0.806	0.107
		M	61	0.848	0.138			M	61	0.853	0.134
		All	122	0.817	0.127			All	122	0.829	0.123
Fear	S	F	19	0.798	0.084	Pride	S	F	19	0.792	0.094
		M	19	0.825	0.128			M	19	0.806	0.112
	F	F	23	0.787	0.106		F	F	23	0.769	0.106
		M	23	0.839	0.137			M	23	0.826	0.133
	L	F	19	0.777	0.106		L	F	19	0.768	0.113
		M	19	0.848	0.145			M	19	0.813	0.144
	Total	F	61	0.787	0.098		Total	F	61	0.776	0.104
		M	61	0.838	0.135			M	61	0.816	0.129
		All	122	0.812	0.12			All	122	0.796	0.118

Table 4. F-statistics and p-values of the ANOVA test to investigate gender and relationship type effects on the average IBI.

	Gender F(1,116)		Relation F(2,116)		Gender:Relation F(2,116)	
Stimulus	F	p	F	p	F	p
EMBARRASS	6.91	**.009**	0.24	.786	0.31	.731
SAD	7.61	**.006**	0.01	.988	0.53	.592
FEAR	5.32	**.023**	0.001	.998	0.32	.726
CALMNESS	3.77	.055	0.02	.977	0.41	.662
ROMANCE	4.39	**.038**	0.04	.957	0.41	.662
PRIDE	3.43	.066	0.06	.941	0.36	.701

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Table 5. Means and SDs of the three typs of physiological synchrony (Surrogate, Stimulus and Co-rpesence) for each emotional context and relationship group.

		Surrogate			Stimulus			Co-presence		
Emotion	Relationship	N	Mean	SD	N	Mean	SD	N	Mean	SD
EMBARASS	Strangers	190	0.079	0.267	171	0.045	0.279	19	0.145	0.290
	Friends	276	0.089	0.263	253	0.157	0.300	23	0.238	0.277
	Lovers	210	0.107	0.237	190	0.204	0.288	20	0.201	0.349
SAD	Strangers	190	0.085	0.241	171	0.187	0.281	19	0.199	0.275
	Friends	276	0.062	0.242	253	0.171	0.297	23	0.257	0.234
	Lovers	210	0.076	0.220	190	0.281	0.241	20	0.188	0.258
FEAR	Strangers	190	0.093	0.222	171	0.130	0.232	19	0.257	0.231
	Friends	276	0.079	0.239	253	0.121	0.251	23	0.149	0.261
	Lovers	210	0.064	0.220	190	0.078	0.280	20	0.079	0.284
CALMNESS	Strangers	190	0.067	0.206	171	0.181	0.240	19	0.289	0.259
	Friends	276	0.069	0.205	253	0.093	0.231	23	0.144	0.250
	Lovers	210	0.089	0.189	190	0.160	0.232	20	0.297	0.210
ROMANCE	Strangers	190	0.041	0.225	171	0.172	0.252	19	0.279	0.231
	Friends	276	0.079	0.225	253	0.130	0.244	23	0.276	0.269
	Lovers	210	0.099	0.221	190	0.160	0.262	20	0.233	0.256
PRIDE	Strangers	190	0.073	0.300	171	0.113	0.295	19	0.299	0.260
	Friends	276	0.075	0.240	253	0.165	0.273	23	0.201	0.205
	Lovers	210	0.062	0.242	190	0.123	0.287	20	0.080	0.257

2.4. Effects of Emotional Context and Co-Presence in Strangers

In the first stage, we focused on the dyads of Strangers to assess whether we could reproduce and extend the results in [16].

The Mann-Whitney tests (see Table 6 for the U-statisics and p-values) indicate an effect of stimulus and copresence for FEAR, CALMNESS and ROMANCE. SAD showed an effect due to the stimulus but not to co-presence; and PRIDE showed only an effect due to co-presence. For the video EMBARRASS, which was also used in [16], neither emotional context nor co-presence had an effect on synchronization. Overall, we partially replicated the findings in [16]; we addressed the main discrepancies in regard to differences in the shorter duration of the stimuli (about 240 s in our pipeline), and to the different types of social group ([16] tested strangers in groups of threes, whereas we tested pairs). As we extended the investigation to other types of emotions, we can conclude that emotional context- and co-presence-driven synchrony in Stranger dyads occur independent of the type of elicited emotion.

2.5. Effects of Type of Relationship

In Stage 2, we focused on the two other categories of relationships, Friends and Lovers, to assess whether physiological synchrony is dependent or independent of the type of dyadic relationship (see Table 5 and Table 6).

In general, while we found again an effect of the stimulus (EMBARRASS, SAD, ROMANCE, PRIDE for Friends and Lovers, FEAR for Friends only and CALMNESS for Lovers only), the effects of co-presence are found only for two videos (ROMANCE for Friends CALMNESS for Lovers). This finding suggests that, when members of a dyad engage in a social relationship, their synchrony is reduced in social situations which do not require direct interaction.

To further investigate, we compared the distribution of the copresence synchrony between the three relationship group for all the emotional contexts (see Table 7 and Figure). We note that in all the three videos where a significant differences is found (FEAR, PRIDE, CALMNESS), Strangers have higher synchrony than Lovers (FEAR, PRIDE) and Friends (CALMNESS) (see Figure 3). However, the

Table 6. Results of the Mann-Whitney tests to compare between Surrogate, Stimulus and Co-presence synchrony for each type of emotional context and type of relationship.

		Surrogate v. Stimulus		Stimulus v. Copresence	
Emotion	Relationship	U	p	U	p
EMBARASS	Strangers	17341	p=0.866	1313	p=0.086
	Friends	30042	p=0.003	2576	p=0.182
	Lovers	15920	p<0.001	1892	p=0.488
SAD	Strangers	12707	p<0.001	1571	p=0.408
	Friends	27963	p<0.001	2356	p=0.066
	Lovers	10629	p<0.001	2274	p=0.926
FEAR	Strangers	14581	p=0.046	1083	p=0.009
	Friends	31537	p=0.027	2663	p=0.251
	Lovers	20119	p=0.558	1869	p=0.453
CALMNESS	Strangers	11565	p<0.001	1215	p=0.036
	Friends	32648	p=0.098	2489	p=0.126
	Lovers	16037	p<0.001	1308	p=0.011
ROMANCE	Strangers	11285	p<0.001	1233	p=0.043
	Friends	30897	p=0.011	1972	p=0.005
	Lovers	16660	p=0.002	1584	p=0.111
PRIDE	Strangers	14944	p=0.094	1064	p=0.007
	Friends	27676	p<0.001	2760	p=0.342
	Lovers	17289	p=0.011	2054	p=0.725

Table 7. Results of the Mann-Whitney tests to compare the distribution of the Co-presence synchrony between the different relationship groups.

	Strangers v. Friends		Friends v. Lovers		Strangers v. Lovers	
Emot.	U	p	U	p	U	p
Embarass	187	p=0.217	218	p=0.390	170	p=0.292
Sad	190	p=0.240	195	p=0.200	183	p=0.428
Fear	176	p=0.144	190	p=0.168	120	p=0.025
Calmness	149	p=0.041	160	p=0.045	188	p=0.483
Romance	214	p=0.460	204	p=0.267	174	p=0.332
Pride	169	p=0.108	170	p=0.074	116	p=0.019

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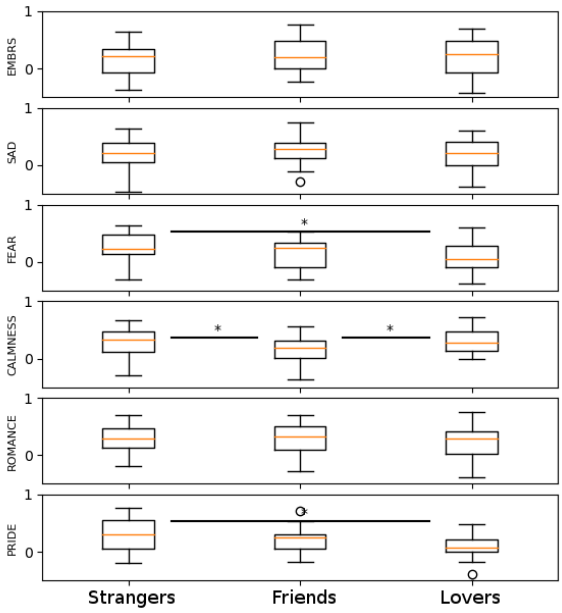

Figure 3. Comparison of the co-presence synchrony between groups, for the six stimuli. Horizontal bars indicate significant differences between the distributions of the two groups.

differences are do not survive the Bonferroni correction and, therefore, the results only suggest a trend and propose a direction for further investigations.

3. Discussion

We come into contact with numerous people in our daily lives, some of whom are strangers with whom we walk side-by-side, but others are friends or romantic partners with whom we share most of our personal lives. It is therefore important to understand how the presence of others, and our relationships with them, affect us at the most basic physiological level. Our study systematically investigated how physiological synchrony occurs in the co-presence of dyads who are romantic couples, friends, or strangers, and under various emotional conditions. With some notable differences, we replicated the results in [16] and showed that synchrony due to co-presence manifests mainly in dyadic pairs of strangers across an array of emotions. Contrary to our expectations, physiological synchrony was more pervasive across emotional contexts among strangers than romantic couples and friends.

One main finding to emerge from our study is that in the absence of a pre-existing social relationship physiological synchronization emerges between strangers. This result may seem counter-intuitive, but numerous examples from ethnic rituals to military drills attest that synchronization of physiological arousal among strangers is more common than realized [18–20]. One postulation for higher physiological synchrony observed among strangers is that there exists a predisposition for strangers to coordinate autonomic responses in an attempt to initiate affiliation [21] and facilitate prosocial behavior [22], which, in this case, is applicable to strangers tasked with watching a video together. Supporting this interpretation, [23] learned that, upon engaging in the same activity and placed in close proximity to each other, strangers exhibit a natural tendency to synchronize behaviors and levels of physiological arousal. The predisposition to affiliate with the opposite gender might have been made more pronounced in our sample which comprised college students who fall within the active "partner-seeking" phase of their lives [24]. These observations bear close resemblance to a coordinated physiological response, known as "physiological linkage." Physiological linkage is widely displayed by social mammals and is presumed to present an evolutionary advantage (i.e., organised response) that enhances the odds of survival [1]. One recent investigation [25] of dyads composed of same-gendered strangers revealed that physiological linkage was also evident between

strangers who spoke or wrote about personal life events to each other. All considered, physiological synchrony may represent a potential mechanism by which social reciprocity between strangers is established [26].

More intriguing is the idea that pre-existing social relationships, whether romantic or friendly in nature, were not so physiologically synchronized. Intuitively, partners in such relationships ought to share emotions, which should be reflected in physiological synchrony [27]. There is also considerable evidence to show that relationships serve as important social regulators of baseline homeostasis, including sleep patterns [28] and emotional arousal [29]. Novelty of co-present individual represents a critical variable that may account for differences in synchrony seen in friends, lovers, and strangers in our study. Unlike strangers, autonomic arousal in friends and lovers may be more resistant to influence of the mere presence of partners as friends and lovers have had prior experience in sharing physical space, reducing the drive to convey immediate information or establish social connection.

Finally, specificities of synchrony in strangers, lovers, and friends could reflect variation in novelty of co-present individuals in the social experiment. Previous studies have reported that the mere presence of another person automatically influences mechanisms activated to drive the sharing of information [30]. Moreover, the actions and goals of a co-present individual can influence one's own performance [31,32]. Hence, the existing literature suggests that physiological mechanisms are unintentionally affected by mere co-presence. However, in most studies, the co-present individual is a stranger to the participant and is therefore a novel social factor with whom the participant may be instinctively driven to consolidate a social bond with [21].

This study has some limitations. Firstly, we categorised dyads broadly into three main groups - friends, romantic partners and strangers. In reality, not all couples within each of these groups function in the same way and subgroups of dyads may have different responses. For instance, the duration of relationship and extent of relationship satisfaction in romantic couples may have influenced the physiological synchrony observed [33]. Similarly, relationship closeness experienced in a friendship falls within a wide spectrum and may have had significant implications in modulating synchrony. Future studies should obtain behavioral measures regarding the characteristics of each relationship so as to better contextualise research findings. Secondly, differences in personality constructs might have driven different physiological responses when viewing the series of video clips. Previous studies have found that the pairing of different personality traits within each dyad influences couple dynamics (e.g. [34]) and could have also elicited unique patterns of synchrony that was not captured in the study. Finally, this study has only investigated the synchrony within a dyadic pair and further work is required to understand whether the same mechanisms are applicable to social groups, such as triads of strangers or friends.

4. Materials and Methods

4.1. Participants

124 heterosexual participants took part in this study. The average ages for the 62 female and 62 male participants were 21.65 (SD = 2.77) and 23.48 years old (SD = 5.57), respectively. They were all Caucasian, and none presented with any medical or developmental condition. Participants were distributed in 62 opposite-sex pairs of friends (23 pairs), romantic partners (20 pairs), or strangers (19 pairs). No information about duration of the relationship and intimacy was collected from the pairs of friends and lovers. Participants were required to provide informed consent before the commencement of the study. Each participant was subsequently awarded university credits following the completion of the study. The study was conducted in accordance with the Declaration of Helsinki, at *Institution blinded for review*.

4.2. Procedure

In each experimental session, a male-female pairviewed a series of video clips together. Romantic couples and friends signed up for the study together; each partner from the pair of strangers was recruited separately and was subsequently paired with a stranger of the opposite sex. All experimental sessions consisted of male-female pairs of participants. Upon arriving at the laboratory, participants were instructed about the purpose of the study and signed the informed consent. Each participant's cardiac activity was recorded using an Electrocardiogram (ECG) sensor (FlexComp, Thought Technology). The ECG signal was measured throughout the entire presentation of 6 emotional videos. The experimental session lasted 30 min in total.

4.3. Stimuli

In a pilot study, 10 participants responded to a forced-choice single-answer questionnaire where they were instructed to pick one emotion from a list of six emotions that best represented each of 20 video clips. Beginning with 20 videos, we eventually selected six video clips that consistently elicited the same basic emotion across all participants. Each video clip was carefully screened for its ability to elicit one of six key emotions (i.e. embarrassment, sadness, fear, calmness, romance, and pride). Every participant was exposed to six 4-min video clips from different popular films or TV series that were used as the main stimuli for this study. To mitigate the possibility that a gory scene from the "The Walking Dead" clip might leave participants feeling uncomfortable if viewed last, we fixed the order in which the clips were presented. Specifically, the sequence of stimuli and order of presentation was:

1. A scene from the movie "When Harry met Sally" was used to elicit the emotion of embarrassment (EMBARRASS);
2. A scene from the movie "Titanic" was used to elicit the emotion of sadness (SAD);
3. A scene from the TV series "The Walking Dead" was used to elicit the emotion of fear (FEAR);
4. A scene of a beach with a relaxing music playing in the background was used to induce calmness (CALMNESS);
5. A scene from the movie "Notting Hill" was used to elicit romantic love (ROMANCE);
6. A scene from the penalty-kick session in the 2006 FIFA World Cup Finals was used to elicit the emotion of pride (PRIDE).

Before the start of each video clip, participants were presented with a 10-sec image depicting the title of the video clip (on a white background) which they were about to watch. At the end of the last clip, a set of instructions would appear on the screen to inform participants that the session had ended. There was an interval of 1 min between the presentations of each video clip, where participants were exposed to an image of a white fixation point on a green background. After the end of the video presentation, participants were asked to self report three items on a 7-point Lickert scale on whether each video was unpleasant/pleasant, scary/funny, embarrassing/non-embarrassing. These ratings served as a manipulation check to validate the effects of the video stimuli. The entire session lasted approximately 30 min.

4.4. Physiological measures

Participant's Heart Rate (HR) was assessed using a 3-electrodes ECG placed on the chest. Two ECG electrodes were placed between left inferior area of the neck and mid-sagittal area of left collarbone. The third electrode was placed near the lowest left rib area. ECG signals were preprocessed to extract Inter-Beat-Intervals (IBIs) (e.g. the R-R interval between peaks of a heartbeat), which is linked to both sympathetic and parasympathetic responses of the nervous system (the main preprocessing steps are represented in Figure 4).

The R peaks corresponding to heart beats were detected from the ECG signal (Figure 4, step S2) after it was first filtered (band pass filtering, cut-off frequencies: 10-48 Hz) to remove noise (Figure 4, step S1). The result of the automatic detection is manually inspected for missing beats or mis-detections

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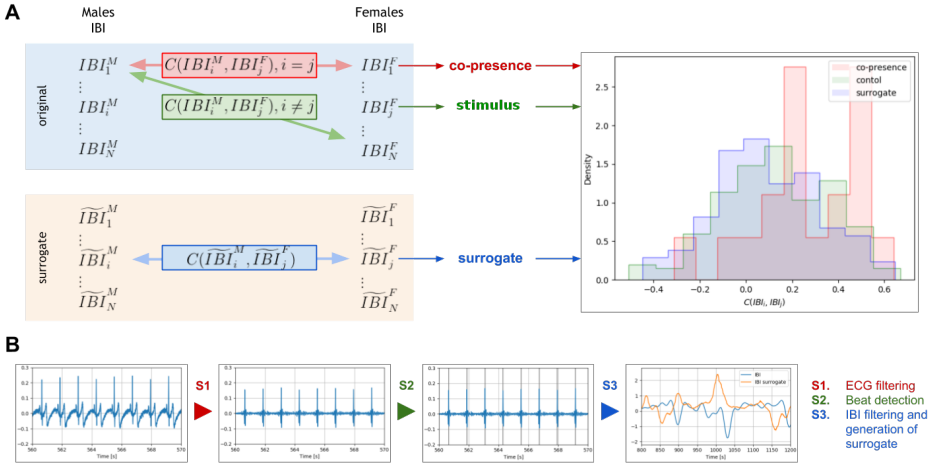

Figure 4. Data Analysis: A) Three types of physiological synchrony and computation schemes, with output distribution of the measures; B) Pipeline for the processing of the ECG signal.

and corrected, to obtain the Inter Beat Intervals series (IBIs). The IBIs were resampled at 2 Hz and filtered (low pass filter, cut-off frequency: 0.04 Hz) to remove high-frequency components of Heart Rate Variability and then standardised (Figure 4B, step S3).

For each IBI series (IBI_i) a surrogate IBI series ($\widetilde{IBI}_i$) was generated using the Iterative Amplitude Adjusted Fourier Transform (IAAFT) [35] smoothed with a moving average filter (length 5 s). The physiological synchrony between two IBI series was computed as the maximal cross-correlation value within a time shift of $\pm 10s$, as in [16,36] to which we refer for more details.

For the analysis of the physiological signals and the computation of the physiological synchrony we used custom scripts based on pyphysio [37].

4.5. Analysis Plan

The first analysis is aimed at validating the adopted stimuli. A principal component analysis (PCA) was performed to obtain a univariate emotional embedding (EE) of the elicited emotion contexts. The PCA was applied on the three-dimensional ratings (unpleasant/pleasant, scary/funny, embarrassing/non-embarrassing) to obtain the *emotion embedding*, *i.e.* a mono-dimensional quantification of the perceived emotion. This step was required to allow comparison of the emotions elicited by the different emotional contexts and effects of group and gender.

The second analysis investigates the effects of the type of relationship and gender on the physiological response of the individuals.

Finally, we analysed the effects of the type of relationship on the physiological synchrony. The analysis of the physiological synchrony was divided into two stages: i) Stage 1: replication of the effects of stimulus and co-presence on synchrony found by [16] and ii) Stage 2: investigating the effects of the type of relationship on synchrony.

4.5.1. Stage 1: Effects of Emotional Context and Co-Presence on Synchrony

As in [16], three types of synchrony of the physiological response were computed (see Figure 4A):

- Co-presence synchrony: between male and female of the Strangers/Friends/Lovers dyad, who watched the videos together. We expected this synchrony to be driven by both the stimulus and the effects of being with the member of the dyad;
- Stimulus synchrony: between male and female belonging to different dyads, who did not watch the videos together. This is the synchrony that was only due to the stimulus;

- Surrogate synchrony: between surrogate signals of males and females. This was used to compose the distribution of the null hypothesis that there was no effect of synchrony due to emotional context or co-presence.

We statistically compared the distributions of the surrogate synchrony and of the stimulus synchrony to assess the effects of the emotional context, then we compared the distribution of the co-presence synchrony and of the stimulus synchrony to assess the effects of co-presence. The significance of the differences in the distributions was assessed with the Mann-Whitney test, fixing the significance threshold to $\alpha = 0.05$. In Stage 1, we used only the data from the dyads of the Stranger group, which was more similar to the sample used in [16].

4.5.2. Stage 2: Effects of Type of Relationship on Synchrony

In Stage 2, we also considered the groups Friends and Lovers and assessed the differences in the co-presence synchrony across the three groups.

5. Conclusion

As social beings, humans are dynamically influenced by our social interactions with others. The mere presence of others can affect us at a physiological level. From this study, we have revealed that the absence of a pre-existing relationship leads to greater physiological synchrony in the context of a shared social task that does not require face-to-face communication. This finding has implications on the mechanisms that drive communal behaviors. From daily activities such as purchasing coffee and commuting to work, to mass gatherings in advance to advance social causes, we may have more in common with the strangers alongside us than previously thought.

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