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Physiological compliance for social gaming analysis: Cooperative versus competitive play

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Abstract

We report the results of an empirical study demonstrating the value of using physiological compliance as a measure of social presence during digital game playing. The physiological activity (facial EMG, electrodermal activity, cardiac activity and respiration) of 21 dyads were acquired synchronously while they were playing a digital game either cooperatively or competitively and either at home or in the laboratory. Physiological compliance was defined as the correlation between the physiological signals of the dyad members. The results of this study confirm that physiological compliance is higher in a conflicting situation than when playing cooperatively. Importantly, the results also demonstrate that physiological compliance is related

to self-reported social presence. This suggests that physiological compliance is not limited to negative situations but rather increases due to rich interactions. Only minor differences in physiological compliance were observed between home play and laboratory play, suggesting the ecological validity of laboratory measures. Finally, we propose that compliance measures can be considered as objective indices of social presence in digital gaming.

Keywords

Physiological compliance, Digital games, Social presence, Facial electromyography,
Electrodermal activity, Cardiac activity

1 Introduction

In the last decade, many studies have proposed tools and methods to better understand the experience of people playing digital games [1–4]. The study of player experience is of central importance to the user-centered design and development of digital games. Moreover, since most games propose rich and complex interactions with the players, analyzing gamers' experience also provides valuable information to the more general field of human computer interaction research.

The analysis of physiological signals, conjointly with the use of questionnaires, has been proposed as a powerful method for player experience studies [3]. Among the main advantages, measuring physiological signals allows to quantitatively and continuously analyze the player experience without interrupting the gameplay. The recording of physiological signals implies the equipment of several sensors, such as electrodes for electrocardiography (ECG), facial electromyography (EMG), electrodermal activity (EDA; or skin conductance) measurements, and a respiration belt. Although it is arguable that this equipment can interfere with the player experience, physiological methods have proven to be effective in many cases and to provide added value compared to traditional think aloud protocols or post-gaming questionnaires. For instance, physiological signals can be used to reliably infer not only the valence and arousal associated with game events [1,5,6] but also discrete states such as boredom, immersion, and flow [7,8]. Most of games are social by nature, with their structure and rules calling on the necessity of having several players. Actually, the fact that games are social activities has been found to be one of the main motivations for playing [9]. Although many digital games are designed for single players, most computer and console games now at least include a multiplayer mode which allows several players to compete against each other or to cooperate

toward a common objective. This has been the tendency especially with the rise of multiplayer online games. Moreover, It has to be noted that even a single-player game can be a social activity when friends or family gather as an audience when one plays, and since players often join together to play and create their own social rules, such as aiming at the best score [10]. Despite of the importance of social aspects in games, there are only a few studies employing psycho-physiological methods to better understand multiplayer's experience (for example, [11-14]). However, those studies have addressed the experience of each player separately instead of considering their joint experience of the game. Analyzing the joint experience of players and the interactions occurring during play can be done by looking at the common patterns present in their physiological signals. This has been called physiological linkage by Levenson and Gottman [11] but also physiological compliance [12]. Observing the relationships between the physiological signals of several persons to analyze social interactions was proposed by Gottman [13,14]. According to him, such information could be very useful in identifying the amount of dyadic behavioral entrainment and the directionality of the underlying interactions (i.e., asymmetric interaction with a dominant member or bidirectional interaction with equal behavior entrainment). One of the main results obtain from the following studies is that physiological linkage is mainly able to capture negative interactions [11]. However, interactions are rather intense in the chosen marital conflicting situations and it is still possible that physiological linkage measures the quantity and intensity of interactions rather than distressed situations only. Using the same measures it was shown that physiological linkage was also related to empathy [15]; people who accurately evaluated the negative emotions of others also displayed a high degree of shared physiology. Finally, more recent studies have analyzed physiological compliance using correlation and coherence measures between physiological signals and examined its relationship with a group's or dyad's performance on a task. The first of

these studies [12] demonstrated that many of the physiological compliance measures computed from heart rate, EDA and respiration are able to predict task completion time with higher compliance indicating a better performance. The task under consideration was a game where the participants had to synchronize their movements to move a cursor in a maze, which demonstrates the relevance of physiological compliance to gaming situations. However, this positive relationship was not confirmed in a second study [16], where self-reported group-performance was negatively correlated with physiological compliance. The authors explained this result by the possibility that the groups who perceived their interactions as more difficult and conflicting were actually the most productive. This is coherent with the findings obtained in previous studies [11,15] concerning the association of high compliance with negative and conflicting interactions.

As explained in [2], we propose to use physiological compliance as a measure of social interaction and social experience when playing a digital game. For this purpose we first need to better understand the origin of physiological compliance and its relationship with the players' perceived experience of the social interaction. We believe that during gameplay physiological compliance can arise due to three factors. Firstly, perceiving the same stimuli can lead to similar physiological activations, especially if players' appraisals of the situation are concordant. It is quite often that in a multiplayer game many players encounter the same situation or that a "pause" screen is displayed to all of them, potentially leading to similar physiological activation patterns, such as orienting responses. Secondly, in most of the multiplayer games, the players are interacting through the generated virtual world. In order to accomplish their objective, they generally have to adapt their behavior to the behavior of the other which would imply a form of physiological compliance because of the supportive function of the autonomous nervous system. In a competitive scenario involving immediate interaction (such as classical action

games), behavior adaptation is rather obvious since a player will have to adapt to the opponent moves or will, at least, adapt his or her behavior to the opponent performance (i.e., investing more effort if the opponent is currently winning). In a cooperative mode, the behavioral adaptation strongly depends on the structure of the cooperation. If it is a sufficient condition for a team to win that one member of the team is winning, the interaction is likely to be limited. However, if the players need to perform actual collaborative actions to reach a common objective, we expect an increase in behavioral adaptation and interaction. Thirdly, physiological compliance can occur because of social-emotional processes, such as empathy and emotional contagion [17] that can also impact mediated interactions [18]. Emotional contagion is the process by which emotions are communicated from a person to another by unconscious imitation of the emotional behavior resulting in the elicitation of the same emotional state. But in the virtual reality of games, there are frequently also other relevant social-emotional reactions, such as “malicious delight” and pleasure due to the struggle of the opponent [4].

The increased popularity of social interaction technologies and collaboration software (e.g., collaborative learning platforms, social network services) has led to the inclusion of social experience in the presence concept. Accordingly, presence can be divided in two components: (a) spatial presence [19,20], the sensation of “being there” which corresponds to immersion and (b) social presence [21–23], the awareness of the others’ presence. According to Biocca and co-workers [21], social presence can be defined as the sense of “being together” in the context of mediated interaction. They decompose social presence into three components: (a) copresence, which relates to the sensation of being in contact with the other; (b) behavioral engagement referring to the interdependence of behavior between two individuals; and (c) psychological involvement, which refers to the level of interpersonal understanding and attention. At least behavioral engagement and psychological involvement are tightly related to two of the

physiological compliance sources that we identified (behavioral adaptation and social-emotional processes). It has also been proposed that physiological measures could be used as indicators of social presence [21]. Social presence has also been suggested as being an important factor during a gaming situation in both a mediated and non-mediated context [24]. For these reasons, we view the social presence theory as an ideal candidate to help understanding the occurrence of physiological compliance during digital game play.

In this study, our objective is twofold: to examine the relationship of physiological compliance with social presence and to compare the degree of physiological compliance between a cooperative and competitive game mode in a classic action game. Given the components of social presence that imply an intense interaction and interdependence of behavior between individuals, it would be expected that social presence is accompanied by higher synchrony also at the physiological level. This leads to our first hypothesis:

H1: physiological compliance will predict the amount of self-reported social presence

Given that the current literature indicates that physiological compliance is higher during conflicting situations, and also considering that the cooperative mode employed in the present game (Bomberman) might not give rise to rich interactions, we formulated our second hypothesis taking into account the specific game context:

H2: physiological compliance will be higher during competitive play than cooperative play

2 Material and Methods

2.1 Participants

Participants were 48 (30 male and 18 female) volunteering Finnish adults, who ranged in age from 18 to 34 years (mean = 24) and played digital games at least 4 hours per month. They were recruited in dyads (consisting of two same-sex people who described themselves as friends) to

play a game together. The 24 dyads were recruited through advertisements in gaming related websites, contacting student mailing lists and student organizations. All participants received three movie tickets for participation in the experiment.

2.2 *Digital game*

The game used was Bomberman (Hudson Entertainment, Inc., Redwood shore, California, US, 2006), played on PlayStation Portable (PSP) handheld game consoles (Sony Computer Entertainment, Inc., Tokyo, Japan). Bomberman is a classic and widely cloned action game where two to four characters, controlled by either the computer (non-player characters - NPCs) or human players, are situated in a small maze formed by breakable and unbreakable walls (Fig. 1). The goal is to use bombs to clear new routes in the maze, reveal bonuses, and ultimately blast the other players. It employs small-sized abstract graphics from isometric view with cartoonish characters and happy music and sounds. There is no realistic violence included in the game.



Fig. 1. Picture of the Bomberman game.

In this experiment the game was played in a battle mode where two teams of two characters compete against each other. Among the four characters, two were controlled by the

participants of a recruited dyad and two were NPCs. Each character starts from a corner of the maze by destroying breakable walls to reach the opponents and collect bonuses. The characters then try to blast the members of the opposite team by positioning the bombs appropriately. A team wins a battle when the two characters of the other team are blasted. The play becomes progressively more intensive as the maze gets more and more open and the characters collect bonuses that grant them with more speed, more bombs to use, stronger blasts and various other helpful and hindering effects.

The participants played two to three battles to determine the winning team of a match. The third battle was played only in the case of a draw after the second battle. The duration of a battle was set to three minutes maximum. The difficulty of the NPCs was set to “weak” which already corresponds to a quite challenging game play. Sudden death was set “off” (a draw occurs when the battle time is elapsed), player starting position was randomly chosen among the 4 corners of the squared maze and skulls were set as “fire proof” (i.e., bonuses that hinder the collector cannot be destroyed). Revenge mode was set to “super” so that when a character is defeated it re-appears and moves on the borders of the maze to try to take its revenge by throwing bombs inside. If such a character successfully blasts an enemy it goes back in the maze. This revenge mode is useful to improve player’s involvement since they have a significant chance to come back into play after an initial defeat.

2.3 Design

One objective of this study was to examine the difference in physiological compliance between competitive and cooperative game playing. As stated by Hypothesis 2 we expected to observe higher compliance in the competitive condition than in the cooperative condition. In the experiment, the play location (laboratory and either participant’s home) was also varied, but

this variation was not in the main focus of the present study. The design of the study was a 2 (game mode: competitive, cooperative) x 2 (playing location: laboratory, home) repeated measures design with physiological compliance as the dependant variable. The dyad members were considered to be indistinguishable since they both have the same sex and followed the same acquisition procedure.

Each participant of a dyad was assigned to a specific team according to the game mode condition. In the cooperative game mode, the participants played the game in the same team, side by side, against a team of two NPC's. In the competitive mode, the two participants played against each other with a NPC on their side. With the exception of team arrangements, the setup of the game was thus identical in both modes.

Concerning the laboratory condition, all participants played the game in the same room. The home condition was defined as being the home of the first registered participant of the dyad and was thus different for each dyad. When arranging the experiment, the experimenter ensured that the participant's home would be peaceful and that suitable chairs would be available for both participants. The order of the playing locations was randomized for each dyad and the order of the game modes was randomized for each location.

In the beginning of the experiment the dyad and the experimenters met in the first playing location. After a brief description of the experiment, the participants filled in an informed consent form. They were seated in comfortable chairs located next to each other. The physiological sensors (see section 2.5) were then attached to both participants. While the sensors were attached, the participants played a separate action game to get used to the game device. This was followed by a five-min practice session during which the participant played the Bomberman game without team allegiances (everyone for him/herself).

A five-min rest period preceded the experimental game play in each location (baseline physiological measurements were performed during the period). After the rest period, the participants played a session for each game mode condition. A play session consisted of two matches and never lasted less than seven min and 30 s. After each play session, the Game Experience Questionnaire (GEQ) [25] was administered to the participants (see Section 2.4). Once the two play sessions were recorded, the participants were moved to the next location (without disconnecting the sensors). A new baseline and two play sessions were then recorded in the new location. During all play sessions, the experimenter was in the adjacent room. When the experiment was completed in the second location, the electrodes were removed and the participants were debriefed and thanked for their participation.

2.4 Game Experience Questionnaire

The three modules of the GEQ were used in this study to assess the psychological impact of the game [25]. The core GEQ module assesses the experience of players during play and is composed of seven components: sensory/imaginative immersion (e.g., “I was interested in the game’s story”, “It felt like a rich experience”), flow (e.g., “I felt completely absorbed”, “I lost track of time”), competence (e.g., “I felt strong”, “I felt skillful”), positive affect (e.g., “I felt good”, “I thought it was fun”), negative affect (e.g., “I found it tiresome”, “It gave me a bad mood”), tension (e.g., “I felt annoyed”, “I felt frustrated”), and challenge (e.g., “I felt stimulated”, “I had to put a lot of effort into it”). The goal of the second GEQ game module, the post-game module, is to evaluate the players’ psychological state following the end of the game on four dimensions: positive experience (e.g., “I felt revived”, “I felt proud”), negative experience (e.g., “I felt bad”, “I found it a waste of time”), tiredness (“I felt exhausted” and “I felt weary”), and sense of returning to reality (e.g., “I felt disoriented”, “I had a sense that I had

returned from a journey”). Finally, the GEQ Social Presence Module [4] assesses player’s involvement in the social interaction with other players on three dimensions: psychological involvement – empathy (e.g., “I felt connected to the other”, “When I was happy, the other was happy” and vice versa), psychological involvement - negative feeling (e.g., “I felt jealous about the other”, “I felt revengeful”), and behavioral involvement (e.g., “My actions depended on the other’s actions”, “I paid close attention to the other”, both also in reverse). Some of the items in the social presence module are inspired by the Networked Minds Social Presence Inventory [21,26] and are particularly well suited to evaluate behavioral and psychological dependency between two players interacting together through a digital game. All the items of the GEQ were evaluated by the participants on a scale ranging from 1 to 5. Each item is reported by first specifying the module and then the dimension, for instance core challenge refers to the challenge perceived during play.

Participants also rated their perceived stress during game playing using a 7-point scale, ranging from 1 (not at all stressed) to 7 (extremely stressed).

2.5 Physiological data acquisition, reduction and preprocessing

The physiological data were recorded from both players with two Varioport-B portable recorder systems (Becker Meditec, Karlsruhe, Germany). The acquired data were time-synchronized by sending a parallel trigger to both devices at the beginning of each play session. All the data were digitized with a 16-bit A/D converter and stored on a compact flash memory card. Among the recorded dyads, three were rejected because of experimental mistakes, like missing triggers, leading to a total of 21 analyzed dyads (42 participants and 84 play sessions). In order to obtain recordings of the same duration, the signals were truncated to match the shortest recording of seven min and 30 s.

Facial EMG activity was recorded from the left zygomaticus major (ZM; cheek muscle, used in smiling), orbicularis oculi (OO; periocular muscle, used in constricting the eye fissure), and corrugator supercilii (CS; brow muscle, used in frowning) muscle regions as recommended by Fridlund and Cacioppo [27], using surface Ag/AgCl electrodes with a contact area of four millimeters diameter (Becker Meditec, Karlsruhe, Germany). Electrodes were filled with Synapse conductive electrode cream (Med-Tek/Synapse, Arcadia, California, US). The raw EMG signals were sampled at 1024 Hz, amplified and bandpass filtered with 57 Hz and 390 Hz cut-off frequencies using the analog filter build in the Varioport device. The raw signals were rectified and a new time series was constructed for each EMG signal by integrating the rectified signal [27]. This was done by computing a running mean over a one second time window with a step of 0.1 second. The window size was chosen according to the long duration of the matches (more than six minutes) and the desire to focus on massive activities rather than short time activations. The new sampling frequency of the post-processed EMG signals was thus of 10 Hz. Finally, the obtained EMG signals were log transformed to normalize the data.

Electrodermal activity (EDA) was recorded with the Varioport skin conductance amplifier that applies a constant voltage of 0.5V across Ag/AgCl electrodes with a contact area of four millimeters diameter (Becker meditec). Electrodes were filled with TD-246 skin conductance electrode paste (Med Assoc. inc.) and attached to the middle phalanges of the ring and little fingers of the participant's non dominant hand after hands were washed with soap and water. This position was chosen to minimize the interference between gaming and EDA recording. For technical reasons, EDA was not recorded for one of the participant pairs, leading to an analysis of 80 play sessions. The acquired signals were sampled at 32 Hz. EDA signals were then low-pass filtered with a cut-off frequency of 5 Hz by truncating the power spectrum obtained from a fast Fourier transform. For normalization a log transform was applied to the signals.

Electrocardiogram (ECG) was recorded with a sampling rate of 512 Hz using Varioport isolated AC amplifier together with three ECG leads in a modified Lead 2 placement. The R peaks of the QRS complexes were automatically detected by using Pan and Tompkins algorithm [28], after which the results were visually inspected and the missing and false positive peaks were manually corrected when possible. After visual inspection of the corrected signals, 3 of the 21 dyads and 11 other play sessions were rejected from the ECG analysis because of bad signal quality (18 teams and 61 play sessions remaining). The inter-beat intervals (IBIs) were then computed from the lists of R peaks and an IBI time series was interpolated at a 4 Hz sampling frequency using the algorithm detailed in [29]. Since the obtained time series started and ended at different point in time, depending on the position of the first and last R peaks, the first and last two seconds of the times series were eliminated. This was applied only for ECG signals and resulted in a signal having a duration of seven min and 26 s.

Respiration was measured with a Varioport piezoelectric respiration belt strung around the thorax and calibrated individually for each participant to ensure that the maximum and minimum of the breathing cycle do not exceed the recordable range. The respiration signal was sampled at 32 Hz and band pass filtered between 0.1 Hz and 1 Hz using the same method as for EDA. The filter is useful to remove high frequency noise due to movement and the usual drift observed in this type of signal.

A six-channel EEG was recorded together with 3D-acceleration of the body and 3D-acceleration of the handheld console. However their analysis is still work in progress and only the results obtained from EMG, EDA, ECG and respiration are presented in this paper.

2.6 Physiological compliance

Physiological compliance was computed between the participants' signals for each dyad over the whole duration of a play session. It was estimated separately for each type of signal (ZM EMG , OO EMG, CS EMG , EDA, IBI, and respiration), resulting in several compliance indices for each play session.

Two indices of physiological compliance were computed depending on the type of the signal. Firstly, the correlation coefficient R_{sig} was estimated to provide an index of compliance in the time domain where sig indicate the type of the considered signals. Secondly, the weighted coherence C_{sig} [12] was used as a frequency domain compliance measure for the IBI and respiration signals. Weighted coherence has the advantage of separating the shared variance of two time series among the chosen frequency bands of interest. This is particularly useful for heart rate variability analysis since it is known to be composed of at least three main periodic components [30]: a high frequency (HF) component ranging from 0.15 Hz to 0.4 Hz associated to respiratory frequency and vagal activity; a low frequency (LF) component between 0.05 Hz and 0.15 Hz mainly associated to sympathetic activity; and a very low frequency (VLF) component between 0.003 Hz and 0.05 Hz associated to several behavioral variables. Due to this decomposition of IBI time series and its tight relation to respiration, IBI and respiration weighted coherence was assessed for the HF, LF, and VLF frequency bands. For this purpose, the power spectrum of the IBI and respiration signals was computed using the Welch algorithm with a window length of 64 seconds and 50% overlap between two consecutive windows. The Welch window length was chosen to have an adequate resolution in the frequency domain ($\Delta f = 0.016\text{Hz}$) and be able to compute the Weighted coherence in the HF, LF and VLF bands.

For a further statistical analysis, it is necessary that the compliance indices were sampled from a normal distribution. The correlation coefficients were thus transformed using Fisher's z-

transformation that results in values where the variance of correlation coefficients is stabilized (not to be confused with standardized z-scores). For convenience, the obtained compliance index was named Z_{sig} where *sig* is the name of the corresponding signal type. Furthermore, coherence measures were normalized by taking Fisher's z-transform of the coherence square root [31]. This last index was referred to as $ZC_{sig}(f)$ where *f* is one of the frequency bands defined above (HF, LF or VLF).

2.7 Statistical analysis

A first step toward dyadic data analysis is to control for dependency between the observations gathered from the two participants in the dyad [32]. While including physiological compliance as a dependant variable in a statistical analysis allows studying this physiological dependency with respect to the different conditions, dependency should also be controlled for the questionnaire measures. The intra-class correlation was computed between scores of the dyad members for each GEQ component to check for dependence of their self-reports. Following [32] a liberal test value of 0.20 was adopted for the test. This liberal value is motivated by the low number of dyads in this study (21) and the desire to improve the test power to avoid false negative decision (i.e. concluding on independence when there is dependence). The tests were significant for all GEQ components, with the exception of core challenge, demonstrating that the members of a same dyad experienced the situation in a very similar way. Because the questionnaire scores are not independent, the dyad should be considered as the unit of analysis. Consequently, the two members' scores for a given GEQ component were averaged to obtain a single score per dyad. By using this method, the physiological compliance score and the GEQ component scores are all computed at the dyad level.

For each signal *sig* the computed compliance indices Z_{sig} were tested to be significantly different from 0 using a two tailed *t*-test. All data were then analyzed using the Linear Mixed Model (LMM) procedure of PASW statistics version 18.0.2, using each of the physiological compliance indices as a dependent variable in a separate analysis. The analyses included two repeated variables that were location (laboratory or home) and game mode (competitive or cooperative) with a compound symmetry repeated covariance matrix. This covariance matrix type was chosen since it produced the lowest restricted log likelihood, AIC, and BIC criteria for all dependent variables. Location, Game Mode, and the Location x Game Mode interaction were introduced in the model as factors with fixed effects. Finally, in order to check for correlation of physiological compliance with some of the questionnaire items, the 14 GEQ components were included as covariates with fixed effects¹. For all statistical analysis the significant level was set to 0.05.

3 Results

3.1 Facial electromyography

All the 84 correlation coefficients R_{ZM} computed between the two ZM time series of the dyad members were positive ($ps < .05$, see Table 1), and the mean of the Z_{ZM} indices was significantly

¹ We also performed a LMM analysis with self-reported stress added to the list of covariates. This analysis was performed to rule out the effects that stress might have on physiological compliance. Adding the stress as a covariate only moderately changed the reported results. An explanation is that the GEQ self-reports already accounts for a lot of stress variance through components such as core tension, core challenge and core competence. For this reason we chose to report the results including the 14 GEQ components only.

higher than zero ($M = 0.64$, $SE = 0.03$, $t(83) = 22.29$, $p < 0.01$). The results indicate that the ZM muscle activities of the dyad members were strongly positively correlated; that is, the smiles often occurred together within the dyads. Applying the LMM procedure on the data with Z_{ZM} as the dependent variable revealed that ZM EMG compliance was significantly predicted by the game mode ($F(1, 63.53) = 9.48$, $p < 0.01$) with higher compliance in the competitive condition ($M = 0.75$, $SE = 0.05$) than in the cooperative condition ($M = 0.53$, $SE = 0.05$; see Fig. 2a). Concerning the GEQ questionnaire, ZM compliance was significantly predicted by the self-reported core positive affect ($F(1, 60.62) = 6.95$, $p = 0.01$), the association being positive ($b = 0.28$, $SE = 0.11$). The results for the OO muscle area were similar to those obtained for the ZM muscle areas. All the dyad members' OO EMG activities were significantly correlated ($p < 0.05$) with positive R_{OO} coefficients (Table 1). On average, the compliance indices were very high ($M = 0.65$, $SE = 0.03$, $t(83) = 22.2$, $p < 0.01$). When LMM analysis was applied on the Z_{OO} data, compliance was found to be higher in the competitive mode ($M = 0.75$, $SE = 0.06$) than in the cooperative mode ($M = 0.55$, $SE = 0.06$, $F(1, 57.89) = 8.25$, $p < 0.01$; see Fig. 2b). The results obtained with the GEQ components as predictors were different from those obtained for the ZM muscle area since only self-evaluated social empathy was found to be significantly and positively correlated with OO compliance ($b = 0.17$, $SE = 0.08$, $F(1, 62.86) = 4.16$, $p = 0.05$).

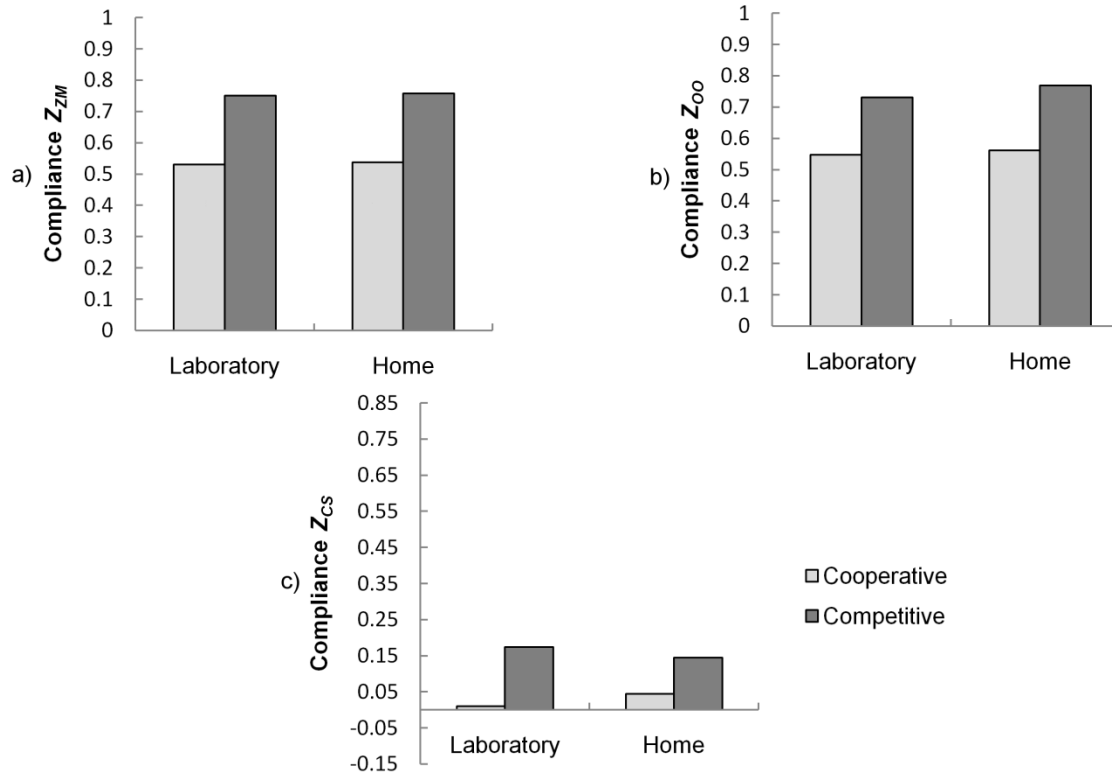


Fig. 2. Estimated marginal means for the compliance measure of a) zygomaticus major, b) orbicularis oculi, c) corrugator supercili EMG activity.

The correlation coefficients for the dyad members' CS EMG activities were not all positive and significant. However, the R_{CS} coefficients tended to be positive as indicated by the median and inter-quartile range displayed in Table 1. Out of 84 correlations coefficients, 73 were found to be significant ($p < 0.05$), 49 coefficients being positive and 24 being negative. After normalization of the coefficients the distribution of the Z_{CS} was also significantly centered on a positive mean ($M = 0.09$, $SE = 0.02$, $t(83) = 3.97$, $p < 0.01$). As for the two other muscle areas, the LMM analysis demonstrated that higher compliance between the CS EMG activities occurred when the participants played the game competitively ($M = 0.16$, $SE = 0.05$) rather than cooperatively ($M = 0.03$, $SE = 0.05$; see Fig. 2c), the effect being significant ($F(1, 62.60) = 4.18$, $p = 0.04$) but to a lesser extent than for the ZM and OO muscles. The answers to the Negative Feeling scale of GEQ

Social Presence Module were found to significantly predict CS EMG compliance with a negative linear relation ($b = -1.45$, $SE = 0.06$, $F(1, 65.50) = 5.03$, $p = 0.03$).

Signal	Variable	Median	Quartiles	Range
ZM EMG	R_{ZM}	0.57	0.43, 0.68	0.05, 0.85
OO EMG	R_{OO}	0.57	0.45, 0.70	0.09, 0.86
CS EMG	R_{CS}	0.05	-0.04, 0.20	-0.30, 0.75
EDA	R_{EDA}	0.22	-0.06, 0.48	-0.60, 0.88
IBI	R_{IBI}	0.22	0.08, 0.33	-0.13, 0.61
	$C_{IBI}(VLF)$	0.20	0.13, 0.34	0.02, 0.68
	$C_{IBI}(LF)$	0.10	0.08, 0.13	0.03, 0.25
	$C_{IBI}(HF)$	0.09	0.08, 0.11	0.04, 0.20
Respiration amplitude	R_{Resp}	0.02	-0.04, 0.08	-0.18, 0.35
	$C_{Resp}(HF)$	0.11	0.08, 0.13	0.05, 0.40

Table 1. Statistics of the correlation and weighted coherence coefficients for the different signals. The quartiles are in the format “first quartile, third quartile”.

3.2 Electrodermal activity

The distribution of the correlation coefficients computed between the EDA signals of the dyad members was rather wide but centered on a positive median (Table 1). 78 out of 80 correlations obtained a p -value inferior to 0.05. Among those significant correlations, 53 were positive and 25 were negative. The t -test was also significant ($t(79) = 5.06$, $p < 0.01$), showing that the Z_{EDA} indices were, on average, higher than zero ($M = 0.22$, $SE = 0.04$).

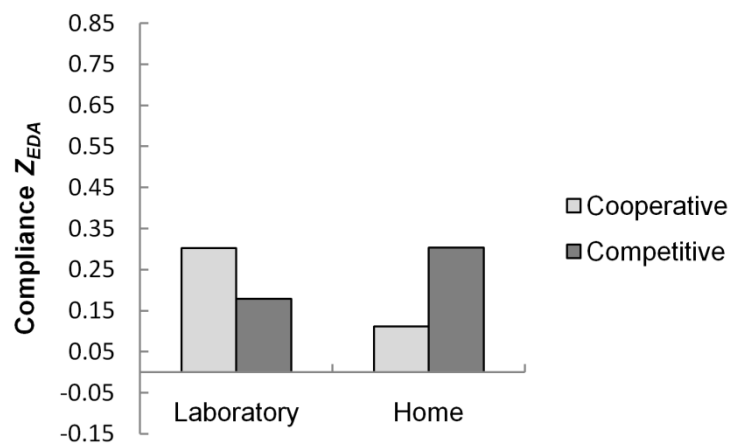


Fig. 3. Estimated marginal means for the EDA compliance measure.

No main effect or interaction was found to be significant for EDA compliance (Fig. 3). Concerning self-reports, only the GEQ core positive affect was positively and highly significantly associated with the Z_{EDA} scores ($b = 0.56, SE = 0.18, F(1, 60.18) = 9.34, p < 0.01$).

3.3 *Interbeat intervals*

The first IBI analysis was done by computing the R_{IBI} correlation coefficients and the associated compliance measures Z_{IBI} . The 61 R_{IBI} values computed between the two interpolated IBI time series of dyad members were centered on a positive median (Table 1): 3 of the coefficients were significantly negative, 49 were significantly positive and 9 were non-significant. The normalized compliance measures were significantly centered on a positive mean ($M = 0.23, SE = 0.02, t(60) = 9.57, p < 0.01$) which confirms the strong tendency of IBI correlations to be positive.

A significant main effect for game mode was found in predicting Z_{IBI} ($F(1,39.31) = 5.53, p = 0.02$). As was the case for the EMG signals, the compliance was higher during competitive play ($M = 0.30, SE = 0.05$) than during cooperative play ($M = 0.17, SE = 0.04$). The LMM estimated marginal means for the different conditions are displayed in Fig. 4a. None of the GEQ components were significantly related to compliance.

In the second step, the weighted coherence coefficients C_{IBI} were computed for the VLF, LF and HF frequency bands. The goal of this new analysis was twofold: (a) removing the constraint of a zero delay between the two IBI time series for compliance computation and (b) separating the two IBI signals' shared variance in the three frequency bands for a more precise analysis. The statistics of the C_{IBI} coefficients are displayed in Table 1. Most of the IBI coherence appeared in the VLF band, showing that the IBI variance was mostly shared between the two dyad participants at this frequency band. The coherence then decreased for the LF band to tightly oscillate around a coherence of 0.09 for the HF band.

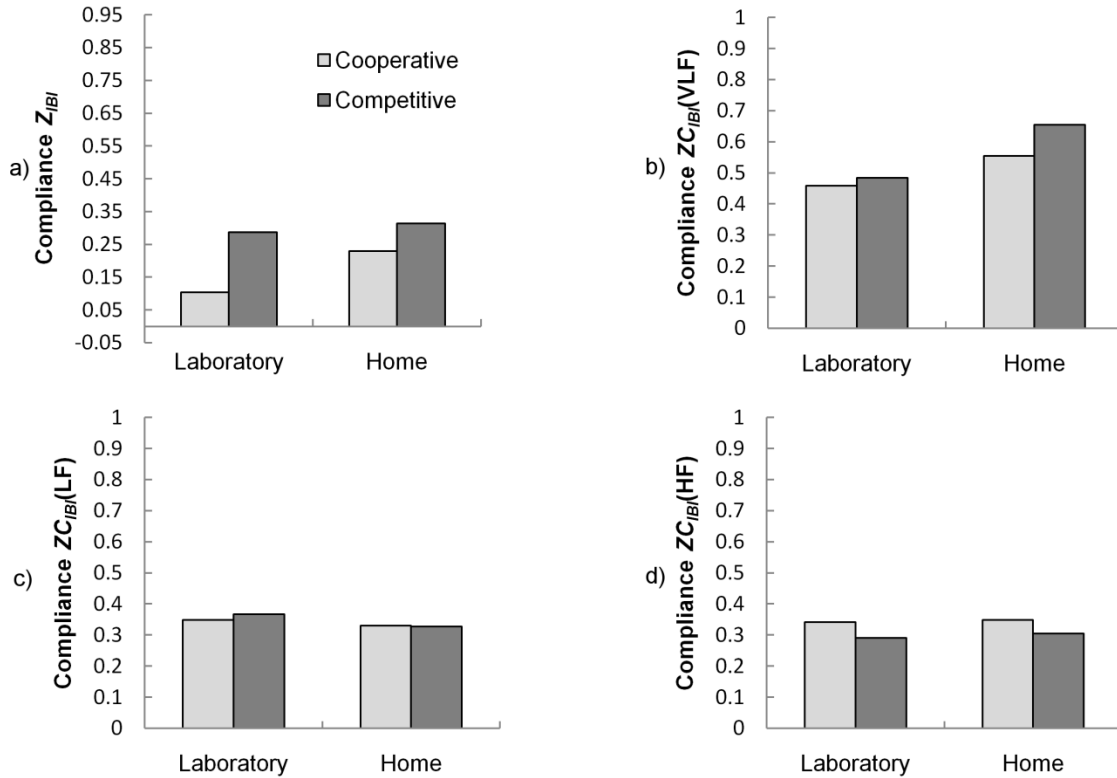


Fig. 4. Estimated marginal means for the IBI compliance measures computed based on a) correlation coefficients, b) weighted VLF coherence, c) weighted LF coherence and d) weighted HF coherence.

A LMM procedure was applied as described above for $ZC_{IBI}(VLF)$, $ZC_{IBI}(LF)$, and $ZC_{IBI}(HF)$ variables.

A significant location effect was obtained for the $ZC_{IBI}(VLF)$, ($F(1, 36.72) = 5.28, p = 0.03$) with higher compliance when playing at home ($M = 0.60, SE = 0.05$) than in the laboratory ($M = 0.47, SE = 0.05$; see Fig. 4b). No significant effects of game mode or location were found for the LF band compliance index. The HF band compliance index $ZC_{IBI}(HF)$ was on average higher for the cooperative game mode ($M = 0.34, SE = 0.01$) than for the competitive mode ($M = 0.30, SE = 0.01, F(1, 42.97) = 4.57, p = 0.04$; see Fig. 4d); that is, the effect was inverted compared to what was observed for the Z_{IBI} , Z_{ZM} , Z_{OO} , and Z_{CS} indices. Finally, the normalized coherence $ZC_{IBI}(HF)$ was significantly predicted by GEQ social negative feeling ($F(1, 39.14) = 5.02, p = 0.03$) with a positive relation ($b = 0.05, SE = 0.02$). Fig. 4 displays the LMM marginal means for the coherence computed in the three frequency bands.

3.4 Respiration

The correlation coefficients computed from the filtered respiration signals were tightly distributed around a median close to 0 (Table 1). Most of the 84 computed correlations were significant with 31 negative and 44 positive correlation coefficients. The t-test revealed that the average Z_{Resp} compliance score was significantly positive ($M = 0.03$, $SE = 0.01$, $t(83) = 2.81$, $p < 0.01$). Although the Z_{Resp} scores were centered on a positive mean, many correlation coefficients were found to be negative. The negative and rather low correlation coefficient distribution can be explained by asynchronous respiration; there is a delay between the breathing cycles of the dyads participants, even when they were breathing at a similar frequency. Results concerning respiration compliance are presented in Fig. 5. In the LMM analysis, no main effects or GEQ covariates were significant.

In order to obtain a compliance measure that is independent of the signals' phase difference, the weighted coherence was computed for the respiration signals in the HF band. The HF band was chosen because it corresponds to the usual respiration cycle duration when at rest and it allows for comparison with the results obtained from the IBI time series on the same frequency band. Table 1 shows that, for the respiration signals, the HF weighted coherence coefficients were much higher than the correlation coefficients.

By substituting the $ZC_{Resp}(HF)$ compliance measure for the Z_{Resp} index in the LMM analysis two effects were found to be significant. First, $ZC_{Resp}(HF)$ was higher for competitive ($M = 0.39$, $SE = 0.02$) than for cooperative play ($M = 0.31$, $SE = 0.02$, $F(1, 65.37) = 10.28$, $p < 0.01$). Second, the GEQ social empathy self-evaluations were positively associated with $ZC_{Resp}(HF)$, ($b = 0.07$, $SE = 0.03$, $F(1, 57.23) = 5.33$, $p = 0.02$).

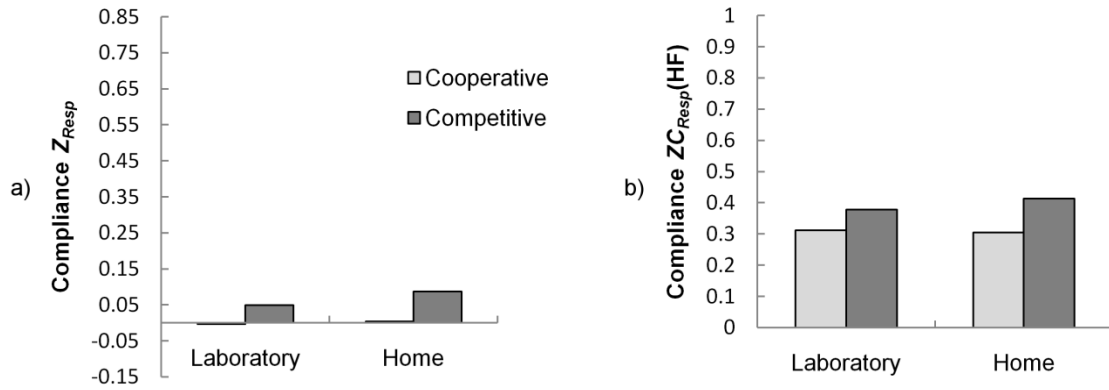


Fig. 5. Estimated marginal means for the respiration amplitude compliance as computed from a) correlation coefficients and b) weighted HF coherence.

4 Discussion

The objective of this study was to analyze whether physiological compliance, as computed from distinct physiological signals, would be able to provide information about the social experience of game players. Two main findings emerged. First, physiological compliance was found to increase with players' self-reported involvement in the social interaction, suggesting that it could be used as an objective measure of social presence. Second, for most of the signals physiological compliance was higher for competitive game play compared to cooperative play; that is, when playing a classic action game (Bomberman), participants' reactions were more similar during competitive play.

4.1 Shared physiology

As can be seen from Table 1, the correlation coefficients computed from all the signals were distributed around a positive median. Moreover, the corresponding normalized Z_{sig} scores were on average positive. This indicates that during play, the physiological activity of the dyad members tended to oscillate synchronously. Similarly, the weighted coherence measures were

also high, confirming the existence of shared physiology between the participants of a dyad. The compliance values were compared to those reported in [12] where physiological weighted coherence and maximum cross-correlation were computed between the physiological signals of two persons cooperating on a maze task. For EDA the distribution of the correlation coefficients is very similar despite of the fact that maximum cross-correlation should increase the reported correlations when a time lag exists between the physiological activities of the participants. Apparently, this is because the maximum cross-correlation is generally obtained at a zero lag for this signal. Henning *et al.* [12] reported higher IBI correlations and much higher respiration correlations which demonstrate the effect of maximum cross-correlation compared to standard correlation. The weighted coherence measures found in [12] were also slightly higher than in our study; however this could be explained by the different frequency range (0.02Hz-1.25Hz) they used for weighted coherence computation. It has also to be noted that the game used in their study was designed specifically to analyze cooperation while we used a standard commercial game. This difference in the game type could also explain the observed differences in compliance.

As mentioned in the introduction, there are several potential reasons why shared physiological activity occurred in the present study. Firstly, the two participants were playing the same game and thus subject to the same stimuli. This common environment might have a double impact on compliance by directly eliciting physiological co-reactions and by fostering a common dyad play experience, which also increases coupled physiological activity. Secondly, physiological compliance might have arisen due to coordination of actions and movements on the console interface. When the participants accomplish the same movements at the same time, their ANS will provide concurrent support for those actions and, as a consequence, their physiological profiles will synchronize. Finally, one possible cause of coupled physiological activity is social

interaction. During play, participants were able to interact virtually through the game mechanics, and they could also use communicate directly since they were seated next to each other. Because those two kinds of interaction were possible, the participants could construct a mental model of the other player and also perceive this player's emotional reactions, which allows for the occurrence of social processes, such as emotional contagion and empathy. Since emotional contagion has been shown to be directly related to commonality of facial expressions [17] and both social processes have been associated with ANS compliance [15], it is likely that they also contributed to higher compliance in the present study.

Most probably, all the three aforementioned sources of shared physiology additively contributed to the overall computed compliance. The view that commonality of stimulation and experience would be a source of compliance is partly supported by the high correlations obtained between the dyad member's self-evaluations, which indicate that the participants had a very similar gaming experience. Unfortunately, it is not possible to assess to which degree common stimuli contributed to compliance in the current protocol. The coordination of movements and actions, the second potential source of compliance, was only assessed using the behavioral involvement component of the GEQ questionnaire. Since no other objective indicator was employed, it is again difficult to infer its impact on compliance. Concerning the social interaction explanation, physiological compliance was successfully predicted by the GEQ social measures, which clearly demonstrates the impact social interaction (as measured by self report) had on physiological compliance in this study.

For two of the measured signals, namely CS EMG and respiration, the correlation coefficients were quite low with a median close to zero. Moreover, many correlation coefficients were also negative for the IBI, CS, EDA, and respiration signals indicating that, in some cases, the signals were oscillating with a relevant phase differences. For respiration, this effect was already

explained in section 3.4; and owing to the effect, the weighted coherence measure was also employed. Since the amplitude of the other signals is directly influenced by game events (i.e. tonic change), they are less oscillatory by nature (i.e. there are no specific cycles). In these cases, negative correlations might indicate specific compliance processes. For instance, positively correlated CS activities indicate common negative experience and could be interpreted as an effect of emotional contagion. On the other hand, a negative correlation for CS activities could signify that negative emotions are experienced in alternating turns by the participants, which better corresponds to social constructs, such as revenge.

4.2 Compliance and social interaction

One of the main findings of this study was the predictive relationship that was found between compliance and the social GEQ components. Facial EMG compliance was particularly interesting in this respect with OO compliance being predicted by social empathy and CS compliance being predicted by social negative feelings. The GEQ social presence “psychological involvement - empathy” component includes items corresponding to the definition of empathy: the ability of a person to understand, feel or respond compassionately to other’s emotions [15]. However, this component also includes items addressing perceived affinity and connectedness. Importantly, the component is exclusively addressing positive empathy and affinity, since none of the items taps negative feelings. Since OO activity is generally associated with smiling and positive emotions [33], the observed relationship indicates that, when the participants were smiling more synchronously they reported higher positive empathy. Synchronous smiling could occur if the two dyad members had the same reaction to a game event and, according to the emotion contagion principles [17], when the participants’ emotions were influenced by their partners’ emotional state. We believe that a common experience of the game stimuli led to higher affinity

between the participants, while emotion contagion phenomenon supported empathic reactions [15,34]. As a result, the GEQ empathy score, which is a combination of affinity and empathy measures, increased together with the degree of OO compliance.

The relationship between CS compliance and social negative feelings was found to be negative. This implies that the more the participants were frowning concurrently the less they reported occurrences of social negative feelings. It is commonly accepted that the amount of CS activity is an indicator of negative experiences [33] while the GEQ social negative feelings component mainly tries to capture the extent to which game-related social negative emotions were felt by the participants. Such emotions include jealousy, revenge and malicious delight. These results suggest that asynchronous CS activity is related to social negative feelings, such as revenge. In an emotion contagion framework, a possible explanation of this phenomenon is that concurrent CS activity is interpreted by the participants as compassion and empathy, as concurrent CS activity would imply that together they have negative feelings elicited by something happening in the game, not against each other. Furthermore, the lack of co-occurrence might be interpreted as a social sign of disinterest and disrespect, since one of the participants is not adequately responding to the other.

Both of the relationships observed between social GEQ components and OO and CS facial muscle activities confirm the importance facial expressions have in a game context. Although the results were obtained using facial EMG data, it is also possible that emotional contagion occurred owing to speech, for example. In any case, the results demonstrate that facial expression synchrony could be used to infer the social climate existing between the participants. Two other physiological compliance measures were also found to be significantly predicted by the components of the Social Presence Module of the GEQ questionnaire: IBI coherence in the HF band was predicted by the Negative Feelings subscale and respiration coherence in the same

band was predicted by the Empathy subscale. An increase in weighted coherence can be due to two reasons: (a) an increase in the signals amplitude covariance at the given frequencies and (b) an increase in the signals phase covariance [35]. There is very limited and controversial literature on respiration patterns during emotion elicitation. However, the results can be again interpreted in the emotional contagion framework: when participants reported a high level of empathy, it is likely that they felt shared emotions, physiological compliance thereby increasing as is demonstrated here by an increase in respiration compliance. Surprisingly, contradictory results were obtained for IBI coherence in the same frequency band, despite of the fact that the IBI HF oscillations should be strongly influenced by respiration because of RSA. This suggests that the RSA effects were not very strong during gameplay.

We view the relationship existing between physiological compliance and self-reported social presence in games as an evidence that physiological compliance is a useful measure in assessing social interaction during a digital game. According to the results, physiological compliance is influenced by both negative and positive social interaction through different processes, such as emotion contagion and commonality of experience. According to BioCCA and Harms [21], commonality of experience and behavioral interdependence are fundamental for the emergence of social presence during mediated interaction. We thus argue that physiological compliance is an objective measure that can be used to assess social presence that can be used in many kinds of both mediated and non-mediated social interactions ranging from conflict or competitive interactions to more positive ones.

Finally, with regard to empathic processes, we did obtain several correlations between self-reported empathy and compliance while this effect was not observed previously [15]. This could be due to differences in the self-report indices used and in the experimental setup. Moreover, compliance was related to positive empathy and feelings while a relationship between empathic

accuracy and compliance was only found for negative emotions previously [15]. Thus, our results extend the proposition of emotional experience commonality to positive feelings.

4.3 Compliance and core experience

The effect of social empathy on ZM and OO compliance was in line with a positive relationship between GEQ Positive Affect and compliance. Similarly, respiration compliance was negatively correlated with core negative affect while it had a positive relationship with social empathy. In our view, these effects demonstrate that empathic physiological coupling (i.e., physiological coupling due to commonality of positive emotional states) was associated with higher positive feelings. This view is further motivated by the results of Jakobs *et al.* [36] who found that co-experience and co-expression of an emotion increases the intensity of the felt emotion. In addition, the negative relationship between respiration compliance and core negative affect might be explained by the following indirect effect: emotional co-experience might have reduced the emotional impact of negative events and increased respiration compliance. Thus, as was already suggested [37], playing a game together is a potential way for players to increase their positive emotional experience, especially if the players are showing empathy and connectedness.

In previous studies physiological compliance was found to positively correlate with performance on a video game [12] and, on the contrary, to have a negative relationship with team work effectiveness [16]. While we did not use any objective measure of performance in our study, we did obtain a positive relationship between CS compliance and self-reported feeling of competence during game-play. Although not significant, this effect might also suggest a positive relationship between play performance and physiological compliance.

4.4 Compliance during competitive and cooperative play

The analyses based on the standardized physiological compliance variables showed that, for most of the participants, physiological activities were more coupled during competitive play than cooperative play. Although the conflicting situation was artificially created by the game mode, these results are in line with those reported by Levenson and Gottman [11] who found higher physiological compliance between spouses during conflicting interaction than during a low-conflict discussion. The pattern observed for CS compliance indicates that higher negative affect reciprocity was observed during competitive play, which is also in agreement with previous results [11]. However, a similar pattern was observed for the ZM and OO muscle areas, showing that the competitive mode also evoked higher positive-affect reciprocity. In addition to the significant correlations of compliance with empathy and positive affect, the latter result demonstrates that physiological compliance is not only associated to negative conflict but also to intense positive social interaction. Although conclusive evidence is lacking, we believe that high physiological compliance is, in general, due to the intensity of the interaction rather than to the existence of a conflicting interaction.

Accepting this hypothesis would imply that the amount of interaction between participants was higher during competitive play than cooperative play. This could be explained by the characteristics of the Bomberman game used. In the cooperative mode, there are no particular game features that encourage collaboration. Consequently, playing cooperatively against a computer is quite similar to playing alone in terms of interaction. On the other hand, the competitive mode intrinsically contains some form of interaction between the players since they have to fight against each other. Therefore, physiological compliance appears to be a promising candidate for an index of the intensity of interactional features in a game.

EDA and IBI were the only signals for which none of the compliance indices was higher during competitive play. For the IBI time series, the normalized coherence in the HF band was actually significantly higher during cooperative play than competitive play. $ZC_{IBI}(HF)$ was also the only compliance index that was significantly and positively related to Negative Feelings (component of social presence). We believe that heart compliance in the HF band might reflect negative social processes such as jealousy and revenge. However, this would lead to the conclusion that the participants had more negative social interactions during cooperative play which is not really plausible.

4.5 Playing in the laboratory

For most of the signals, compliance was very similar irrespective of whether the participants played the game at home or in the laboratory. Only the $ZC_{IBI}(VLF)$ compliance index was found to differ depending on the location, with compliance being higher when playing at home. It is conceivable that more social interactions are taking place when playing in a familiar social context rather than in a neutral laboratory. Although we tried, as much as possible, to control for changes in environmental variables (using similar chairs, ensuring a reasonable amount of light, etc.) it is still possible that the compliance difference observed between the laboratory and the home is due to changes in the environment. Nevertheless, since only one compliance index was affected by play location, which is not too alarming, we believe that compliance results obtained in a laboratory might be considered as ecologically valid.

4.6 Limitations and future work

A main limitation of this study is that only one game was used. Since game play features can vary a lot from a game to another it is difficult to draw conclusions applicable to all games, and even more so, to other types of mediated or non-mediated interaction. It is clear that in

different types of video games (e.g., point-and-click adventures, first-person shooters and strategy games) the interaction between participants is different, not to mention in other kinds of activities, but it is not obvious how each difference affects the use of physiological compliance in assessment of social presence. For this reason, we strongly encourage the analysis of compliance using different types of mediated and non-mediated interaction. The analysis conducted in this study was limited to dyad members who already knew each other. Some studies have demonstrated that physiological reactions could be different when playing with a friend or a stranger [37,38]. More research is thus needed to extend the results we obtained to other types of social relationships. It would also be interesting to better understand how social factors, such as attractiveness and affinity, influence physiological compliance. Correlation and weighted coherence were used to compute physiological compliance indices. Both methods are able to detect only linear relationships between the signals. Recently, new methods have been developed in the field of dynamical system analysis to detect non-linear relationships [35,39]. However, those methods have mainly been applied to brain signals analysis [40] and not to peripheral signals. In addition, we analyzed only inter-person compliance for the same signals while the analysis of compliance between different signals should also be considered (e.g., computing compliance between EDA of the first participant and EMG activity of the second). We believe that non-linear methods, coupled with the analysis of heterogeneous signals, are promising tools to fully understand physiological compliance. Finally, the computation of a unique and general index of compliance that would take into account all the signals' dependencies should also be considered. Such an index would be valuable as a more robust measure of interaction.

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