

Exploring Skin Conductance Synchronisation in Everyday Interactions

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ABSTRACT

Detecting interpersonal and emotional aspects of behaviour is a growing area of research within HCI. However, this work primarily processes data from individuals, rather than drawing on the dynamics of an interaction between people. Literature in social psychology and neuroscience suggests that the synchronisation of peoples' biosignals, in particular skin conductance (EDA), can be indicative of complex interpersonal aspects such as empathy. This paper reports on an exploratory, mixed methods study to test the potential of EDA synchronisation to indicate qualities of interpersonal interaction in real-world relationships and contexts. We show that EDA synchrony can indicate meaningful social aspects in everyday settings, linking it to the mutual emotional engagement of those interacting. This connects to earlier work on empathy in psychotherapy, and suggests new interpretations of EDA synchronisation in other social contexts. We then outline how these findings open opportunities for novel HCI and ubicomp applications, supporting training of social skills such as empathy for doctors, and more generally to explore shared experiences such as multiplayer games.

AUTHOR KEYWORDS

Biosensors, Empathy, GSR, Physiological synchrony, Mixed methods, Skin conductance

ACM CLASSIFICATION KEYWORDS

H.5.3 [Group and Organization Interfaces]: Synchronous interaction

INTRODUCTION

HCI research is growing increasingly interested in looking at ways in which technology can, automatically or semi-automatically, detect emotional and interactional aspects of peoples' behaviour, and the potential of using such information in interactive systems.

This growing interest is manifested by the emergence of specific sub-communities such as Affective Computing (AC) and Social Signal Processing (SSP), more than 150 relevant publications in the CHI conference alone (e.g., [3, 26, 29, 35]), as well as a number of recent reviews of the relevant literature [8, 30, 39]. However, despite this impressive growth over recent years, most of this work is still based primarily on data from individual persons, rather than on the dynamics of the emotional expression and exchange crucial for social emotions [8], and the "machine analysis of social emotions such as empathy, envy, admiration, etc., is yet to be attempted" [39]. Such focus on the individual's bio- and other data in isolation does not draw on one of the key features of social interaction: the socially constituted nature of emotion. Boehner et. al. [6], and similarly others, e.g., [15], argue that emotion is socially constituted, and, as such, emotion is intrinsically connected to the interaction. In other words, although some aspects of emotion can play out on the level of individuals (e.g., their physiological changes), interpretation can only take place within a particular interaction, and between those interacting.

One potential approach to such indicators of interpersonal aspects is suggested by recent literature in psychology and social neuroscience, showing how peoples' physiological signals can mutually react and synchronise during an interaction, and how the extent of such synchronisation can be indicative of particular qualities of interaction [10, 17, 20, 34, 13, 19]. As yet however, HCI has not taken advantage of the possibilities of such physiological synchrony in a social context, even though it suggests an approach to detecting social aspects which is inherently interpersonal and bound up with the ongoing interaction.

Of particular interest to this paper is the work suggesting a connection between *synchronisation of skin conductance* (also called electrodermal activity, EDA) and *empathy*, shown in psychotherapeutic settings [23, 24]. Such a connection is especially interesting for HCI as empathy has been understood as an important concept in various areas of HCI (e.g., autism research [37], design [41], as well as leadership training [14]), but is only now beginning to be explored in detail. In fact, very little research has focussed on systems to support or develop empathic interactions in HCI so far, and empathy is one of the core interpersonal aspects that is yet to be addressed by AC or SSP. As such, an indicator of empathic interactions could inspire and allow for novel systems in all these domains.

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While EDA synchronisation might fit that role, it is, however, not clear whether the connections between EDA synchronisation and empathy transfer from therapeutic relationships to other more everyday social settings (such as friends, family or workplace interactions), which are of key relevance to HCI. Indeed, the only other work looking at EDA synchrony suggests a very different interpretation within marital interaction, where a lab study, asking married couples to discuss a problem in their marriage, associated high EDA synchrony with problematic, negative interactions (and even correlated with higher divorce rates later) [19, 20]. So although a different interpretation of EDA synchrony is possible in each of the two settings explored by earlier work (thus suggesting the potential usefulness of it as an indicator for HCI systems, be it for empathy or other interactional aspects), it is unclear if and how these seemingly incompatible results would transfer to other everyday relationships, contexts and interactions, and whether it can be applicable, and thus of use, to HCI.

To start addressing this gap, this paper provides an initial exploration of the potential of EDA synchrony as an indicator for HCI, including its potential for real-world deployment within HCI systems. Such test of the feasibility of EDA synchrony use in the real-world is the first critical step to bridge the controlled findings from psychology to possible HCI use, and is crucial to inform future HCI work using indicators based on EDA synchrony in deployable, interactive systems [25, 27, 35].

Our results draw on a mixed methods study with 40 participants (i.e., 20 pairs), whose interactions were collected under a reasonably unconstrained and ecologically valid setting (a lively pub), specifically selected as a form of a 'breaching' setting to test the robustness of the EDA synchrony in conditions close to a real-world deployment. We analyse how the changes of participants behaviour correspond to EDA synchrony and vice-versa, i.e., what can EDA synchrony be an indicator of. Our key result links *consistently high synchrony* with *mutual emotional engagement* of the pair. Drawing on this data, we hypothesise that EDA synchrony corresponds to 'emotional reactivity' between the pair, outlining how emotional reactivity could explain the apparently incompatible results of previous work. We then outline, in the 'Implications for HCI' section, how such ability to detect empathy/engagement in real-world settings opens opportunities for novel interactive HCI systems, listing social skills learning for autism/neuro-typical populations, remote communication, or games research as possible application areas.

The main contributions of this work are:

- Providing evidence that EDA synchrony can be interpretable in everyday settings (and therefore serve as a real-time indicator of interpersonal aspects).
- Outlining the opportunities such an indicator brings for novel HCI and ubicomp applications.
- Providing a clear hypothesis, directly building on our data, that explains the seemingly incompatible results from earlier studies and could guide future work.

RELATED WORK

Synchrony complementing Affective Computing and SSP

Despite the large body of work on Affective computing (AC), there are still recognised challenges. In the Introduction, we raised the focus on single subjects rather than interaction dynamics. Additionally, existing work has looked mostly at distinguishing a fixed list of emotions, such as anger, surprise and other 'basic' emotions suggested by Eckman's work, rather than the more complex interpersonal aspects [30, 15]. It is now increasingly recognised that, in many cases, aspects other than the basic emotions are relevant for real-world applications (e.g., [4, 11]). This brings an emerging focus on social signal processing (SSP), with initial work looking into aspects such as dominance, negotiation outcomes, or agreement and disagreement in the interaction (see [39] for a review). For specific examples of such more interpersonally oriented work, Kim et. al. [16] sense and give feedback on dominance during group discussion, Pentland et. al. focus on detecting influence or activity within the interaction [31], and there are initial attempts towards detecting mimicry (at the moment under lab situations) [36, 5]. However, even this work still draws mainly on sensing data at an individual level, predominantly relying on audio- or video-based data, and increasingly on bio-signals. Real-world deployment of these technologies is still a challenge, as many come with strong assumptions on the input signal (e.g., no occlusions, face tilt or larger body position changes in the video signal) [39, 30].

Should EDA synchrony be indicative of interpersonal aspects such as empathy, it would complement much of the research above. On one hand, it is complementary to the audio/video SSP approaches, by drawing on other aspects of the interaction (physiological arousal rather than non-verbal signals). It is also complementary to existing bio-signals work as it is the first that looks at the *interaction* and *mutual* relation of signals rather than analysing each individually. It also brings complementary challenges for signal collection, for example being much less sensitive to light condition changes, movement or position, when compared to video-based techniques. Indeed, recent work shows that EDA can be indicative of aspects of interest even in real-world settings (e.g., interruptions [29] or work engagement [26]).

Synchrony research in other disciplines

Multiple strands of research in psychology and social neuroscience have explored synchrony of bio- and non-verbal signals and its relationship to interactional aspects.

The extent of EDA synchronisation has been associated with different social aspects depending on the context, as already mentioned in the Introduction. It correlated with patient perceptions of empathy in the psychotherapy setting [23], and lack of synchrony indicated whether a therapist is purposefully emotionally distant during an interview with a patient [24]. For marital interactions, EDA synchrony was connected to distressed discussions (e.g., "being locked in" a destructive interaction during a conflict) when couples were asked to discuss a problematic aspect of their marriage [19]. Similarly, synchrony between an external observer and a spouse was associated with higher recognition of negative affect on

the part of the observer [20]. However, the overall view on what synchrony means is mixed and the literature so far does not provide explanations of such strong differences dependent on context.

For bio-signals other than EDA, synchronisation of heart rates was shown to indicate the closeness of a relationship in several studies. For example, Konvalinka [17] observed a synchronisation of heart rate between observers and participants in a fire-walking ritual as long as the observers were in a close relationship to the participants; and Cwir [10] describes how a subtly induced feeling of closeness with a stranger (e.g., being told that they share a birthday) strongly increases heart rate synchronisation between the participants. In addition, social neuroscience studies find analogous results on the neurological level, showing how the brain areas associated with experiencing pain light up if we see others experiencing pain, suggesting that people co-experience the situation to some extent [34]; and show how such neurological synchronisation can be affected by manipulating attention away from others' experiences [13]. Finally, a large body of literature explores how non-verbal mimicry both affects and is affected by rapport, empathy, attraction and other emotional states [9].

While the existing evidence points to using synchrony as a potential indicator of interpersonal aspects, all prior research analysing the synchrony of EDA and other bio-signals was performed either under tightly controlled and restricted laboratory conditions [10, 20, 34, 13], or in very unusual situations such as the fire-walking ritual in [17] or the psychotherapy session in [24, 23]. This could be an important limitation for the use of synchrony in HCI work. It has been shown that many laboratory-based effects seen in psychology do not transfer into the real world at all, or can even change the direction of effect. See for example Mitchell [27] for a meta-review of the ratio of psychology lab results transferring to field, with social psychology being the worst, with approximately 20% of studies changing the direction of effect when tested in the field; and, e.g., [25, 35] for specific examples of such changes from within HCI literature. Similarly, as can be seen on the work of EDA synchrony, it is not immediately clear how the results change outside of the unusual contexts in which individual studies were run.

In summary, if EDA synchrony does indicate complex interpersonal aspects of behaviour, such as empathy, it would complement and point to novel light-weight approaches within the social signal processing and affective computing domains, as well as open opportunities for novel HCI applications supporting social skills. However, it is not clear if and how the suggested link between EDA synchrony and interaction transfers to other contexts and if that link is robust enough to support real-world applications.

THE STUDY

To explore this, we designed a study collecting quasi-naturalistic conversations between 20 pairs of friends. We conducted a qualitative analysis looking at recurring patterns between the EDA synchrony and the interaction, triangulating our results with external raters.

Study design

We employed both qualitative and quantitative methods to triangulate our findings, using the different approaches to provide multiple indications that EDA synchrony can be interpretable (and therefore serve as an indicator of aspects of interest) and do so even under a reasonably unconstrained and ecologically valid setting (which has been specifically selected as a form of a test for the robustness of EDA synchrony).

Participant selection: We choose to recruit twenty *pairs of friends*, who can be expected to talk naturally and be willing to share emotional issues with each other. This allowed us to tap into an everyday relationship setting, where some extent of empathy is likely, but where participants have not been formally trained¹.

Study setting: A key focus of this study was testing the practical usability of EDA synchrony for HCI applications. For this reason, we selected a setting that would include many potentially intervening factors that would also be present in real-world applications of systems built on EDA synchrony. We selected a local pub/bar as the best option, as a setting which is lively, does not resemble a laboratory, but is still a place where friends come to talk.

Task: To facilitate as natural a conversation as possible in the context of the study (and a greater variability of topics), we asked our participants to discuss issues of their choice, only suggesting that they choose a topic that was personally meaningful and that they believed the other participant could relate to. In summary, the study was structured into three parts. Participants were first asked to each think about an issue they could discuss. Second, we asked them to hold a conversation on one of the topics (*natural* phase). Third, we included a manipulated interaction asking one participant to ignore the other (*ignoring* phase). The aim of this third part was to create a disrupted, conflicting situation, exploring its effects on EDA synchrony as a way to connect to the work on marital conflicts [19].

Study process

Sensors and video-recording set-up

Skin conductance (EDA) was collected from each participant using a medical grade MindMedia Nexus-10 unit, capturing at a data rate of 128Hz. Electrodes were attached to the index and middle finger on the non-dominant hand of each participant and the data was transmitted by bluetooth to a nearby server. Video of the interaction was captured using a Sony GoPro Hero 2, positioned to capture both participants, with sound recorded using a directional condensing microphone. Additional video and audio was captured from a second camera with an omnidirectional microphone. Video from both sources was captured directly on the server and synchronised with the skin conductance data. To manage the data we used

¹In comparison, the therapists are extensively trained in empathy over the period of many years. Moreover, a therapy session is a very unusual social context, where the main goal of the therapist is to “be empathetic” and devote their full attention to the client.

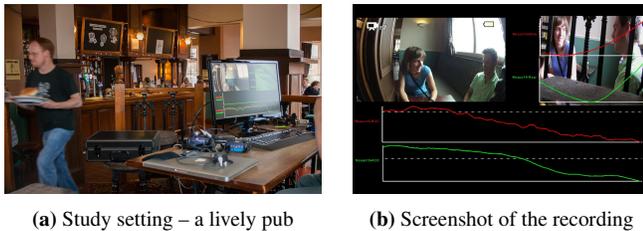


Figure 1: Study in process

the *Vicarious* system [38], which allowed us to capture, synchronise, monitor, process and simultaneously play back the video, audio and data feeds. Figure 1 shows this in context.

Signal processing

The raw skin conductance was smoothed using a rectangular smoothing algorithm, then isotropically scaled based on a running minimum and maximum value taken from each participant [23]. We then used the rate of change of the signal for the calculation of the index of synchrony described below (as SSI). This goes some way to address the issue of skin conductance signal drift in a raw signal.

Computation of EDA synchrony

We replicated the algorithm from Marci’s et.al. work [23] to calculate the value of moment-by-moment physiological concordance as well as the calculation of single session index (SSI) of physiological synchrony.

The average rate of change for each signal was calculated using a 5 second rolling window with a roll-rate of 1 second. This resulted in a series of values at a rate of 1 value per second. Next, pairs of these signals were combined using a Pearson correlation with a 15 second window (also rolling at a rate of 1 second) to give a moment-to-moment correlation value for each pair. Each of these values reflects the moment-to-moment synchrony, i.e., the extent of the synchronisation between the two participants in the last 15 seconds.

The SSI represents an index of synchrony over a longer period of time and is calculated as the natural logarithm of the ratio of the sum of positive synchrony divided by the sum of negative synchrony over the specified time. In the context of this paper, we used it mainly to compare the ‘average’ synchrony over whole sessions (again using methodology following [23]). To minimise the effect of starting and ending disruptions, we cut off the first and last 30s and ran SSI analyses on the remaining 4 minute fragment. Note that the SSI indicator takes into the account both the duration as well as the extent of the synchronisation over time.

Detailed study procedure

Participants (A and B) were invited to discuss a “topic they felt was meaningful and to which their partner could relate.” Details of the purpose of study were kept deliberately vague at this point. First, A and B were separated and left alone for five minutes to think about topics. Then they sat at a table together and A led the conversation with their chosen topic. This formed the *natural* period of the study. After five minutes they were separated for a short period under the pretense

of a questionnaire, during which A was secretly told that, for the following session (discussing B’s topic), they should actively ignore B, avoid eye contact, and answer only very direct questions. B was then invited back and this last section formed the *ignored* period of the study. Finally a joint debrief was conducted, including explicit clarification of the ignored condition, along with a short interview of both participants, who were then compensated for their time. Care was taken to balance the gender of A in mixed gender groups, i.e., A being male in one group then female the next and vice versa, and participants were asked (despite the pub setting) to refrain from drinking alcohol before or during the recordings.

Participants

Forty participants (i.e., twenty pairs of friends) were recruited by fliers posted around the campus and in the pub. Of these, 23 were male and 17 female. Within pairs, 5 were both female, 8 were both male and 7 were mixed gender. The ages ranged from 20 to 35, with a mean age of 23.8 and a median of 24.5. Twenty-two of the participants were of European or North American origin, 14 were of Arabic or Indian backgrounds, and 4 were of east Asian origin. The duration of the relationships ranged from 6 months to 18 years, with an average duration of 3.3 years and a median of 1.25 years. Participants further rated their relationship on a scale of 1 (closest friends) to 7 (complete strangers), with the average relationship score 2.3 and a median of 2.

ANALYSIS

The aim of the analysis was to explore the correspondence between differences in interactional aspects and differences in the underlying EDA synchrony signal.

However, tapping into such correspondence between behaviour and the synchrony signal is methodologically challenging: First, prior work suggests links between synchrony and several complex, interpersonal aspects such as empathy, emotional distance, or interpersonal conflict, none of which is reliably identified by a set of micro behaviours, verbal or non-verbal, that could be coded; especially as the goals of this study are to understand possible hypotheses and interpretations of synchrony, rather than test its correspondence to a single particular aspect. Second, the extent of these aspects is expected to change substantially over the duration of each interaction, pointing to the need to include annotations of interactions over the whole duration. Finally, each single synchrony value always refers to a longer segment of the interaction (approx. 20 seconds), rather than a particular moment, which is an inherent property of the way it is computed.

For these reasons, our analysis approach builds on the large body of interpersonal judgements research in psychology [1, 2], drawing on the reliability of intuitive, social judgements we humans make every day.

Analysis approach taken

We ran the analysis in two major phases. The first consisted of our qualitative video analysis, aiming to reach hypotheses about the possible links between the computed EDA synchrony levels and observed behaviour. In the second, we triangulated our observations with external raters’ judgments.

Phase 1: Reaching qualitative understanding of the data

The first phase of qualitative analysis took place in several steps. We first watched all sessions without any access to physiological data. The aim was to get an initial feel for the interaction without being affected by looking for correspondences with the signal data. We repeatedly watched through the videos, looking for interactional aspects suggested by earlier literature such as active listening, attending to the other person, emotional or 'deep' discussions, periods of disagreement/conflict etc. We annotated the videos with time-stamped notes pointing to the moments of interest, thus preparing a set of potentially relevant moments to be compared with the moment-to-moment synchrony values in the next phase.

The second step focused on matching fragments of interactions that were extreme in *computed EDA synchrony* to changes within interaction. The rationale was that *if* changes in synchrony do correspond to differences in interaction, comparing parts that are extreme in the underlying signal should reveal large effects, which can be then explored in a more focused way within the remaining interactions. Moreover, if we found no obvious differences even among fragments varying the most in synchrony, the practical usability of synchrony for HCI real-world applications would likely be problematic. We first identified parts of the interactions for which synchrony values were extreme (e.g., long consistent high/low; or a very fluctuating synchrony signal) and then looked for any recurring patterns in interactional differences between these periods extreme in synchrony, building on the analysis notes from step one but also re-analysing the videos in depth. Methodologically, this is similar to thematic analysis, run on annotated video data rather than transcribed interviews. See, e.g., Figure 2 for an example of the screen used for analysis; and the video figure for an illustration of the kind and extent of interactional differences we are drawing on.

In the third step, we returned to the remaining data, matching the observations and created hypotheses from the extreme moments analysis to the rest of the interactions.

Phase 2: Triangulating with external raters

To triangulate the qualitative findings, we recruited a group of 3 external raters to give their qualitative impressions of the full 'natural' sessions. All of the raters were counselling students (as these can be expected to be particularly sensitive to interpersonal aspects through their training), females (as earlier literature suggests they can be more sensitive than men [2]) and had no prior connection to the project.

All three raters met for a single session of 3.5 hours and were asked to first independently write their impressions of each session. We offered no indications of what to look at, apart from explaining the study is most interested in 'interactional aspects' (rather than explicit content of the discussions). Second, we asked them to, still independently, judge each session on four suggested aspects, drawn from the understanding of the data we gained in our analysis. We asked about the perceived engagement of the pair with each other, their engagement in the topic, the importance of the issue discussed, and how well the conversation 'flowed'. The goal was to orient the raters to concepts we were interested in, and prepare



Figure 2: Combination of video and sensor data used for the qualitative video analysis. The vertical bar in the physiological data stream indicates current timeline position in the video. The top line depicts the moment-to-moment synchrony changes during the course of the session. The bottom line shows a special version of the SSI, computed as a rolling window over each 30 seconds. That is, each single point on the SSI graph corresponds to the ratio of high/low synchrony over the last 30 seconds. It is thus an indicator of consistency of the signal over that period.

ground for the last phase. In that last phase, all the raters together selected 3-6 discussions they could all agree on as the most emotionally engaged, and 3-6 discussions that were the least emotionally engaged, and point out any others they wished (for whatever reason). They were then asked to explain their choices, including brief summaries of why they chose the particular interactions; and finally asked to talk about the remaining videos, summarising their impressions of them. We then compared all this data with the notes from our own qualitative analysis.

KEY FINDINGS

Our particular focus in this analysis was on if and how the observed changes within interactions corresponded to changes in synchrony, and vice versa. In particular, we outline the observed link between changes in the perceived *emotional engagement* of the pair and the EDA synchrony data. Our results also highlight the role that consistency of the synchrony signal plays in possible interpretation. Due to space concerns, and the fact that we found similar recurring patterns over both conditions, we will mostly focus on the *natural* interaction in the rest of the paper, referencing the *ignoring* discussions only briefly.

Exploratory qualitative analysis

Our initial focus was on looking for patterns in second-to-second changes in synchrony and their correspondence to observed interactional aspects, first exploring the interactions without the physiological data, and only later linking changes in synchrony to identified changes in the interaction.

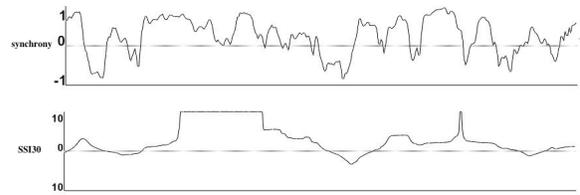
Our participants led a wide range of conversations, with marked differences in both the importance of the topic as well as the general 'mood' and flow of the conversation. For example, the topics ranged from very serious personal or work-related issues (e.g., a father becoming bankrupt and losing his

factory, a long-distance relationship, drug problems, or problems with a dissertation very close to submission), to talking about relatively trivial matters (e.g., a shared interest in pub-quizzes or a dislike of coconut in food). The overall mood of the discussions also varied extensively, from a 5 minute monologue with few back-channel responses from the listener; to what seemed like polite chit-chat on trivial topics with good flow but no emotional substance; to very deep and intimate conversations full of self-disclosure. This allowed us to identify many moments that differed strongly in the perceived extent of active listening, empathy etc., and formed a basis for the next analysis phase. We then turned to exploring the physiological data and its connection to the different types of conversations we saw in our dataset. As described in the Analysis section, we started by exploring the patterns of interactions within moments extreme in synchrony, drawing on the earlier observations. We then validated the identified patterns across the remaining videos.

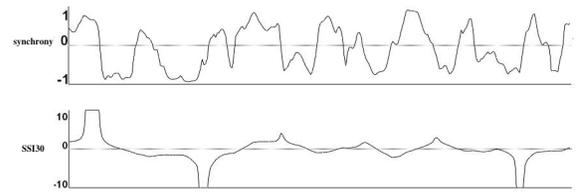
The key observation is that *consistently* high EDA synchrony was associated with *high emotional engagement* of both participants in the conversation; and that the situations with inconsistent, fluctuating EDA synchrony were predominantly low in emotional engagement. We use 'emotional engagement' as a label for situations where the participants were attending to each other in a focussed way (e.g., sustained eye-contact, back-channel responses, good flow of interaction), and the topic seemed emotionally relevant for both. Consistently high/low synchrony means that the moment-to-moment synchrony was consistently either high or low over a longer period, such as e.g., 30-40 seconds. See Figure 3 for an example of two sessions differing in consistency of synchrony. The video-figure then showcases the corresponding differences in emotional engagement.

In particular, consistent synchrony was not associated only with intimate, self-disclosing interactions (as one would expect if it were directly related to empathy), but appeared in a much wider range of contexts, with emotional engagement as the key aspect shared by all. For example, while we saw consistent synchrony in a discussion of a very intimate relationship issue (session 18), we also saw it for a pair passionately discussing a shared interest in a fantasy miniature game (session 17); as well as conflict situations such as a disagreement between a pair (session 19, one participant taking pills to lose weight, the other advising against it), or a shared expression of anger because of an unjustly lost competition (session 8).

Moreover, changes in synchrony were often 'interpretable' in discussions perceived as high in emotional engagement. For example, the drop and a later increase in synchrony in the middle of the Session 17 (see Figure 3a) corresponded well to a change in the interaction – from a fluent dialogue full of back-channel responses and joint laughter, to a monologue in which one of the participants was going through a list of activities he is planning to do, and then returning to its previous dialogue form. Similarly, session 18 is characterised by periods of deep self-disclosure and interaction between the pair, interleaved by moments where the speaker disengages and reflects on her memories and experience of the situation they talk about. These fluctuations of engagement fit well with the



(a) Session 17 – consistent synchrony and high emotional engagement



(b) Session 5 – fluctuating synchrony and low emotional engagement

Figure 3: Two examples of the EDA synchrony signal over a whole session, with the sessions differing in the consistency of synchrony. In particular, notice how for Figure (a), the synchrony values (top line) are above zero most of the time, as also reflected by the SSI values (bottom line). See also the video figure for short excerpts from these two interactions, illustrating the link between synchrony and emotional engagement.

changes in synchrony within the interaction, as shown by the graph in Figure 2.

In contrast, discussions that were not perceived as engaged had remarkably fluctuating synchrony. An example of extreme disengagement is session 5, which was a sustained monologue by one of the participants, with little perceptible correspondence between moment-to-moment synchrony and interaction throughout (see Figure 3b and the video figure). Similarly, session 6 has identical fluctuating synchrony, and is another example of a discussion judged low in emotional engagement, where the pair spent the 5 minutes politely discussing one participant's dislike of coconuts. While the discussion itself is somewhat fluent, with repeated shared laughs, both participants kept fidgeting, breaking eye-contact and appeared to be going through the motions. We could not connect the moment-to-moment changes of synchrony to differences in interaction in either of these two sessions (nor other sessions similarly low in engagement).

In addition, emotional engagement turns out to be key when analysing the 'ignoring' condition of the study. We saw similar increases in consistency of synchrony for moments high in emotional engagement. Due to the particularity of the situation (one participant asked to try and ignore the other, and give only short answers to direct questions), such emotional engagement and associated consistency of synchrony occurred especially in moments when the speaker was becoming angry/confused, asked direct questions and attempted to 'get a response' from the ignoring participant. In contrast, for situations where the speaker didn't notice or act on the other's ignoring behaviour (thus, situations low in emotional engagement), synchrony was again mostly fluctuating, and we again could not connect its changes to differences in interaction.

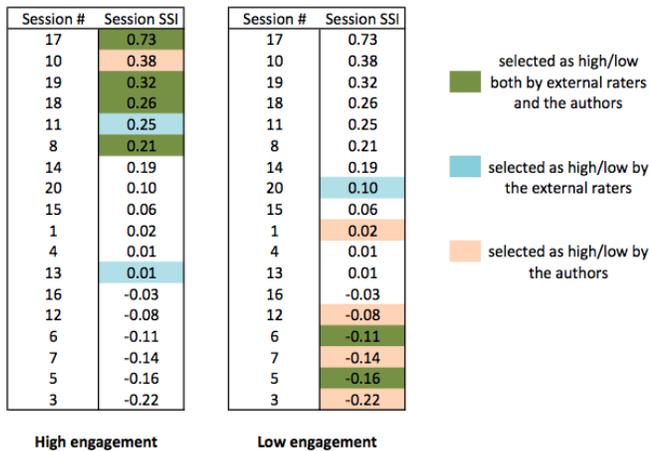


Figure 4: Overview of judgments of sessions high (left) and low (right) in emotional engagement. Sessions are sorted by the SSI index computed over the whole discussion time.

Triangulation – involving external raters

To triangulate our observations and validate our judgements of the interactional aspects, 3 external raters gave us their impressions of the sessions, without them being aware of the physiological data.

Overall, we found a very good match between the external raters and our own analysis, both in terms of the open observations we asked for each session, as well as judgments of emotional engagement. In particular, the raters also picked up on the different forms of emotional engagement present in our dataset, i.e., not necessarily emotional engagement bound to deep, empathetic conversations. They highlighted the concerned disagreement in session 19, shared passionate anger in session 8 etc.; as well as the marked differences between the ‘mood’ of individual interactions.

For example, to return to the differences of synchrony between session 17 and session 5 depicted at Figure 3, session 17 was described as surprisingly engaged, despite the potentially shallow topic: *“They were extremely engaged [...] they actually made something that was essentially quite dull, like painting soldiers or whatever it was, but the way they were talking about it, it was so exciting!”*. In contrast, session 5 was perceived as remarkably different: *“He just went on and on and on, didn’t he? He [didn’t seem to notice] the other one was bored out of his brains.”*. Similarly, the raters’ descriptions closely corresponded to ours even for sessions which were selected as specifically (non-)engaged just by us, or just by the raters. For example, session 3 was not highlighted as non-engaged by the raters, but was still described as *“Not really a conversation [...] he was just answering the questions which she kept asking”*. Figure 4 visualises this match between the judgements of raters and our analysis, comparing the sessions selected as high/low in emotional engagement.

Moreover, the sessions judged as high in engagement also tended to be high on overall synchrony, as measured by the SSI, an index of average synchrony over the whole session. Indeed, this is supported by quantitative analysis as well.

The SSI of sessions judged as high in engagement by both external raters and authors ($M = .38, SD = .24$) is significantly higher than the SSI of all other sessions ($M = .02, SD = .17; t(3.9) = 2.857, p < .05$). T-test was used as the data does not show significant deviations from normality (which also holds for every other test reported below). Similarly, looking at sessions selected as engaged by the external raters only, i.e., judgements independent on the authors, again give significant difference in SSI to all others ($t(6.6) = 2.836, p < .05$); and the results stay significant also for other possible comparisons, such as comparing sessions selected by either authors *or* raters as engaged against sessions selected as non-engaged ($t(8.7) = 4.017, p < .05$).

These quantitative results complement the qualitative analysis, providing another indication of the association of consistent (high) synchrony and high emotional engagement. Importantly, it also suggests that the overall index of synchrony across sessions could differentiate discussions that are (perceived by observers as) different in emotional engagement.

Summary

To summarise, across both our own analysis and the external raters, consistent synchrony corresponded to high emotional engagement in the conversation; and low emotional engagement was associated with fluctuating synchrony. These findings are also supported by the quantitative analysis, showing that the interactions judged as high in emotional engagement are significantly higher in synchrony across the session than the remaining interactions.

DISCUSSION

To gain insights into possible use and interpretations of EDA synchrony in real-world settings, we collected data about the interactions of twenty pairs of friends, in the real-world busy environment of a lively pub.

Qualitative analysis shows a strong connection between EDA synchrony and emotional engagement within the interaction. In particular, the interactions that were perceived as high in emotional engagement, both by the authors and a set of external raters, were also significantly different in EDA synchrony values; both on the level of moment-to-moment synchrony, as well as when comparing a form of average synchrony (SSI) over the whole interactions.

Due to the busy nature of the setting used, this is by itself a very promising result, suggesting that synchrony could be of practical use in real-world contexts. In addition, we draw on these results to propose an hypothesis for EDA synchrony interpretation, which could help to better understand the observations here, as well as explain the seemingly incompatible results of earlier studies. We then outline the implications of these findings for HCI applications and research.

EDA synchrony as emotional reactivity – a hypothesis

Earlier research has connected synchrony to various specific interpersonal concepts, such as empathy [23], distressed discussion [19, 20], and emotional distance [24], making the interpretation of synchrony seem to be strongly dependent on context.

Synthesising these earlier results with our work here, we instead suggest a *hypothesis linking synchrony to a more general concept* which can explain all the different manifestations of synchrony mentioned above: we hypothesise that consistent synchrony corresponds to *emotional reactivity* — i.e., moments when two people react emotionally to each other. This does not necessarily mean that they feel the same thing, but that they attend and react to each other on an emotional level.

Emotional reactivity corresponds well to the intuitive understanding of what synchrony, as a signal, reflects. By definition, consistent EDA synchrony simply means that:

- *the EDA signals of the two individuals ...*
(i.e., signals corresponding to changes in their arousal)
- *... correlate with each other ...*
(i.e., they change in a synchronised way)
- *... consistently.*
(i.e., do so over longer periods of time).

Synchrony, as a measure, thus simply indicates that changes in arousal happen synchronously between the two people, and consistently so over time. The consistency over time is particularly important, as it is (statistically) likely that two random signals— such as signals from participants who are not interacting with each other—would still correlate on occasions by chance; but it is highly unlikely that such spurious synchronisation would be sustained over a longer period of time.

An understanding of EDA synchrony as emotional reactivity fits well with the focus on emotional engagement and the observations from our study showing that a sustained engagement with the other is needed for consistent synchronisation to appear (e.g., the patterns of increases and decreases in synchrony corresponding to changes in engagement in session 18); and that the emotionality of the issue can create strong changes in arousal, and thus EDA, to synchronise with (e.g., as seen in session 19 for concerned disagreement, ignoring sessions for conflict, and sessions 8 and 17 for a shared topic that participants felt emotional and very engaged about).

We also argue that this hypothesis can explain the seemingly incompatible findings of earlier work, both in therapeutic and marital settings; and the wide range of emotional engagement seen here. In psychotherapy, empathetic behaviour is characterised by attentiveness to the other, 'being with the client', and reflecting, reacting and acknowledging their subtle emotional changes (e.g., [23]). All of these can be understood as related to underlying emotional reactivity. In the marital conflict discussions, high synchronisation reflected "the ebb and flow of negative affect, the escalation and de-escalation of conflict, and the sense of being locked into the interaction and unable to step-back" [19], again suggesting a form of 'locked in' reactivity of the participants to each other. Moreover, synchronisation was much lower in other discussions of the same couples on different topics in the same study (e.g., events-of-the-day), again pointing to the importance of emotional load and involvement in the discussion.

In summary, the combination of something both participants feel emotionally about, and their mutual attending to each

other — i.e., emotional reactivity — is what ties all these observations of interactions consistent in synchrony, and which is not present in the remaining ones. Emotional reactivity then manifests as a *particular* interactional characteristic such as empathy, conflict, or engagement with each other under different contexts. Synchrony is thus not in and of itself an indicator of these higher level emotional states, but with an awareness of the context, such states may be inferred.

Implications for HCI – areas of application

The combination of the earlier work, and the results here, makes it plausible that EDA synchrony could be used to indicate complex interpersonal aspects such as empathy, conflict and mutual engagement in real-world, uncontrolled contexts, and thus making it viable for use in practical HCI systems. The hypothesised connection of synchrony to emotional reactivity then suggests how the indicator interpretation might extend into other settings and relationships than those already tested.

For example, feedback of EDA synchrony can play a key role in augmenting current approaches in empathy training for leadership [7, 14], medical staff and students [28], or autism therapy [37]. While the importance of such training is acknowledged and a large number of such courses are widely used in practice (e.g., [12]), the curricula struggle to support timely feedback on skills like active listening or empathetic understanding, necessary for successful learning and practice [32, 40]. Novel systems based on EDA synchrony could, for example, provide real-time cues relevant to empathy (inferred from emotional reactivity in these contexts) through a wearable technology or ambient display; helping participants to reflect, interpret, and modify their behaviour on the fly during the training. Such systems would fit perfectly with the current teaching practices, adding an important layer of timely feedback [28, 40]. This also builds on prior research showing how such real-time feedback on similar indicators can help people re-interpret and change their behaviour (e.g., [3, 16]); or used to support post-hoc reflection on a practice session, serving as a cue to locate 'important' moments to reflect on (e.g., as per [33] in a different context), again enhancing existing teaching strategies.

As a more specific example of supporting empathy training, we outline an exemplary system supporting the training of active listening. Active listening is an exercise widely used in many contexts, from negotiation training in business [7], to developmental courses for medical students [32], or school education [12], or therapeutic settings [21]. Normally, this technique involves one person adopting the role of the speaker while the partner listens silently, only to paraphrase the content and feelings of the speaker at the very end. However, it is difficult for the listener (or the trainer) to gauge how attentive/empathic the listener is during the listening phase. A training system drawing on EDA synchrony could provide a real-time feedback of the physiological synchronisation to the listener, e.g., through a tactile stimuli, alerting them to moments when their engagement with the speaker might have slipped. Such real-time notification could not only support individuals' engagement in that particular session (similarly

to [3]), but also help students discover patterns of own behaviours that allow them to stay engaged and attentive for longer.

Moreover, understanding EDA synchrony as shared emotional reactivity also suggests additional contexts, where EDA synchrony might have useful interpretation. In particular, the existing work has looked at contexts where participants directly interact with each other. However, we would expect that a shared attention towards an emotionally relevant input such as a movie, computer game, or presentation might again trigger synchronisation on a physiological level. In this case, EDA synchrony could, for example, also complement current bio-sensor based evaluation strategies in multiplayer games research and design [22], as well as complementing audience research [18] – both areas which are already familiar with the use of skin conductance.

Novel analysis approach – interpersonal judgments

EDA synchrony has been linked to complex interpersonal aspects, requiring the analyst to connect changes in an interaction to patterns in a physiological signal. This problem is not restricted to EDA synchrony – much social signal processing and affective computing literature is heading in this same direction, with the increased focus on ‘social emotions’.

While these fields have already embraced the ‘thin slices’ aspect of the interpersonal judgments literature in arguing why detection of interpersonal signals from non-verbal stream is possible (e.g., [31]), they are still mostly using micro coding of non-verbal aspects to create and validate algorithms. However, the same literature suggests that macro judgements might actually be more relevant and accurate for social signal processing: “In general, judgments of impressionistic, fuzzy, molar variables related to affect and interpersonal functioning have yielded more accurate judgments than have quantitative assessments of microlevel behavior such as smiles and nods. This is because the same specific behavior might signal very different types of affect.” [1, p.241]. For example, using the macro judgements of external raters on recordings of naturally occurring behaviour could complement the micro-coding approaches, with the potential to lead to larger interactions corpora (as macro judgments are cheaper to collect), as well as higher ecological validity.

CONCLUSIONS

This work has explored the potential of EDA synchrony as an indicator of interpersonal aspects, such as engagement and empathy, outlining the novel opportunities this opens for HCI applications. We advance previous research by providing evidence that EDA synchrony is *interpretable* in real-world, everyday situations, connecting changes in synchrony to changes in emotional engagement. Additionally, drawing on the data from this study, we suggest a hypothesis linking synchrony to *emotional reactivity*, explaining the seemingly incompatible results from earlier work.

This work also connects to the recent interest on social signal processing in the HCI community, suggesting a complementary approach to what has been so far mostly drawing on a single subjects’ data rather than the interaction dynamics.

While much further work is needed for EDA synchrony to be well understood, this paper provides an important first step, and provides both techniques and approaches for future research in this intriguing direction.

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