Design Science

Interpersonal aspects of creativity: indicating interactive level dynamics with biosignal synchrony

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Abstract

Collaborative design (co-design) is a team effort fostered through the creative involvement of all participants in co-creative collaboration (co-creation). This new approach to design as a creative social activity heightens the need to study the interpersonal aspects of creativity. Though co-creation has become widely used in recent years, few studies focus on its dynamics, which emerge from intense interactions created by the shared subjectivities of participants in an intersubjective environment. The management and enhancement of interpersonal factors can help create this shared environment by leading the process from personal to interpersonal creativity. Some of these interpersonal factors could be measured by observing the data of biosignals that are used as social cues, particularly if studied in comparison with the data of one of the partners of the social interaction, thanks to the synchrony rate between these datasets. This synchrony of biosignals related to shared behaviours can be associated with the interactive level dynamics that occur during co-creation in team of two (pairwork). This study presents the results of an experiment where biosignal synchrony results were compared to subjective feedback regarding the interactive level to understand the dynamics of the interaction. The results suggest the possibility of using the synchrony rate measured by the Damerau- Levenshtein distance (Ld) or dynamic time warping method (DTW) to approximate the dynamics of the interactive level in co-creative pairwork. This study will contribute to our understanding of the influence of the socio-cognitive process on interactions during co-creation to improve the co-creative design process.

Keywords: biosignal synchrony, intersubjectivity, interpersonal factors, interactive level, co-design, co-creation

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1. Introduction

Design is a creative social activity where the interactions and experiences fostered are as important as the process itself, and this is something the collaborative design (co-design) methodology emphasises (Simonsen & Robertson 2012). From a social perspective, there are incentives to make co-design as accessible as possible, as explained in Mitchell *et al.* (2016), allowing more people to participate in designs that affect them, in line with the words of Taura & Nagai (2011) as "the process of

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composing a desired figure towards the future." This democratisation of the creative processes would allow a bottom-up participation of citizens. Focusing on the mechanism behind social relationships in social design opens the possibility of attaining a well-being society (Matsumae *et al.* 2020). However, these dynamics have so far been studied mainly through qualitative analysis as an outcome of the design process, an approach that only offers a narrow perspective of the complex and shared design space created through intersubjectivity. Intersubjectivity is the underlying mechanism created together by interactive participants, joining subjectivity through social interactions. This interactive and dialogic approach to perception opens the possibility to go further than the previous personal understanding of human factors, such as creativity, to study it at the interpersonal level, directly constitutive and key in the understanding of the dynamics of said interactions (Ehkirch & Matsumae 2024). In other words, a focus on interpersonal factors (phenomenological factors used to study social interactions that can be measured and quantified) in the co-design process is needed to better understand the dynamics of the interaction created through intersubjectivity, supported by a dialogic approach to creativity going from personal to interpersonal creativity (Ozer & Zhang 2022).

2. Background

2.1. Intersubjectivity & interactive level

Interaction forms the basis of our understanding of reality, and it is through the experience of interaction that we can create our subjectivities. First conceptualised by Husserl in his Fifth Cartesian Meditation as the mechanism behind empathy, see Bower (2015), the main idea of intersubjectivity is that subjects do not constitute a world alone but jointly with other subjects. It can be understood as a field that allows social interactions created jointly between subjects – a socially interactive field (Ehkirch & Matsumae 2024). Serving as the main idea to fuel the shift to dialogism in fields studying human factors in social situations, such as cognitive science, psychology and behavioural science, this new view has led to important steps forward in our understanding of social interactions. Coming from the study of the interpersonal aspects of language and the social co-construction of meaning in it, this shift from the previous personal perspective of cognition was then applied to study the interactional aspects of social cognition in Linell (2007), pushing for a new way to analyse intersubjectivity as an aspect of discourse subjects (Gillespie & Cornish 2009). From a dialogical perspective, intersubjectivity can be approximated through the flow of interaction. This flow is understood through the measurement of interpersonal factors to integrate interactive moments together through their intensity level, dependent on the social situation studied (Ehkirch & Matsumae 2024). Applied in a design context, it can overcome the previous individual aspects of creativity to focus on the collaboration that sustains it at an interpersonal level. Pushing for a better understanding of creativity in design using knowledge and tools from socio-cognitive research (Gero & Milovanovic 2020).

In the case of co-design, to quantify interactive level dynamics, previous research has used factors such as shared understanding in Cash *et al.* (2017), or boundary objects (Star 2010). These factors focus on the results of the dynamic context created by the integration of personal static moments through the flow of

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interactions that is formed during the co-design process. They can then help quantify not only the level of the interaction (static) but also its direction (dynamic), and are key to understanding the steps that will follow. The interactive level can then be quantified using interpersonal factors that are reflective of the principles that make empathy through the sharing of cognitive states such a powerful tool in the shared design context between designers (Chang-Arana *et al.* 2020; Svanæs & Barkhuus 2020). These feelings of connection and sharedness, in this study, are referred to as the *pairness* factor, which allows the creation of a new social space, where the sharing of norms and values becomes easier and more complete (Keating & Jarvenpaa 2011). It has also been related to intersubjective engagement, correctly measuring the interactive level (García-Pérez *et al.* 2007).

In addition, collaboration is reached by creating engagement from its participants to maintain it (Cheung & To 2011; Kleinsmann *et al.* 2012). In that sense, co-design is also heavily reliant on the *motivation* of the individuals participating, especially so in the case of co-creative work. Indeed, a positive correlation was found between the rise of intersubjectivity (understood as the interactive level) and co-creativity (defined as a shared motivation among individuals) in realising a concept (Matsumae & Nagai 2018). Motivation is then closely related to the goal and individual design context of each participant, as explained by Amabile (1983), and co-creative collaboration (co-creation) cannot be sustained without a shared motivation and agreement on common directions for the creative process. Using the knowledge from intersubjectivity research opens the possibility to go beyond the personal study of such factors and to develop the interpersonal aspects of creativity, shining light on the social mechanisms at play in co-design.

2.2. Co-creation

The need to bring the concept of creativity from the personal to the interpersonal level was recognised during the development of design methodology in the 1970s as the key to the successful transition from participatory design to collaborative design. Co-creative collaboration needs more complex and intricate social interactions between its participants to foster not only interesting and creative results but also a better experience of design as a social activity (Busciantella-Ricci & Scataglini 2024). From a design cognition perspective, it is characterised by both divergent and convergent processes implicated in the co-evolution of the iterative exploration between problem space and solution space (Cascini *et al.* 2022). This means that the social interactions experienced during co-creation directly influence the creative output of it by modifying the dynamics of said interactions (Cheung & To 2011; Ozer & Zhang 2022). There is then a need to focus on human factors in co-design to better understand the social interaction mechanisms that influence interpersonal creativity, as explained by Beghetto & Karwowski (2019), leading to a better experience of design that could help bridge the boundary between designers and users in a social design approach.

Furthermore, from a process perspective, there are two different collaborations taking place during co-design, one being co-operative collaboration (i.e. *cooperation*), where only participation is needed to achieve a defined common goal based on each member's subjectivity, and the other being co-creative collaboration (i.e. *co-creation*), where each member's creative participation is required. The latter is based on intersubjectivity during the socialisation phase, making

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possible the sharing of tacit knowledge and allowing a richer experience (Nonaka *et al.* 2000; Matsumae & Nagai 2018). Co-creation is then a process that occurs during co-design where the co-creativity of participants synergistically reaches heights that exceed the sum of their creativity (Trischler *et al.* 2018). It is a similar idea to group flow creativity, presenting creativity as interpersonal and collaborative by nature (Sawyer 2017). The idea of a flow state in a group collaborative effort (as a shared experience of an interaction) can be associated with the idea of intersubjectivity being approximated by the flow of interaction, understood through the measurement of interpersonal factors to integrate interactive moments together through their intensity level. It defends the idea that this creative shared flow state is dependent on a shared understanding of the goal, a diverse communicational style and tacit knowledge created by the team. The main difference between the two concepts is the distinction between subject and process, which is interpersonal subjectivity for intersubjectivity (i.e. emerged in interactions) while being mostly situational for group flow (i.e. emerged from social contexts). This paper then defends an interpersonal approach to creativity as a cognitive state of the co-design experience. This state can be understood through the interactive level dynamics approximating the intersubjective field in co-creation (Ehkirch & Matsumae 2024). It thus seems that intersubjectivity can be understood as a shared basis that maintains and aggregates the vectors of the different participants, leading them to co-creative collaboration. This transition in the shared creative state of a team in co-design is made possible by the intersubjectivity formed between participants' subjectivities, arising from their experience during the design process. It is an unstable state that requires a high level of interactivity before it can blossom from cooperation to co-creation (Roschelle & Teasley 1995), and is sustained by the sharing of motivation, goals and design context between participants, as explained by Amabile (1983), which fuels the push forward. The creative resonance that results can then grow into a richer experience of participatory creation, pushing even everyday creativity to new heights, in particular in the simple creative task realised in pairs, hereinafter referred to as *pairwork* (Ho & Lee 2012; Won *et al.* 2014; Matsumae *et al.* 2022). Pairwork showed improvement in measurable requirements of design compared to solo work (Al-Kilidar *et al.* 2005). However, most research done in this direction still focuses on a single measurement approach to these constructs, relying on qualitative analysis to study the outcomes afterwards of the interaction, losing the essence of their dialogical aspects (Sosa & Gero 2016; Hay *et al.* 2020). This means that there is a need to study them dynamically from a dialogical perspective using measurement of behaviour and cognition simultaneously (Granados 2000; Balters & Steinert 2017). Such cognitive states are heavily dependent on smooth social interactions that can be objectively observed through biosignal indicators of social behaviour.

2.3. Biosignal indicators of social behaviour

Design cognition has seen increasing attempts to connect with psychological theory to integrate and build upon the findings of earlier exploratory protocol analyses (Hay *et al.* 2020). This led to advocating for multi-modal measurements that include measuring behaviour, cognition, physiology and neurophysiology concurrently (Cascini *et al.* 2022). While also proving to be useful to study design

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creativity and innovation in the interaction between personal and interpersonal levels (Somech & Drach-Zahavy 2013).

Social cognitive studies have long examined the role of specific social and communicative behaviours in interactions, such as the chameleon effect in Chartrand & Bargh (1999) or gaze (mutual eye contact) effects (Akechi *et al.* 2013). These interpersonal factors have so far been mainly studied using subjective reports (Silvia *et al.*, 2014) and/or exterior observations (Mundy *et al.*, 1992; McClintock & Hunt, 1975), but the shift towards dialogism has opened the possibility of linking both objective and subjective results at an interpersonal level to provide a dynamic view of the interactions by introducing new interdisciplinary methodologies. For example, a recent study Barraza *et al.* (2020) of the concept of shared intentionality used the interbrain method to deepen our knowledge of such socio-cognitive processes. From an objective standpoint, *non-verbal communicative behaviour* can help approximate the interactive level by providing objective markers (Mundy *et al.* 1992; García-Pérez *et al.* 2007; Won *et al.* 2014). Furthermore, there is evidence that by focusing on biosignals related to different socio-cognitive processes at different levels of cognition, a better understanding of the roles these behaviours play in specific contexts (in our case, during co-creation) can be found (Ehkirch & Matsumae 2024). These biosignals need to be reactive to the social environment and constituted of empathy through a shared perception of social interactions at an interpersonal level to become key interpersonal factors in a specific interaction (Balters & Steinert 2017; Gero & Milovanovic 2020). In any team creation, a deep cognitive process is needed that shares not only a current understanding of the situation but also how one feels about it. In other words, the cognitive state must be shared (Mundy *et al.* 1992; Masclet *et al.* 2021).

Previous studies have shown how the interactive level of interactive situations can be studied by using objective markers of shared behaviours, such as the study of sympathy using PET scan data together with skin conductance (SCR), blood volume pulse (BVP) and respiratory rates in Decety & Chaminade (2003), or shared subjectivities from physiological signals using data from: electroencephalography (EEG) recording, electrooculography (EOG), electrocardiogram (ECG), respiration, electrodermal activity (EDA) and finger electromyography (EMG) in (Maÿe *et al.* 2021). In design research, such a physiological state has shown the importance of including the cognitive status related to empathy, strongly influencing interactions (Salmi *et al.* 2023; Chang-Arana *et al.* 2022; García-Pérez *et al.* 2007). From an interactive perspective, such social cues and answers can be measured through facial electromyography analysis (fEMG) (Huang *et al.* 2004). This method is used to measure muscle activity by detecting and amplifying the tiny electrical impulses that are generated by muscle fibres when they contract. Previous research has shown that fEMG can identify a social cognitive state by focusing on the zygomaticus major and corrugator supercilii muscles, see Larsen *et al.* (2003), linking them to strong emotional reactions to social situations (Wolf *et al.* 2005). This method provided an indication of underlying affective valence rather than literal proxies of corresponding facial expressions. A link between the results of a comparison of fEMG data and the intersubjective state corresponding to their interactive level was also found (Ehkirch *et al.* 2021). In design research, empathy has been studied using EMG before, see Chang-Arana *et al.* (2020), or similar facial mimicry from automated facial expression recognition, focusing on the same associated shared behaviours: smiling and frowning (Ikäheimonen *et al.*

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2024). Proving to be a good compromise between the precision of measurement methods and complexity of use (Geoghegan *et al.* 2018). In fact, fEMG is able to detect even unconscious patterns, allowing separation between real and feigned associated behaviours as shown in Korb *et al.* (2008).

In a similar vein, another shared behaviour related to a deeper cognitive state is the blinking pattern (Irwin 2011). Electrooculography (EOG) can be used to measure blinking patterns that are related to the deeper cognitive functions needed during creation, such as mind wandering and cognitive flexibility (Kruis *et al.* 2016). It can be used to approximate the amount of sharing in a cognitive state. EOG is measured by observing the corneo-retinal standing potential that exists between the front and the back of the human eye and is often used to study eye movements and recognise blinks (Bulling *et al.* 2011).

This leads us to the use of fEMG and EOG biosignal data to objectively grasp the current social cognitive state of someone engaged in a co-creative task. However, following the dialogical approach to intersubjectivity, to move from this personal status to the interpersonal, these data need to be compared with other participants to study the synchrony of social behaviours. Here, synchrony should be understood as a measure of the similarities (timewise) of specific socio-cognitive behaviours between persons who are interacting. The study of the synchrony of physiological statuses in design cognition already has produced promising results from a dialogical point of view (Chang-Arana *et al.* 2022; Papadopoulou 2024). To this end, this research will propose some new methods of quantifying the synchrony rate of biosignals that can then become objective indicators of the interactive level in co-creation.

3. Aim

The goal of this research is to understand the interpersonal aspects of creativity from the study of interpersonal factors (pairness, motivation, non-verbal communicative behaviour) by measuring biosignal indicators during co-creative pairwork. For this, the following research question will be answered: Can biosignal synchrony taken from fEMG and EOG approximate the interactive level dynamics measured through subjective reports of motivation and pairness during co-creation in pairwork?

The authors decided to limit the study of co-creation to the pairwork level (team of two), as the complexity coming from the interrelations of the factors studied would rise exponentially with a greater number of participants. An experiment corresponding to co-creative pairwork was conducted, where biosignal indicators (fEMG, EOG) were measured throughout the task. From there, the synchrony rate of biosignals was computed, and their relationship with the results of the interactive level reported afterwards by the participants was investigated. More precisely, the following hypothesis was tested: the synchrony rate of biosignals (fEMG, EOG) is related to the variation in the interactive level (motivation, pairness) at the pair level during co-creation. This research should contribute to a better understanding of the role these social behaviours play in the interaction dynamics and their influence on co-creation, helping to determine which interpersonal factors should be particularly considered to foster a better experience of co-creation.

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4. Methodology

To ensure the new methodology that was developed could be used to quantify interactive level dynamics in co-design, an interactive situation as close as possible to a real co-design process was needed. Co-creation is a particular collaborative process in co-design that requires intense dynamics and high interactive levels between its participants to be sustained. In addition, co-creation itself can nurture high interactive levels in a vortex mechanism as a driving force of the interactive flow (Ehkirch & Matsumae 2024). All these observations justified the selection of the interactive situation as the co-creative task. To answer the research question, there was a need to simplify the situational factors, that is, factors that influence the initial state of the interactive situation studied and enable creative pairwork that would be conducive to a co-creative dynamic in a realistic amount of time. Following the principle of everyday creativity, as explained by Silvia *et al.* (2014), which emphasises the possibility of freedom and participation in the creative aspect of the work, simplified creative tasks that would demand almost no prerequisites were adopted. This kind of simple creative task is often used in design, particularly during the ideation phase. Notably, on pairwork creative tasks allowing freedom for goals and directions, necessary for the appearance and sustain of co-creation, storytelling is often used to evoke a narrative that will help ease the communication between the different stakeholders (Gausepohl *et al.* 2016). It provides an accessible way to engage with the creative task and spark creative collaboration (Behnam-Asl *et al.* 2024). In addition, the experience was designed to have play-like elements to it, following Loudon *et al.* (2012) recommendations, to reduce the impact of observation on the examinees, so that they could immerse themselves without being distracted by the measurements being taken. For these reasons, the experiment was designed as a storytelling pairwork exercise using clay, divided into two creative tasks in which biosignals (fEMG, EOG), along with video and audio data, were recorded. These supplementary data were taken for possible further analysis on the behaviours of the examinee during the experiment, such as studying the interaction using the interactive analysis model from the verbatim (Floren *et al.* 2021). From there, the synchrony rate of the biosignals was computed, and their relationship with the results of the interactive level reported afterwards by the participants was investigated. The use of clay was chosen because of the need to have almost no skills required for its use, while presenting a game-like element, keeping the playfulness intact.

4.1. Experiment

4.1.1. Examinees

Forty healthy examinees (24 men and 16 women) aged in their twenties participated in the experiment. They were divided into 20 pairs, named 1–20 in chronological order. All subjects were students who willingly gave their agreement to participate in accordance with ethics regulations. They had previous experience in creative tasks and teamwork, as 24 were registered with the undergraduate and 15 with the graduate school of design, plus one participant from the graduate school of law.

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4.1.2. Procedure

The experiment was carried out over 20 sessions, as the equipment used to record biosignals was only able to record two persons (corresponding to one pair) at a time. To be able to collaborate without hindrance, the participants were seated in front of each other, across a table on which a canvas (created using a panel and plastic film to make sure that the clay would not stick) with 12 coloured lumps of clay was set. You can see the setting of the experiment in the following picture (Figure 1).

To facilitate the appearance of co-creation, the pairwork was divided between two creative tasks, the first one serving as an icebreaker that allowed examinees to get used to the situation, while the second was the actual co-creative task. The first task was defined as the shared creation of "a character that can fly" to be completed within a 5-minute time limit. The goal of this task was to get the examinees used to their partner (as some were meeting for the first time), the setting of the experiment and the equipment used to record the biosignals. It also served to foster the basis needed for interactions that would bring about co-creation during the second task. The instruction of task one to create "a character who can fly" was also given as a precursor to support the next creative task. Five minutes was considered to be sufficient time to serve as an icebreaker, thanks to the playful aspect of the creative task introduced by the use of clay.

The second task was defined as the "creation of a scene (explained as a scene such as one can see in a movie) around the first character," with the freedom to add any elements needed to make it a coherent story (storytelling aspect). This task was given a 20-minute time limit, but examinees were allowed to continue beyond 20 minutes if needed to avoid disturbing the flow of interactions. The goal of this second task was to spur the appearance of co-creation between the examinees by

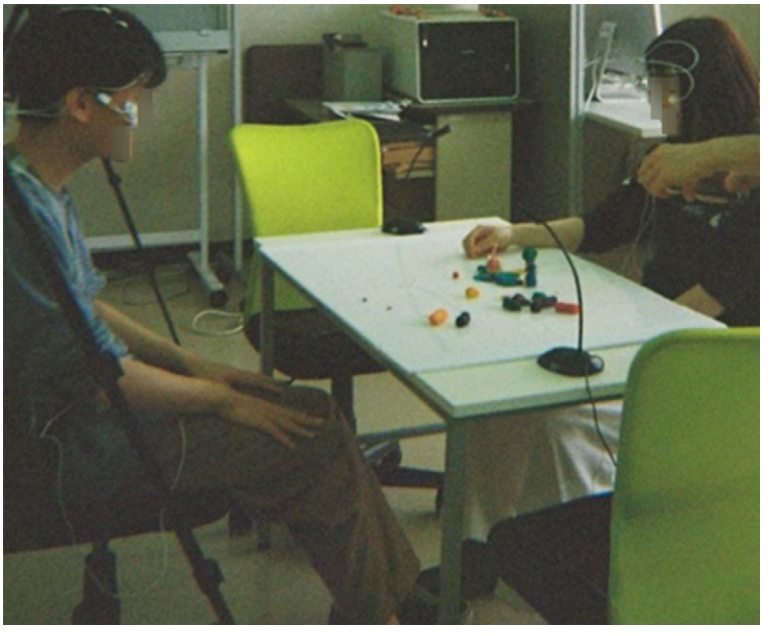


Figure 1. Setting of the experiment.

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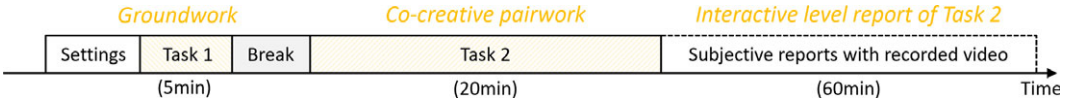


Figure 2. Experimental procedure.

removing any specific predefined goals or constraints and letting them decide on their own how to proceed.

After these two tasks were completed, the examinees were each asked to subjectively report their interactive level during task 2 (see section evaluation of the interactive level) along with an indication of their familiarity level (i.e. whether the examinees in the pair knew each other beforehand). This experimental procedure is illustrated below (Figure 2).

These results were related to the biosignal data recorded during task 2 and quantified through a synchrony rate computed from the data of both examinees (see section synchrony rate of biosignals). The main goal of this study was to find at the pair level a relation between the synchrony rate of the three biosignals (fEMG × 2, EOG × 1) computed by two methods (Ld & DTW) and the interactive level quantified through three different approaches (average, difference and dynamics). Each construct is explained in the following section.

4.2. Evaluation of the interactive level

Referring to previous studies such as Matsumae *et al.* (2022), the interactive level was subjectively evaluated after the completion of task 2. The requirements for the measurement methods were that they needed to concern key interpersonal factors in co-creation that could be studied from a subjective perspective. These factors should be integrated as results of the interaction while having an unstable intensity, meaning enough influence to shift the dynamics of the interactions and change the intensity of the interactive level (see Ehkirch & Matsumae (2024) for the selection of suitable methods for subjective evaluation). They also needed to be shared between the participants to make it pertinent at the pair level. Each examinee was asked to fulfil a dynamic/continuous rating between 0 and 100 of two interpersonal factors: *motivation* and *pairness.* Arguments can be made on the choice of these two factors in particular, to quantify the interactive level in the specific case of co-creation as explained in the Background section. There are not only necessary but also directly vital as determinant interpersonal factors for the dynamic fluctuations of the co-creative interaction (García-Pérez *et al.* 2007; Matsumae & Nagai 2018; Ehkirch & Matsumae 2024). Hence, their choice as the first two "candidates" for proxies of the interactive level. To help with this process, a research assistant put these ratings in a waveform to reveal their dynamics. Asking the examinee to report their motivation and pairness level while looking at a video recording of task 2 immediately after the session to reduce recall bias (this reporting took around twice as long as task 2, see Figure 2 for details). Finally, it could be argued that assigning numerical values to feelings is inherently problematic due to the subjective nature of the scale, also wondering why our constructs were assigned values between 0 and 100, contrary to the often-used predefined questionnaires, using a Likert scale. This continuous approach to these factors was justified by the dialogical perspective taken from intersubjectivity studies that argues for focusing

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on the dynamics of constructs, which cannot be done with standardised techniques. This approach for continuous physiological measures was inspired by previous work on affect reporting (Gottman & Levenson 1985).

- *Motivation*: Motivation was defined beforehand as a key factor needed for the appearance of co-creation (see background). Any type of collaboration needs engagement that is measured through their degree of personal motivation to complete the task given. It was explained to the examinee as: *"your feeling of engagement to realise/finish the task given, with 0 corresponding to none and 100 corresponding to full interest."*
- *Pairness*: To help understand the interactive level in co-creation, the pairness factor was designed as a measure of the depth of sharing between participants at a given moment (see background). It corresponds to a subjective feedback measurement method (as explained in Ehkirch & Matsumae (2024)) of the degree of connection with their partner and was previously used in research as a main factor to study the interactive level as felt by the examinees themselves (García-Pérez *et al.* 2007). It was explained as: *"the feeling of shared behaviours, emotions, motivation and goal with your partner, with 0 corresponding to none and 100 corresponding to a full resonance/connection with your partner (feeling as one)."*

As the recording continued, many of the examinees chose to exceed 100 to define their subjective perspective on the interactions at that point. Motivation values ended up ranging from 20 to 150, while pairness values were between 0 and 150. However, this overrating did not present a problem as the goal was to record the dynamics of these factors, and, as such, the measurements were rescaled afterwards to make them compatible. This was justified to standardise the measurements between all examinees, following recommendations explained in McKeown & Sneddon (2014), especially as it would be elevated at the pair level afterwards. This is explained in more detail in the following pair interactive level method explanation. Here is a pattern of a report for the pairness factor of the interactive level (Figure 3).

4.2.1. Individual level

To help further analyse the factors, the data taken from task 2 was broken into smaller subdivisions. Following previous research done by Matsumae *et al.* (2023),

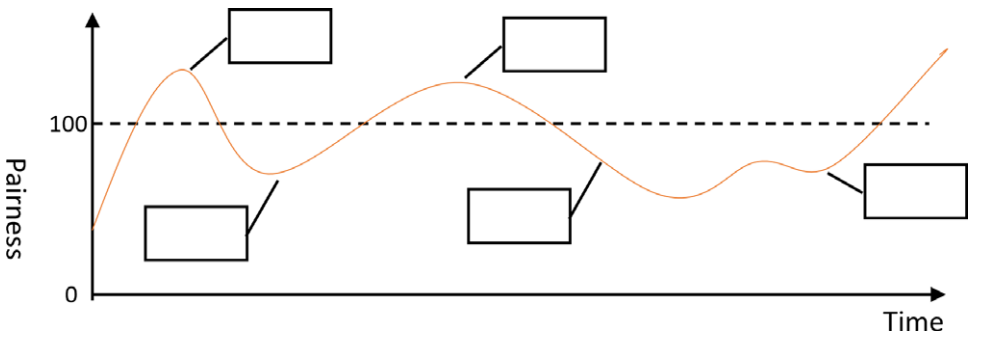


Figure 3. Subjective report of interactive level pairness factor.

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a 15-second subscale division of the data was selected as the minimum time between two reports of values of interpersonal factors. From there, the value of each factor was determined for each 15-second timespan by either direct correspondence with the value indicated on the paper data or by a linear approach at points where the value was missing/uncertain due to troubles in the collection of data (representing around 10% of the data pool). In total, out of the data for 20 pairs, 3514 datapoints of 15-second subdivisions were recorded ($M = 175.7, SD = 6.6$).

Finally, for the individual level, both motivation and pairness were used to quantify the interactive level in previous research (see background). A correlation analysis helped confirm that they had a strong positive correlation $r(3514) = .55, p < .001$, with a high level of motivation associated with a high level of pairness. This would suggest that the interactive level can be measured at an individual level using either motivation or pairness for co-creative pairwork.

4.2.2. Pair level

To quantify the interactive level, individual-level data at the pair level was examined by comparing the results of both examinees in a pair. To simplify the analysis, one factor needed to be selected to indicate the pair's interactive level. A stronger correlation coefficient was found between the pairness level of both examinees in a pair, $r(3514) = .35, p < .001$, than with their motivation level, $r(3514) = .20, p < .001$. To verify that there was a significant difference between the two correlation coefficients, a Z-test was carried out (Viertl 2009). The calculated Z value is 9.5706, and the acceptance region for the null hypothesis at $\alpha = 0.05$ is $-1.96 < Z < 1.96$. So, we can reject the null hypothesis and conclude that the pairness level of two examinees in a pair has a significantly higher correlation than that of the motivation level. This is why three approaches were designed to quantify the pair interactive level from the pairness level value:

1. **Average**

The average approach was used to obtain the *intensity* value of the pair's interactive level, from low to high. It was computed by using the mean of the relative measures of pairness levels of both examinees in a pair (see Eq 1). It was then divided into three categories: low (between min and Q1), middle (between Q1 and Q3) and high (from Q3 to max). Here, min, Q1, Q3 and max are to be understood as quartiles used in order statistic.

$$\begin{aligned} Average &= ((PL_{EXa} / \max PL_{EXa}) + (PL_{EXb} / \max PL_{EXb}))/2 \\ PL_{EXx} &: \text{Pairness level of examinee(x)} \\ \max PL_{EXx} &: \text{Maximum reported values of the pairness level of examinee(x)} \end{aligned} \quad (1)$$

2. **Difference**

The difference approach was used to understand the *disparity* of interactive levels between the examinees in a pair, from low to high. It was computed by using the absolute differences of the relative measures of pairness levels of both examinees in a pair (see Eq 2). They were then divided into three categories: low (between min and Q1), middle (between Q1 and Q3) and high (from Q3 to max).

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Table 1. Direction categories from the dynamic approach

Name	Direction of interactive level	Meaning for the next level	ΔPL_{EXa}	ΔPL_{EXb}
Increase (i)	↗↗	Both examinee's interactive level increase	>0	>0
Alone (a)	↗→, →↘	One examinee's interactive level stays the same while the other either increase or decrease	$\begin{cases} >0 \\ 0 \end{cases}$	$\begin{cases} 0 \\ >0 \end{cases}$
Same (s)	→→	Both examinee's interactive level stays at the same level	0	0
Opposite (o)	↗↘, ↘↗	One examinee's interactive level increase while the other decrease	$\begin{cases} >0 \\ <0 \end{cases}$	$\begin{cases} <0 \\ >0 \end{cases}$
Decrease (d)	↘↘	Both examinee's interactive level decrease	>0	>0

$$Difference = |PL_{EXa}/\max PL_{EXa} - PL_{EXb}/\max PL_{EXb}| \quad (2)$$

3. **Dynamics**

The dynamics approach was used to understand the *direction* of the next interactive level by looking at the derivatives of pairness levels of both examinees in a pair. For each participant pairness level, there are three possible directions, creating a combination of five categories at the pair level (see Table 1 for details of the calculation using the derivate of each examinee). From there, they were categorised incrementally into categories relating to the variety of possible next interactive levels: increase (i), alone (a), same (s), opposite (o) and decrease (d). Details are in Table 1.

These three approaches not only helped to quantify the interactive level intensity (average) at a given moment (corresponding to a 15-second datapoint) but also how it is shared between the two examinees in a pair through its disparity (difference) and how it can predict the direction (dynamics) of the next level.

4.3. Familiarity level

Though the experiment was designed to keep the influence of situational factors (e.g. creative environment used) as low as possible, co-creation, like any social activity, is dependent on social factors that can influence the interactive level or, more specifically, its initial state. However, to focus on the link between the biosignal synchrony and the interactive level, there was a need to reduce as much as possible these external (in the sense of not mainly responsible for the co-creation interaction dynamics) factors. As such, only one factor was kept for further analysis, as it was not possible to reduce its influence, the familiarity level between examinees. Previous research showed a link between the level of familiarity and the interactive level attainable (Deppermann 2019). In a control environment, with a limited amount of time and a controlled interactive channel, pairs that already

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know each other were able to get more reliably to a higher interactive level during a coordination task. To balance this out, the measure of familiarity examinees in a pair had in working with each other was added as an independent factor in the study. This measurement was done at the same time as the subjective report on the interactive level following task 2. Each examinee was asked how used they were to working together on a 3-point Likert scale. This was done to obtain a simple, unbalanced view of the familiarity the examinees had with each other and to limit possible sway between the pair's members, going from 0 (meaning the first time) to 2 (pretty used to working together). This measure of familiarity at the individual level was then raised to the pair level by taking the average value of both examinees in a pair, meaning that the scale was divided into five possible values (0/0.5/1/1.5/2). This value was then tested with the other data coming from biosignals synchrony and the interactive level to see if it was influencing our results.

4.4. Biosignal measurement

4.4.1. Biosignal indicators in design settings

During the experiment, the measurement of biosignals needed to be as unintrusive as possible to minimise its impact on the interactions. In recent years, interesting research has been conducted using neurocognitive tools, such as electroencephalography (EEG). The main drawback of these protocol-heavy physiological measurements is that they limit the possible situations studied to simplified tasks far from real-world design practices (Gero & Milovanovic 2020). These limitations from cognitive tools developed to understand human behaviour in more socially realistic and complex settings were determinant to the feasibility of this research. Indeed, fEMG, EOG and other biosignals were still difficult to measure accurately without heavy equipment just a decade ago, making it unrealistic to attempt to use them in tasks where communications between examinees would be the subject of study. However, thanks to today's lighter equipment, researchers can easily dimmish and/or control the influence of the measurement on the situation itself, making it more relaxing for the participants and allowing them to focus on the task at hand. These improvements justify the choice of this measurement method to get a detailed reading of socially related behaviours without being too invasive for the examinee (see Figure 4 for the level of invasiveness) (Franz *et al.* 2024). Computer vision–based expression/emotion recognition and eye tracking represent important non-invasive alternatives that have shown significant progress. Still, fEMG and EOG emphasise physiological accuracy (some may not be visually observable or detectable by computer vision methods), robustness to environmental factors (e.g. no lighting issues) and fine-grained temporal resolution. Previous studies, such as Larsen *et al.* (2003); Wolf *et al.* (2005), presented the possibilities of using fEMG analysis of the zygomaticus major (EMGZ) and corrugator supercilii muscles (EMGC) to understand the social cognitive emotional state. In addition, fEMG has been used to study empathy as a socio-cognitive status in the design process (Chang-Arana *et al.* 2022). This was rounded off with an EOG (electrooculogram of vertical eye movement used to measure blinking) to better understand the relation of this social cognitive indicator on the interactive level. Both fEMG and EOG use surface electrodes to measure accurately the related behaviour, having a better precision than comparable methods such as computer

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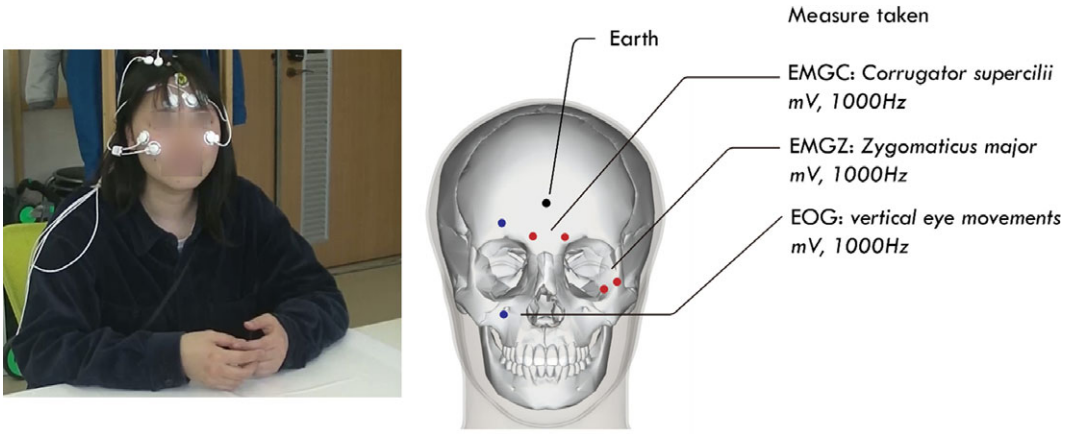


Figure 4. Placement of electrodes for biosignal indicator measurements.

recognition, while staying relatively easy to use compared to multimodal affective computing systems (Egger *et al.* 2019).

4.4.2. Measurement in this study

Simultaneously recording two people and then bringing measurements to the pair level required a strong synchronisation (done to the ms) of the measuring devices. For this, two 4-Channel biosignalsplux Kits from PLUX that allow a simultaneous recording of four channels of fEMG (2 muscles × 2 examinees) together with two channels of EOG (1 per examinee) were adopted. They were recorded with OpenSignal software from the same company. Non-intrusive electrodes were used to measure muscle activity, minimising the chance that the examinee might be overly distracted by them during recording. Eight electrodes were used per examinee (fEMG × 4, EOG × 2, earth × 1). The placement and installation of the electrodes were done following previous research on good practices in recording human electromyography, see Fridlund & Cacioppo (1986), and activity recognition using electrooculography (Bulling *et al.* 2011). The following figures (Figure 4) show the electrode placement.

Both fEMG and EOG data were measured at a sampling frequency of 1.0 kHz (Fridlund & Cacioppo 1986). The fEMG dataset was then rectified by ARV (average rectified value). The data were cleaned before analysis with neurokit2 library from Makowski *et al.* (2021) as a pre-processing step before computing the synchrony rate of biosignals. To do this, a fourth-order 100 Hz highpass Butterworth filter was used, followed by a constant detrending. In all, of 20 pairs (40 examinees), 405 minutes of data were recorded, corresponding to around 24 M single points of data per biosignal. This massive amount of data meant that a methodology was needed to simplify the analysis of the biosignal indicators, even more so for the pair level. A synchrony rate was needed to understand the results from a dialogical perspective to grasp the cognitive status of a pair, following the direction of hyperbrain research (Barraza *et al.* 2020; Maÿe *et al.* 2021).

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4.5. Synchrony rate of biosignals

To understand the relationships between social cognitive statuses in pairs using biosignals, a comprehensive amount of time-wise similarities between biosignals coming from each participant needs to be computed. However, as biosignals are physiologically unique for each person, direct comparison is difficult. To address this issue, a synchrony rate must be computed between the two datasets to see if there are similarities in their waveforms, considering the time delay that is inherent in any conversation between people. Following previous research done by Ehkirch *et al.* (2021), two methods were used to compute the synchrony rate of biosignals: the **Damerau–Levenshtein Distance (Ld)** and the **dynamic time warping method (DTW)**. The Ld method was developed to answer the problem of direct comparison and the delay inherent to any study of synchrony of biosignals. From there, the DTW method was proposed to elaborate on the synchrony rate computed from the Ld method to integrate more subtle changes in the behaviours studied.

1. **Ld**: As fEMG and EOG are by nature continuous voltage fluctuations related to the movement of specific muscles, or of the eye, there was a need to focus on the comparison time-wise of the activation of the behaviours as detected by it, corresponding to a peak in the data wave. However, to efficiently compare that data, it had to be simplified through binarisation to then correspond to the study of similarity between binarised character data. This was done using the Damerau–Levenshtein distance. The computed distance between two words corresponds to the minimum number of operations (consisting of insertions, deletions, substitutions of a single character, or transposition of two adjacent characters) required to change one word into another. The formal definition of a generic recursion found in Boytsov (2011) describes a method that gives a reliable approximation of the similarity between two waves of binarised character data while considering chronological misalignment. It was implemented using the Damerau–Levenshtein distance function of the jellyfish library (Turk 2022). To be used, raw biosignal data must be converted into a binarised series, with "0" corresponding to no activation and "1" corresponding to activation of the studied behaviour, that is, activation of the corresponding muscle in the case of fEMG and blinking in the case of EOG. To be able to binarise the dataset, the neurokit2 library was used to detect activation of the muscle using the BioSPPy methodology for EMG, while the neurokit method was used to detect blinking from the EOG (Makowski *et al.* 2021). As Ld is a distance, it is affected by the total length of the dataset used to compute it. Thus, it was divided by this same length, which in this case was 15 seconds worth of data (15,000 data divisions for one biosignal for one examinee), to facilitate analysis by corresponding to the subdivision of the interactive level of the same moment.
2. **DTW**: The Ld method requires processing of the data before it can be used, as some of the finer details may be lost if used as is. To study these more complex and subtle matches, the dynamic time-warping method (DTW) was implemented. DTW measures a distance-like quantity between two given sequences that vary by time to determine their similarities. As such, the DTW method is used to understand the synchrony of patterns inside the biosignals. Contrary to the Ld method, it does not concentrate only on the "peaks" but also gives an indication of the resting state of behaviours, considering downtime and tempo differences to compute the overall synchrony rate. The main algorithm of DTW can be found in (Müller 2007). It is often used in partial shape-matching

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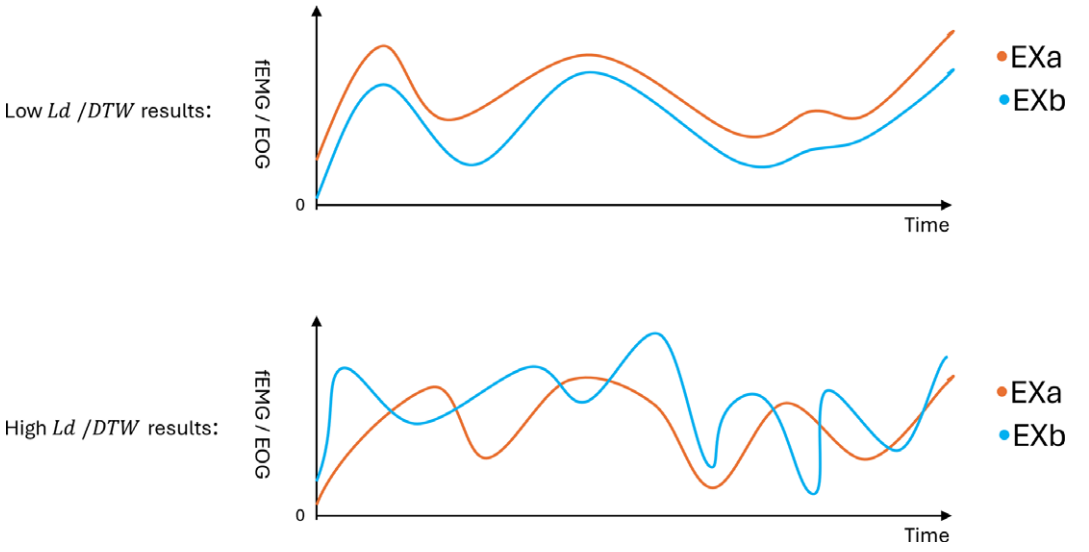


Figure 5. Relation between biosignals synchrony and distance results.

applications and presents an interesting aid to understanding the synchrony rate of two waveforms. It was implemented using the FastDTW library (Salvador & Chan 2007). As with Ld, DTW results were also divided into 15 seconds worth of data corresponding to the total length of the dataset used.

By using either the Ld or DTW method, it is possible to compute a numerical value representing the synchrony rate of given biosignals between two examinees in a pair. As both methods represent **a distance, the longer they get, the more differences they indicate between the datasets, meaning more asynchrony. Conversely, smaller values correspond to a higher synchrony rate between examinee biosignals.** Hence, either Ld or DTW results are inversely proportional to the amount of synchrony between the two participants for each given biosignal and the associated shared behaviour. See the following figure (Figure 5) for a simpler representation of the distance results.

It is worth mentioning that, by design, these methods will produce non-parametric data, requiring further analysis with a Kruskal–Wallis test and completion with Pairwise Mann–Whitney tests. Following the recommendation of Ikäheimonen *et al.* (2024) for a simplified reporting of the data-intensive research, we created a study workflow with steps and outcomes (see Figure 6).

5. Results

The main goal of this study was to find a relation between the synchrony rate of three biosignals (fEMG × 2, EOG × 1) computed by two methods (Ld & DTW) and the interactive level quantified through three different approaches (average, difference and dynamics). As for the nomenclature used, the results will be presented as follows: `Methodname_biosignals` refers to a corresponding synchrony rate of the given biosignals, for example, as `Ld_EMGZ` corresponds to the synchrony rate of the fEMG analysis on the zygomaticus major muscle data from both

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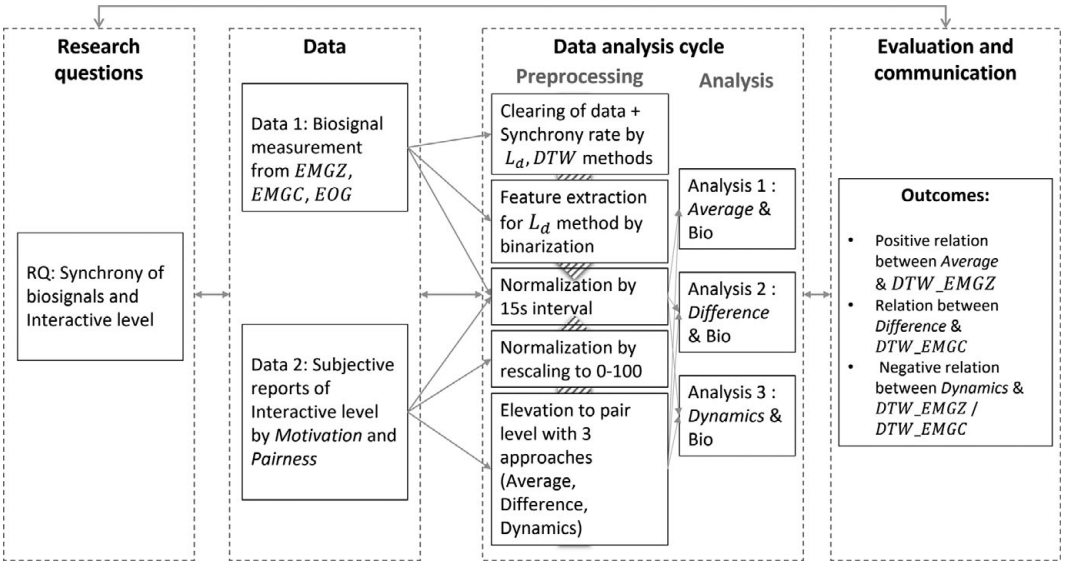


Figure 6. Study workflow steps and outcomes.

examinees in a pair, computed using the Damerau–Levenshtein distance. This nomenclature is summarised in the following Table 2.

Likewise, of the 20 pairs of biosignal datasets collected, some were incomplete or corrupted due to unstable Bluetooth connection of the equipment sometimes leading to a disconnection, reducing their number to 1620 15-second individual synchrony rates collected per method and per biosignal, except for `Ld_EMGZ` (1617) and `Ld_EMGC` (1619), both of which lost some data in the process. An analysis was then conducted of this data pool corresponding to the roughly 6 hours and 45 minutes of biosignal interactive data studied. The presentation of the results takes a divided style that first summarises all 18 relations (2methods × 3biosignals × 3approaches) in a table (see Table 3). From there, statistically significant

Table 2. Nomenclature meaning

Nomenclature	Meaning (synchrony rate computed by…)	Number of data
Ld_EMGZ	Damerau–Levenshtein distance of fEMG analysis on the zygomaticus major muscle	1617
Ld_EMGC	Damerau–Levenshtein distance of fEMG analysis on the corrugator supercilii muscle	1619
Ld_EOG	Damerau–Levenshtein distance of vEOG analysis	1620
DTW_EMGZ	Dynamic time warping method of fEMG analysis on the zygomaticus major muscle	1620
DTW_EMGC	Dynamic time warping method of fEMG analysis on the corrugator supercilii muscle	1620
DTW_EOG	Dynamic time warping method of vEOG analysis	1620

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Table 3. Overall Kruskal–Wallis results between the interactive level and the synchrony of biosignals

Synchrony of biosignals	Interactive level approaches	Average	Difference	Dynamics
Interpretation		Interactive level intensity	Interactive level disparity	Interactive level direction
Kruskal-Wallis test value		$\chi^2(2)$	$\chi^2(2)$	$\chi^2(5)$
L_d_EMGZ		4.57	2.30	1.98
L_d_EMGC		5.49	**16.43****	5.65
L_d_EOG		**30.69****	**15.77****	**19.97****
DTW_EMGZ		**18.55****	5.36	**11.22***
DTW_EMGC		2.47	4.15	**15.51***
DTW_EOG		4.37	**12.02***	4.34

Significant results (*p < .05, **p < .001) are shown in bold.

relations ($p < .05$) found with the results of methods for specific biosignals are presented. This choice was made to provide a robust view of the data trends across all approaches, and which allows an overview of the different ways biosignals could indicate the interactive level.

5.1. Overall

As explained earlier, by design, the methods used to compute the synchrony rate of biosignals, be it Ld or DTW produce non-parametric data. Each distance/biosignal-coupled relation gave different results that will be explained later in the following sections (see Figure A1 in the appendices for details of the data distribution). To compare the different categories of the interactive levels understood through the approaches, a Kruskal–Wallis test was used. The assumptions of continuous variable, independence (by timing) and similar distribution shape were determined to have been met (see Figure A1 in the appendices for details of the data distribution). The results of all 18 relations are presented in Table 3, with significant results ($* : p < .05, ** : p < .001$) in bold.

In the following section, the significant results will be presented in more detail, along with further analysis with a Kruskal–Wallis test and completion with Pairwise Mann–Whitney tests with Hochberg adjustment to check the multiple testing correction, divided by approaches: average, difference and dynamics (title of the corresponding sections as explained in the methodology).

5.2. Average

The average approach was used to classify the interactive level according to its value in three intensity categories: low (l), middle (m) and high (h). There was a significant difference in `DTW_EMGZ` across three intensity categories, $\chi^2(2) = 18.55$, and $p < .001$. The median `DTW_EMGZ` figures were 0.0082 for low, 0.0066 for middle and 0.0064 for high. Post hoc comparisons using Pairwise Mann–Whitney tests indicated that the median `DTW_EMGZ` of low was significantly higher

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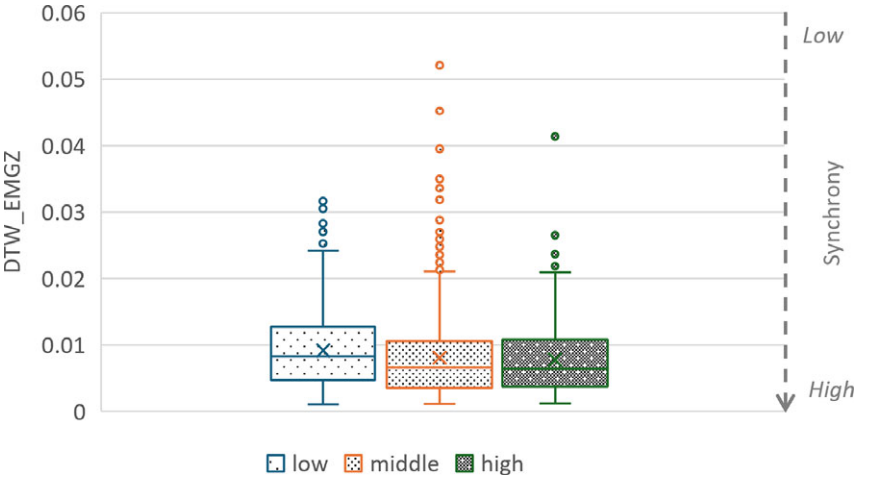


Figure 7. Repartition of DTW_EMGZ by intensity of interactive level from the average approach.

than that of middle, $p < .001$, and high, $p < .001$. However, there was no significant difference between the median DTW_EMGZ of middle and high. These results show a negative relation between DTW_EMGZ and the intensity of the interactive level qualified by the average approach, meaning that higher intensity levels corresponded with higher synchrony rates of EMGZ from the DTW method (see Figure 7).

Furthermore, there was a significant difference in Ld_EOG across the three intensity categories, $\chi^2(2) = 30.69$, and $p < .001$. The median Ld_EOG figures were 0.0008 for low, 0.0009 for middle and 0.001 for high. Post hoc comparisons using Pairwise Mann–Whitney tests indicated that the median Ld_EOG of low was significantly lower than that of middle, $p < .001$, and high, $p < .001$, and the median Ld_EOG of middle was significantly lower than that of high, $p < .05$. These results indicated a positive relation between Ld_EOG and the intensity of the interactive level qualified by the average approach, meaning that higher intensity levels corresponded with lower synchrony rates of EOG from the Ld method (see Figure 8).

Both results support our hypothesis and seem to indicate a difference in roles that specific social behaviours, indicated by different biosignals and computed as a synchrony rate by different methods, play in the interactions.

5.3. Difference

As the synchrony rate was computed at the pair level, it was necessary to have a comparison of the difference in values between examinee-reported interactive levels. The difference approach quantified an individual level by its disparity between examinees in a pair in three disparity categories: low (l), middle (m) and high (h). A significant difference in Ld_EMGC across three disparity categories was found, $\chi^2(2) = 16.43$, and $p < .001$. The median Ld_EMGC figures were 0.0818 for low, 0.0902 for middle and 0.0813 for high. Post hoc comparisons using Pairwise Mann–Whitney tests indicated that the median Ld_EMGC of low was significantly lower than that of middle, $p < .05$, and the median Ld_EMGC of middle was significantly higher than that of high, $p < .001$. However, there was no

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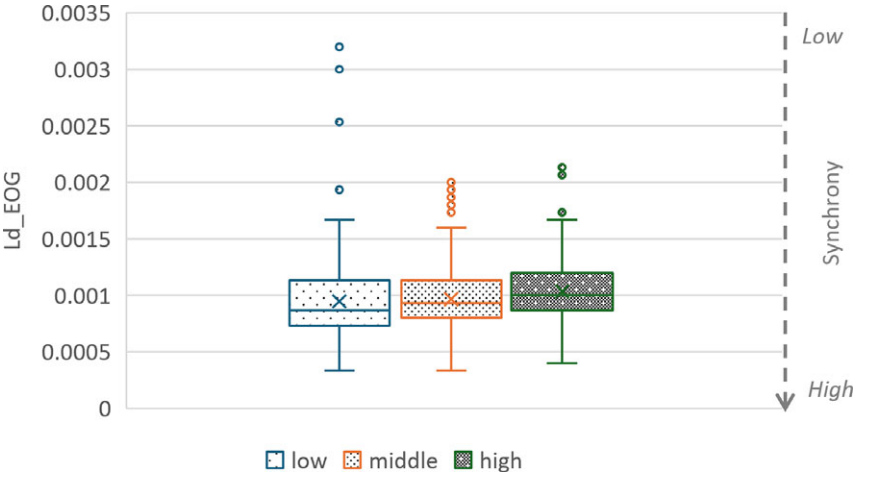


Figure 8. Repartition of `Ld_EOG` by intensity of interactive level from the average approach.

significant difference between the median `Ld_EMGC` of low and high. These results indicate a relation between `Ld_EMGC` and the disparity of the interactive level qualified by the difference approach, meaning that both low and high disparity in the interactive level correspond to a higher synchrony rate of EMGC using the Ld method (see Figure 9).

The results further showed a significant difference in `Ld_EOG` across three disparity categories, $\chi^2(2) = 15.77$, and $p < .001$. The median `Ld_EOG` figures were 0.001 for low, 0.0009 for middle and 0.0009 for high. Post hoc comparisons using Pairwise Mann–Whitney tests indicated that the median `Ld_EOG` of low was significantly higher than that of high, $p < .001$, and the median `Ld_EOG` of middle was significantly higher than that of high, $p < .05$. However, significant differences between the median `Ld_EOG` of low and middle were not confirmed, $p = .05$. These

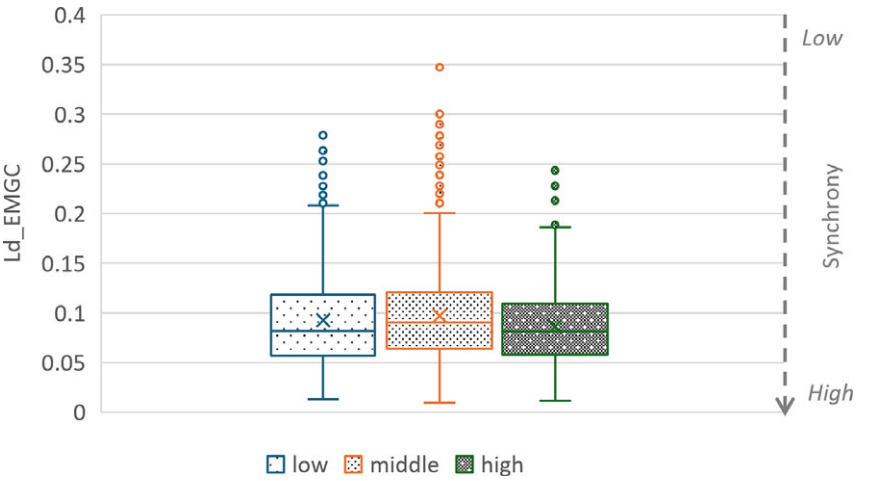


Figure 9. Repartition of `Ld_EMGC` by disparity of interactive level from the difference approach.

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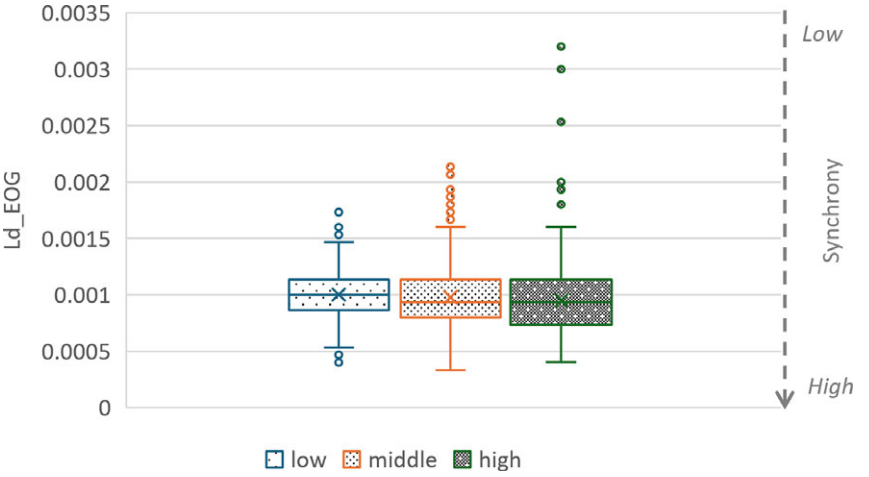


Figure 10. Repartition of Ld_EOG by disparity of interactive level from difference approach.

results indicate a negative relation between Ld_EOG and the disparity of the interactive level qualified by the difference approach, meaning that a higher disparity in the interactive level corresponds to a greater synchrony rate of EOG using the Ld method (see Figure 10).

In the same regard, there were significant differences in DTW_EOG across three disparity categories, $\chi^2(2) = 12.02$, and $p < .05$. The median DTW_EOG figures were 0.1017 for low, 0.0924 for middle and 0.0962 for high. Post hoc comparisons using Pairwise Mann–Whitney tests indicated that the median DTW_EOG of low was significantly higher than that of middle, $p < .001$, and high, $p < .05$. However, there was no significant difference between the median DTW_EOG of middle and high. These results indicate a negative relation between DTW_EOG and the disparity of the interactive level qualified by the difference approach, meaning that a higher disparity in the interactive level corresponds to a greater synchrony rate of EOG using the DTW method (see Figure 11).

These results show a trend similar to the average approach by supporting our hypothesis and indicating a difference between biosignals and the method used to compute the synchrony rate. It appears that the synchrony rate of biosignals not only indicates the intensity of the interactive level but is also related to disparity while observed in pairwork.

5.4. Dynamics

The main purpose of using an intersubjective approach to interaction is to create a continuum between interactive level integrated into an interactive flow. This is why the dynamic approach was developed, to see if the synchrony rate of biosignals can be related to a prediction of the direction that the pair's interactive level will take afterwards. To do this, the direction of the interactive level was separated into five possible categories for the next interactive level: increase (i), alone (a), same (s), opposite (o) and decrease (d). For simplification's sake, in the following analysis, these categories will be considered as presented in increasing order. A significant

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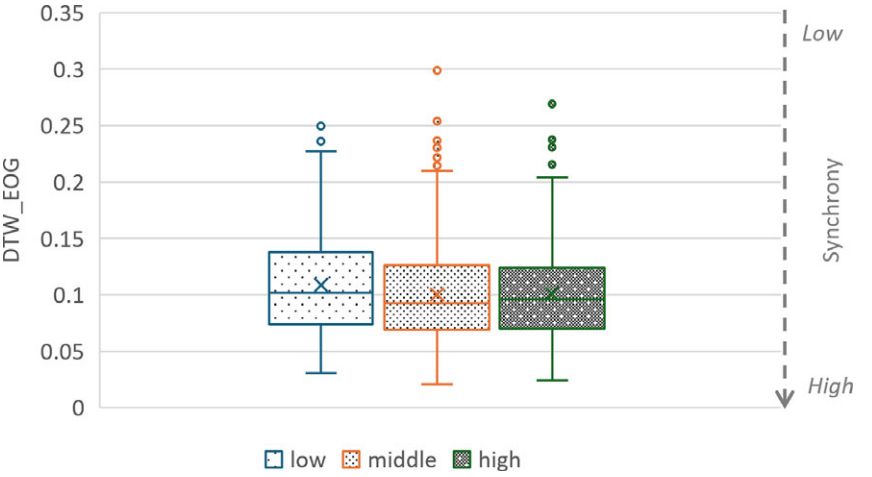


Figure 11. Repartition of DTW_EOG by disparity of interactive level from the difference approach.

difference in DTW_EMGZ across five possible categories was found, $\chi^2(2) = 11.22$, and $p < .05$. The median DTW_EMGZ figures were 0.0076 for increase, 0.0069 for alone, 0.0066 for same, 0.0065 for opposite and 0.0050 for decrease. Post hoc comparisons using Pairwise Mann–Whitney tests indicated that the median DTW_EMGZ of increase was significantly higher than that of decrease, $p < .05$. However, none of the other differences were significant. These results indicate a negative relation at the extremes between DTW_EMGZ and the direction of the interactive level qualified by the dynamic approach. This means that if an interactive level is going to decrease, the synchrony rate of EMGZ using the DTW method will be greater than with an increase (see Figure 12).

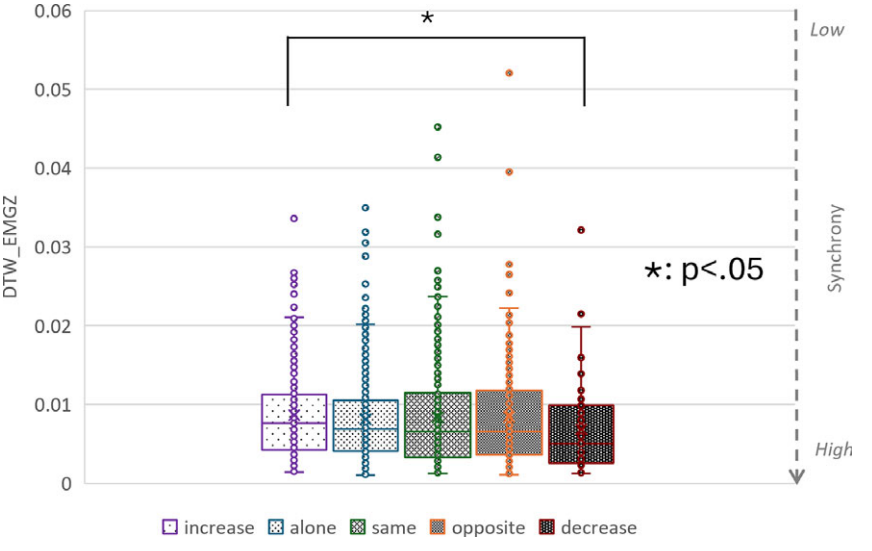


Figure 12. Repartition of DTW_EMGZ by direction of interactive level from dynamics approach.

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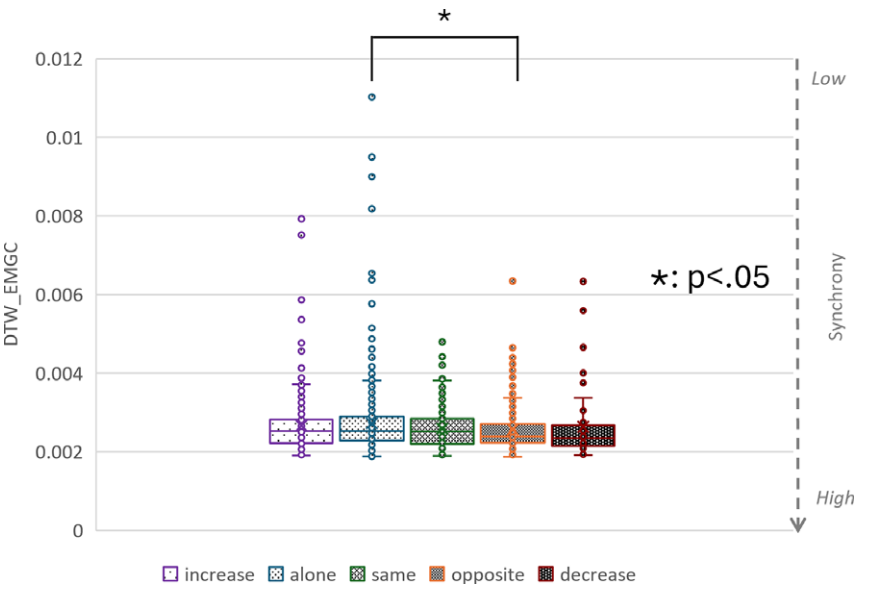


Figure 13. Repartition of DTW_EMGC by direction of interactive level from the dynamics approach.

In the same vein, the results showed a significant difference in DTW_EMGC across five possible categories, $\chi^2(2) = 15.50$, and $p < .05$. The median DTW_EMGC figures were 0.0025 for increase, 0.0025 for alone, 0.0025 for same, 0.0024 for opposite and 0.0023 for decrease. Post-hoc comparisons using Pairwise Mann–Whitney tests indicated that the median DTW_EMGC of alone was significantly higher than that of opposite, $p < .001$. However, none of the other differences were significant. These results indicate a negative relation between DTW_EMGC and the direction of the interactive level qualified by the dynamic approach. This means that if an interactive level is going to decrease (for one of the participants), the synchrony rate of EMGC from the DTW method will be greater than with an increase (see Figure 13).

Finally, a significant difference in Ld_EOG across five possible categories was found, $\chi^2(2) = 19.97$, and $p < .001$. The median Ld_EOG figures were 0.001 for increase, 0.001 for alone, 0.001 for same, 0.0009 for opposite and 0.0009 for decrease. Post-hoc comparisons using Pairwise Mann–Whitney tests indicated that the median Ld_EOG of decrease was significantly lower than that of increase, $p < .05$, alone, $p < .05$, or same, $p < .05$. However, there was no significant difference in the median Ld_EOG of decrease and opposite. In addition, the median Ld_EOG of opposite was significantly lower than that of increase, $p < .05$, alone, $p < .05$, and same,$p < .001$. Contrarily, the other differences were all insignificant. These results indicate a negative relation between Ld_EOG and the direction of the interactive level qualified by the dynamic approach. This means that if an interactive level is going to decrease, the synchrony rate of EOG using the Ld method will be greater than with an increase (see Figure 14).

These results, supporting our hypothesis, have two implications that should be noted. First, the same differences in methods and biosignals can be found in all three approaches, indicating a need to better understand the role of each biosignal

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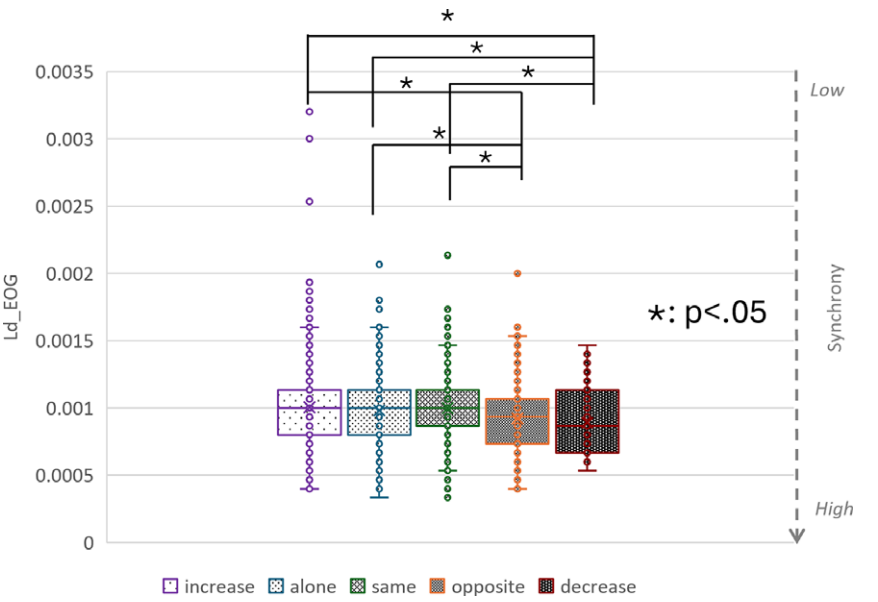


Figure 14. Repartition of `Ld_EOG` by direction of interactive level from dynamics approach.

as a marker of specific socio-cognitive behaviours and a need for a finer comprehension of the method of computing the synchrony rate for them. Second, an overall decrease in the method distance value is apparent as the interactive level declines (corresponding as an opposite if only one examinee reports it or a decrease if both do), which would indicate a better synchrony rate than when the interactive level rises. These implications and their meaning are further explored in the discussion section.

5.5. Influence of familiarity

As was explained previously, even though the situation was designed to reduce the influence of situational factors, one factor that needed to be considered was the familiarity level (i.e. how well the examinees knew each other before the experiment). To understand the influence of familiarity on the results, a correlation analysis was conducted between the results of familiarity at the pair level and the interactive pair level using the average and difference approaches. The dynamic approach was excluded from this analysis, as it was thought that if familiarity could influence the intensity and disparity of the interactive level, it would be difficult to identify a correlation between the direction of the interactive level and the familiarity level of the examinees interacting. In other words, it was thought that if the starting point of the interactions could change, it would not significantly change the flow afterwards, at least in this case. Indeed, if previous research has showed a link between the interactive level attainable (intensity) and the familiarity of examinee, they also showed that the dynamics of said interactions are less dependent on it and overtaken by the influence of interpersonal factors, in our case motivation, pairness and non-verbal communicative behaviour. The correlation

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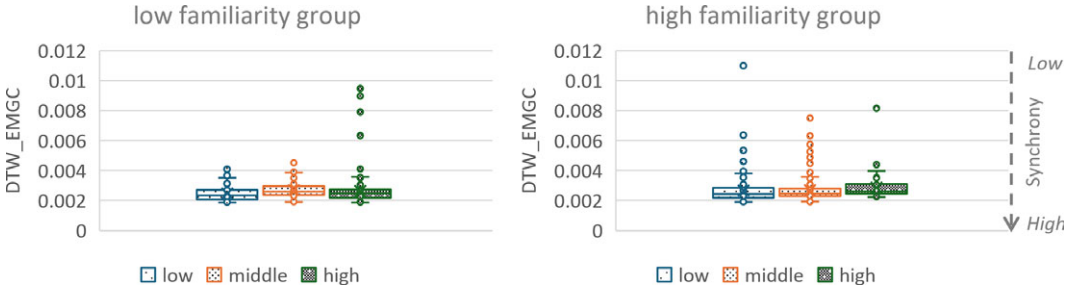


Figure 15. Comparison of the repartition of DTW_EMGC by intensity of interactive level from the average approach between the low and high familiarity level groups.

analysis between familiarity levels and average interactive levels showed that they held a weak negative correlation $r(3514) = -.25, p < .001$, with a higher level of familiarity associated with a lower intensity at the interactive level. In other regards, no correlation was found between familiarity and differences in interactive level results $r(3514) = .07, p < .05$. These results indicate that the experiment's design greatly helped to reduce situational factors such as familiarity, as its influence was almost insignificant, except when it came to intensity. This weak negative correlation can be explained by the tendency to more freely report a lower interactive level when the partner is one the subject has had previous experiences with.

To better grasp the influence of familiarity on our results, the pairs were classified into two groups: a low familiarity group for pairs with familiarity levels between 0 and 1 (10 pairs) and a high familiarity group for pairs with familiarity levels between 1 and 2 (10 pairs). For both groups, the relationships between the intensity of the interactive level resulting from the average approach and the synchrony rate of biosignals were then compared to see if such a relationship could be altered. If the relations showed no significant influence, only DTW_EMGC results per intensity of the interactive level changed relationships from a peak in the middle category to a positive relation. This implies that the synchrony rate of EMGC using the DTW method with the high familiarity group was lower than that of the low familiarity group for a high-intensity interactive level (see Figure 15).

One explanation for these results could be the different roles played in the interactions by specific social behaviours, indicated by different biosignals and computed as a synchrony rate by different methods.

6. Discussion

By using a dialogical approach to measurement coming from the intersubjectivity field, it was possible to open the study of interpersonal factors and their influence on the interactive level in co-creation from both subjective and objective standpoints. Our hypothesis was confirmed by the data, as a relation was found between the synchrony rate of biosignals (fEMG, EOG) and the variation of the interactive level (motivation, pairness) at the pair level during co-creation. The implications of this will be first discussed by comparing the relationships between the methods and the biosignals, and what they tell us about the interactive level. Afterwards, they will be developed on the interpersonal aspects of creativity before going on to discuss the limitations of this research.

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6.1. Method used to understand socio-cognitive shared behaviours by synchrony

One of the main trends observed during the analysis of the results was the influence of the method used to compute the synchrony rate from biosignals, as only one result was significant with both methods (the negative relation between the synchrony rate of EOG and the disparity of the interactive level). There is a need to discuss in greater detail the different uses of both methods (Ld & DTW) and what this experiment reveals about our understanding of socio-cognitive shared behaviour synchrony. Computed from two methods, the synchrony rate indicated different aspects of how these behaviours influenced the interactive level.

First, after having learnt that the synchrony rate of biosignals could be computed by using different methods, each one adapting a specific distance, was designed with a different goal in mind (synchrony in timing of activation for Ld, while synchrony of patterns for DTW) to quantify the synchrony rate of specific biosignal indicators of shared behaviours. If the distances had already been used in different contexts, it was the first attempt to utilise them to compute a synchrony rate from these specific biosignals, meaning that the methods needed to be applied in this context to correspond to the most integrative understanding of the studied behaviours.

6.1.1. Damerau–Levenshtein distance (Ld)

The Ld method, with a binarisation process that is run before computing the cost from the Damerau–Levenshtein distance, simplified the analysis of the given behaviours to an activation versus non-activation difference. In the case of fEMG, this meant it corresponded to the activation of a muscle, while it was the presence of a blink that was detected for EOG. This simplification helped to reduce the influence of each individual's physiological factors on the biosignals, as the binarised process was done at the individual level, leaving only the activation part to be compared in timing at the pair level. The Ld method was used to understand synchrony in the activation of the given biosignals, which can be understood as a similarity in the timing of activation of the corresponding behaviours between two examinees in a pair. An analogy would be to see it as a measure of the conversation level between participants' shared behaviours. A low Ld result (=high synchrony rate) is comparable to a stable conversation in which cues and answers are quickly exchanged, while a high Ld result (=low synchrony rate) indicates delays and instability in the conversation, meaning that the activation of the behaviours is more dispersed in time between examinees.

In short, the Ld method provides a good overview of the similarity (timewise) of the activation of one behaviour between two interacting participants. It can simplify and quickly compute a distance, providing a reasonable estimation of the conversation state of the behaviour. The simplification of the biosignal data is key to keeping a clean signal that can then be binarised, corresponding to the activation of the behaviour. This binarisation process is needed to focus the comparison on the synchrony (as similarity in timing) of only the activation. However, it is limited to a given number of behaviours that can be summarised in this manner while still remaining pertinent enough to indicate the interactive level.

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6.1.2. Dynamic time warping (DTW)

To address this, the DTW method concentrates on using the biosignal data as is, using the distance directly without any preprocessing, by looking at it more as a series of patterns and seeing if these patterns bear similarities with those from the partner's biosignals, while also shifting the time axis (Bringmann & Kunnemann 2015). It is thus more dependent on individual physiological differences that play a role in the shapes of the patterns. As such, the DTW method is used to understand the synchrony of patterns inside the biosignals. It does not concentrate only on the "peaks" but also gives an indication of the resting state of behaviours, considering downtime and tempo differences to compute the overall synchrony rate. It provides a more detailed and finer approach to specific behaviours than Ld but is also more influenced by other factors, as it is situational or personal.

In short, the DTW method findings can indicate individual similarities in a specific behaviour that also considers unconscious processes. It can quickly compute a number representing the shape matching said behaviour. The simplification of biosignal data is also relevant here in correctly interpreting the small variations. However, it is subject to more influences brought by personal and situational factors, making it more difficult to interpret.

6.1.3. Relation between Ld and DTW

As both methods were used to compute similar but slightly different synchrony rates of biosignals in this study, the relation between Ld and DTW method results needed to be determined, so a correlation analysis was conducted for each biosignal. For EMGC, the analysis helped confirm that they were related by a moderate positive correlation $r(1619) = .45, p < .001$, with high Ld results associated with high DTW results, and vice versa. EOG results gave the same moderate positive correlation $r(1620) = .46, p < .001$. For both EMGC and EOG, it appears that the synchrony rate of biosignals is moderately influenced by overall pattern similarities and the activation of corresponding shared behaviours. However, the analysis of the results from Ld and DTW methods from EMGZ shows no correlation $r(1617) = .09, p < .001$. This would be evidence of the possibly greater influence of external factors on the synchrony rate of the behaviour related to the activity of the zygomaticus major, with a difference found when comparing the peak of the signal with the overall pattern synchrony.

This leaves us with the influence of the method used to compute the synchrony rate, which differs depending on the biosignal. This influence needs to be studied along with the role that the corresponding shared behaviour plays in co-creative interaction to understand how this biosignal synchrony can approximate interactive level dynamics.

6.2. Interactive level influence on biosignals

As discussed previously, each biosignal and its corresponding shared behaviour were influenced by the interactive level in a different manner, and can help us understand different aspects of it, as the results of the various approaches show. The significance of the results of each biosignal will be discussed separately here.

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6.2.1. EMGZ

For EMGZ (biosignals corresponding to the facial electromyography analysis of the zygomaticus major), indicating a smiling motion and linked to a positive emotive response to a given social situation, see Cacioppo *et al.* (1988), the correlation analysis conducted between the results of Ld and DTW methods (used to compute the synchrony rate) shows no relationship. EMGZ data synchrony between two examinees in a pair was influenced by other factors and not just concentrated around the activation of shared behaviour. Possibly, the socio-cognitive behaviour related to the arousal/sharing of positive emotions (indicated with a smile) is related to the interaction level during co-creative pairwork, but at different degrees depending on the synchrony in activation or overall activity, as understood by the methods used to compute the synchrony rate. In the case of DTW, it would give us a good understanding of the nuances of such behaviours with more matching of short and incomplete motions, detected through patterns and not activation in timing synchrony, than would be detected by the Ld method. With this understanding, it can be said that our results show a positive relation between the synchrony rate of the `DTW_EMGZ` and the intensity of the interactive level, meaning that greater synchrony appears more often during higher levels of interaction. However, this synchrony was also often indicative of a decrease in the interactive level in the next step, as a negative relation between the synchrony rate of the `DTW_EMGZ` and the dynamics of the interaction showed. As such, this would then indicate a peak of the interactive level, as the subsequent dynamics often trended downward. It would indicate that there is a need to have a low-level synchrony, corresponding to a shared smiling motion, even if it is not complete (as only the DTW method gave significant results), to reach high interactive levels in co-creation. These results are compatible with the idea of the inverted vortex model that was developed by Matsumae & Nagai (2018), as they indicate a positive relation between the interactive level and co-creation. They are also in accordance with the theory of creative resonance, as described in Matsumae *et al.* (2022), which suggests that, during co-creation, it is possible to reach an asymptote in which the interactions reach their full potential, allowing augmented intersubjective creativity to appear. In design science, previous research could not find a correlation between synchrony of EMGZ and empathic accuracy scores; however, this leaves open the possibility to use for more emotionally charged topics and towards different dyadic interaction paradigms, such as the one used in this study (Chang-Arana *et al.* 2022).

6.2.2. EMGC

On the other hand, EMGC (biosignals corresponding to a facial electromyography analysis of the corrugator supercilii), indicating a frowning motion, has been linked to a negative emotive response to a given social situation, see Cacioppo & Petty (1981), while at the same time indicating of mental effort, in Topolinski & Strack (2015) and cognitive load, as explained by Mead *et al.* (2017). Its synchronic results can qualify another part of the same phenomenon. Indeed, the results did reveal a negative relation between the synchrony rate of `DTW_EMGC` and the direction of the interactive level qualified by the dynamics approach, again indicating greater synchrony before a decrease in the interactive level (see Figure 11 in the results section for details). However, this was particularly centred on contrary changes in

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the interactive level (alone and opposite categories), where only one examinee's interactive level changed its direction while the other either remained neutral or went in the opposite direction, meaning that the synchrony of EMGC tends to be a good indication of current and future dynamics between participants in the interactions, underlying the participation balance between participants in the making of these interactions. This was also supported by the relation found between the disparity of the interactive level and the synchrony rate of `Ld_EMGC`, which displays higher synchrony for low and high disparities compared to the middle. As such, it seems that EMGC synchrony is more telling of the relation between the participants in the interactions, as it was also the only biosignal that was influenced by the familiarity level, the only situational factor linked to pair characteristics that was studied in this research. Often associated with negative emotion but also related to the seriousness of a participant, as indicating the cognitive workload that was found to be a key aspect of the creative resonance phenomena in previous research Matsumae *et al.* (2023), the synchrony rate from EMGC tends to anticipate the interactive level by telling us more about the current balance of the interaction from a personal perspective. As it is a smaller muscle than the zygomaticus major, it is believed to be more telling of smaller details in the interactions that could also be more unconsciously synchronised as an indication to one's partner of one's mood, a process reflecting the chameleon effect theory (Chartrand & Bargh 1999). Unlike EMGZ synchrony, it is not directly related to interactive level intensity and does not indicate the current status of interactions. This is going in a similar direction to previous research done in studying the effect of synchrony on the designer's accurate empathy with users (Salmi *et al.* 2023). However, it could be useful in balancing the building of said interactions for each participant by telling their relative participation. It can also give hints for when one participant's mood could tilt the interactions in a specific direction, influencing the co-creative process.

6.2.3. EOG

Finally, EOG (biosignals corresponding to electrooculography analysis that detects vertical eye movement), indicating a blinking pattern, was linked to the depth of the cognitive process (Kruis *et al.* 2016). The synchrony results here were quite different from the others. They often showed a different relation on the interactive level and need to be further analysed to be understood. As the `Ld_EOG` results were focused on blink synchronisation between participants, a correlation analysis between those and the total number of blinks detected in a pair was conducted, showing a strong positive correlation $r(1620) = .99, p < .001$, with high Ld results associated with more blinks. This strong influence of the number of blinks can be explained by the average speed at which human blinks, around 26 blinks/min in a conversational setting for adults (Bentivoglio *et al.* 1997). That would mean that, during our 15-second units of pairwork, the number of blinks (corresponding to the number of 1 in the binarised series) would be low, heavily influencing the results of the Ld method, which would become more of an indication of the total number of blinks exchanged by the examinees during this period rather than a true comparison of the matching in time of blinks between participants. With this new understanding of `Ld_EOG` as indicating the total number of blinks in a pair, it could be said that there is a relation between the intensity of the interactive level

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and the number of blinks, with more blinks during higher levels of intensity. They were also related to the directions of the interactive level qualified by the dynamics approach, with more blinks if the interactive level was going to increase (see Figure 12 in the results section for details). At the same time, blinking numbers were related to disparities in the interactive levels, with more blinks detected when fewer disparities were reported. This last part was also supported by a similar correlation with the synchrony rate of `DTW_EOG`, indicating that not only blinking but all vertical movement patterns of the eye were more similar between examinees who declared fewer disparities in their interactive levels. Contrary to the fEMG results, EOG is not related to an emotive answer to a given signal but indicates deeper cognitive processes, indicating the current cognitive state of the pair during the co-creative pairwork. This status can indicate the interactive level from a shared perspective via the pair's blinking conversation. All these results support the resonance phenomena that is inductive of more complex socio-cognitive processes, as explained by Matsumae *et al.* (2023), hence the increase in blinks.

6.3. Interpersonal aspects of creativity

This research took an interdisciplinary approach based on cognitive science to better understand a specific aspect of design from an interpersonal perspective: the dynamics of interactions in co-creation. Conventionally, fEMG and EOG are usually studied at a personal level, related to a classic subjective understanding of perception. By incorporating intersubjective research knowledge, it became apparent that a dialogic approach was necessary to compare them at an interpersonal level, spurring the development of methods used to compute a synchrony rate from different distances.

This research used motivation and pairness as the main ways to subjectively measure the interactive level, and then used non-verbal communicative behaviour linked together by synchrony rates to approximate it from objective data coming from three biosignals: EMGZ, EMGC and EOG. The use of subjective data was justified by a dialogical approach to intersubjectivity approximated by interactive level dynamics. This study was exploratory in the intersubjective methodology used towards the analysis of interactions, justifying the use of continuous self-report for the measure of the interactive level. However, further improvement could be made towards the measurement methods chosen for this construct, maybe using a mixed methodology in the method. This kind of multifaceted approach towards a construct could be taken to shine its intersubjective nature, as it was presented with *motivation* as unstable and always fluctuating, heavily dependent on the current state of the interactive flow and participating in its sustainment or its decay (Matusov 2001).

One of the main thoughts behind this research was that creativity could not only be studied from a personal viewpoint as an individual characteristic of a person, but could also be nurtured and grown through interactions if the correct conditions are met, synergistically leading to a higher level of creativity than the sum of each individual would amount to (Trischler *et al.*, 2018). This approach to creativity, understood as a cognitive state of the co-design experience, means that interaction dynamics, understood by the fluctuation of interpersonal factors, are the main mechanism behind the co-creation. It justified our choice to use motivation and pairness as interpersonal factors to study the interactive level dynamics

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during co-creation (Ehkirch & Matsumae 2024). Co-creative pairwork was studied as the ideal way to create this environment for co-creation, as co-creative collaboration, to appear and push the interactive level. This has been confirmed by the data, as all pairs finished with higher interactive levels than when they started, and most of the data were categorised by their dynamics on the positive side (either increase or alone), representing 67%, compared to the 17% of the same and 16% of the negative dynamics (either opposite or decrease). Hence, not only was co-creation confirmed to be positively related to the interactive level, as found in previous research (Matsumae & Nagai 2018), but it was also possible to study the effect of specific interpersonal factors involved. Previous research on design also showed similar results on the relation between interpersonal relationships and creativity (Ozer & Zhang 2022). This need for diverse team composition, opening the possible interactions and then leading to better results in team creation was also advocated (Somech & Drach-Zahavy 2013; Aggarwal & Woolleyb 2019). As discussed in the previous sections, co-creative interactions were influenced not only by factors specific to the participants, such as their own creativity, but were also related to how some situational factors influenced the interactive level, such as the familiarity participants had with each other. This influence of balance in the creation of the interactions was mostly reflected in results coming from the corrugator supercilii muscle (EMGC), showing a relationship with the difference and dynamics approached related to the individual aspects of it. This supports the findings of Mead *et al.* (2017), who defended that EMGC results are more indicative of cognitive workload, a personal construct and then its synchrony would be more influenced by the possible shift in workload balance during the activity.

From a dialogical perspective, this research helped illuminate the importance of interpersonal factors in the co-creation process and which factors should be concentrated on to create a better co-creation experience. The main factors studied were *motivation*, *pairness* and *non-verbal communicative behaviour*.

As explained previously, motivation is closely related to the goal and individual design context of each participant see Amabile (1983), and co-creation cannot be sustained without a shared motivation and agreement on common directions for the creative process. Motivation is a prerequisite for co-creation, as co-creative collaboration is only attained once designers agree to participate in it (Kleinsmann *et al.* 2012). The main implication of this result is that co-creation can only be used in an environment that sustains it, where the motivation of participants is assured by allowing them the freedom to decide what direction to pursue. In this way, it is mostly a bottom-up design approach, without the centralised top-down management that is traditionally used in design in a work environment (Ahire & Dreyfus 2000). Co-creation is by nature needing time, freedom and possibly changing of directions even in the goal of the creative process, making it more difficult to be used reliantly from a goal-oriented perspective.

On the other hand, the pairness factor that measures the feeling of depth of sharing between participants is the main factor influencing the interactive level during co-creation. As a collaborative creative exercise, the sharing of status is necessary to keep the interaction going and to attain higher levels via creative resonance (Matsumae *et al.* 2022). This means that the co-creation process is heavily dependent on the participants' interactions to produce results that would satisfy them (Mitchell *et al.* 2016).

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Non-verbal communicative behaviours indicate the sharing of cognitive states between participants that, in return, approximate the dynamics of the interactive level. This underlines the importance of having natural and direct interactions that are not constrained in any way to reach the best possible experience of co-creation (Masclet *et al.* 2021). These subtle shared behaviours can be difficult to reproduce or maintain in other types of interactions, such as in remote workshops with online tools (Brazauskayte 2019). Indeed, the underlying cognitive process responsible for this synchrony of social behaviours is believed to be heavily influenced by the channel used in the interactions (Chartrand & Bargh (1999); Fuchs & de Jaegher (2009) that are, of course, modified or limited in an online environment. The specificity and greatness of co-creation shine the brightest when enjoyed in person in an environment that allows as much freedom as possible while maintaining reasonable management of the process itself from a time perspective (Beghetto & Karwowski 2019).

Of course, this research is by no means an intent to undermine the personal factors influencing the interactions, such as experience and demographic or cultural background. Previous research has often shown how much these factors need to be seriously considered to depict the complex possibilities in interactions in design. However, the scope of our study was to study the interactive phenomena from an intersubjective understanding, justifying the reduction of the factors at an interactive level and considering personal factors such as familiarity as complementary. It would be interesting to test to see if these results are robust enough to be replicated in other situations where the participants (and then their personal factors) are more diverse. Even if the method still lacks precision and reliability, its simplicity and ease of use could be useful to other researchers who wish to study a special social situation from a dialogical perspective. To sum up, this study has found:

- It is possible to approximate the dynamics of interactive levels in co-creative pairwork using objective markers such as the synchrony rate of biosignals (EMGZ, EMGC, EOG) computed by the Damerau–Levenshtein distance (Ld) or Dynamic time warping method (DTW). By using knowledge from intersubjectivity research and tools coming from socio-cognitive research, it was possible to expand the previous personal vision of creativity at the interpersonal level from a dialogical perspective.
- The dynamics of the interactive level can be related to the synchrony rate from DTW for both EMGZ and EMGC, indicating direction, which is also positively related to the total number of blinks (associated with the synchrony rate computed by Ld_EOG). Its intensity and disparity were also related to the synchrony rate, but differ depending on the method and the biosignal studied.
- The differences found between biosignal synchrony indications of the interactive level in co-creative pairwork can be explained by the different methods used to compute the synchrony rate (Ld focusing on the conversational aspect and DTW more on physiological behaviour), along with the role of each associated shared behaviour that illuminates different aspects of the interactions.

6.4. Limitations & futures studies

The goal of this research was to understand the interpersonal aspects of creativity through the roles of specific social behaviours in an interaction by measuring

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biosignal indicators during co-creative pairwork. To do this, biosignals at the pair level needed to be elevated by computing a synchrony rate using two methods (Ld & DTW). This means that the analysis was conducted on the synchrony rate of each biosignal, related to specific socio-cognitive shared behaviours and on how they qualified the interactive level, understood through three approaches (average, difference and dynamics). This was also done in a large-scale experiment that collected a large pool of data, corresponding as much as possible to a realistic experience of co-creation in pairwork. However, to limit situational factors, there was a need to simplify and gamify the creative tasks, making it less able to represent all possible interactions that could occur during a real co-design process. Familiarity level was used to control its influence on the initial state of the interaction, but further development could be made into studying other situational and social factors, such as the effect of the creative environment, the influence of the channel used to communicate, or the previous experience of the participants.

Several aspects of this research have the potential for evolution. As has been explained, the scope of this study was centred on the interpersonal aspects of creativity by focusing on interaction during co-creation. Personal factors such as gender or experience in creative tasks were considered outside the scope and negligible so far as determining interactive level dynamics at the pair level during co-creation. Furthermore, it was suspected that using examinees from a similar socio-cultural background also influenced the results, as almost no divergence in terms of communication between participants was observed during the task studied. In a similar direction, cultural aspects might have influenced the shared behaviours synchrony as differences were previously found between Japanese and Scottish mother–infant dyadic interaction (Negayama *et al.* 2021). Previous research has also shown that if there is a universal use of facial expression, its associated meanings might be influenced by cultural aspects (Chen & Jack 2017). There is then a possibility that cultural differences might influence the conversational aspect (i.e. the meaning of it) of the co-creative interaction by showing more or less emphasis on the synchrony (timewise activation similarities) of particular associated behaviours to give key information for the direction of the dynamics of the interaction. Future research is needed to test how much these cultural aspects coloured our results and their interpretations (Christensen *et al.* 2017). It would be interesting to test to see if the results found in this research are robust enough to be replicated in different settings with more variations in the social factors of participants. In addition, as links between the interactions and biosignal synchrony were developed in this study, it would be interesting to further study their influence on co-creation itself by looking at the actual experience of co-creation. This means that there is still a need to pursue further research to see how this new understanding of interactive levels qualified by biosignal synchrony of social behaviours can contribute to the co-creation process and its results. This will be needed to justify its implementation during co-design and to build a better experience in design. There is also a need for further reflection on design cognition aspects of co-creation and how they relate to design research to broaden the field of application of this study. For example, in Bonnardel & Zenasni (2010), the cognitive aspects linked to the ideation process were judged to improve through human–interface interaction, resulting in enhanced creativity. This study of similar cognitive aspects led to the proposition of a dual-process theory of ideation (Gonçalves & Cash 2021). In addition, following the scope that was chosen, this research did

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not study the results of the co-creative task (see Figure A2 in the appendices for the creative outputs of task 2) from an outcome-oriented design perspective that could have completed an understanding of the interactive level as influenced by their results (Cheung & To 2011; Ozer & Zhang 2022). This would have required another research question followed by changes in the experimental protocol. Further research is then needed to link these results with the creative output of the co-creative task, justifying its use in more traditional real-life design processes.

Finally, the relations found between biosignal synchrony and subjective ratings may be overstated or unreliable due to inconsistencies in subjective measurement. This weakens the study's conclusions regarding the effectiveness of using biosignal synchrony to assess interaction dynamics. The reliance on subjective reports, which are prone to biases and variability, casts doubt on the generalisability of the findings. The study may not provide a solid basis for using biosignal synchrony as an objective measure of engagement in real-world settings.

7. Conclusion

Through this study, an understanding of the interpersonal aspects of creativity seen through the roles of specific social behaviours in creative interactions was investigated by measuring biosignal indicators during co-creative pairwork. An experiment corresponding to co-creative storytelling using clay pairwork was conducted in which biosignals from fEMG analysis of the zygomaticus major (EMGZ) and corrugator supercilii (EMGC) muscles, together with an EOG, were measured on both examinees. After the task was completed, the examinees reported their interactive levels in terms of two factors (motivation and pairness) that were afterwards transformed into three approaches to interactive pair-level thought: average (intensity), difference (disparity) and dynamics (direction). They were then compared with the synchrony rate computed by the Damerau–Levenshtein distance (Ld) or dynamic time warping method (DTW) for each biosignal. A relationship was found between the objective and subjective data.

The synchrony rate of `DTW_EMGZ` was positively related to the intensity of the interactive level, whereas a relation was also found between the synchrony rate of `DTW_EMGC` and the disparity of the same. The dynamics of the interactive level were negatively related to the synchrony rate of `DTW_EMGZ` & `DTW_EMGC`. Finally, the synchrony rate of `Ld_EOG` was correlated with the total number of blinks, being positively related with intensity and dynamics, while being negatively related with disparity in the interactive level. These results demonstrate the potential use of biosignal synchrony to approximate the interactive level dynamics in co-creation. The differences found between biosignal synchrony indications on the interactive level in co-creative pairwork can be explained by the different methods used to compute the synchrony rate (Ld focusing on the conversational aspect and DTW more on physiological behaviour), along with the role of each associated shared behaviour that illuminates different aspects of the creative interactions.

By challenging the conventional individual-centred perspective of creativity and replacing it with a dialogical approach, an understanding of the influence of human interpersonal factors on interactions in design was broadened. These results will help advance research on intersubjectivity in co-design from the viewpoint of socio-cognitive science. By better understanding interactions through biosignal synchrony, the co-creative process can be improved to bring about a

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better design experience, one that will allow more people to become actors in their own creative process, democratising creativity with a social design approach.

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Appendices

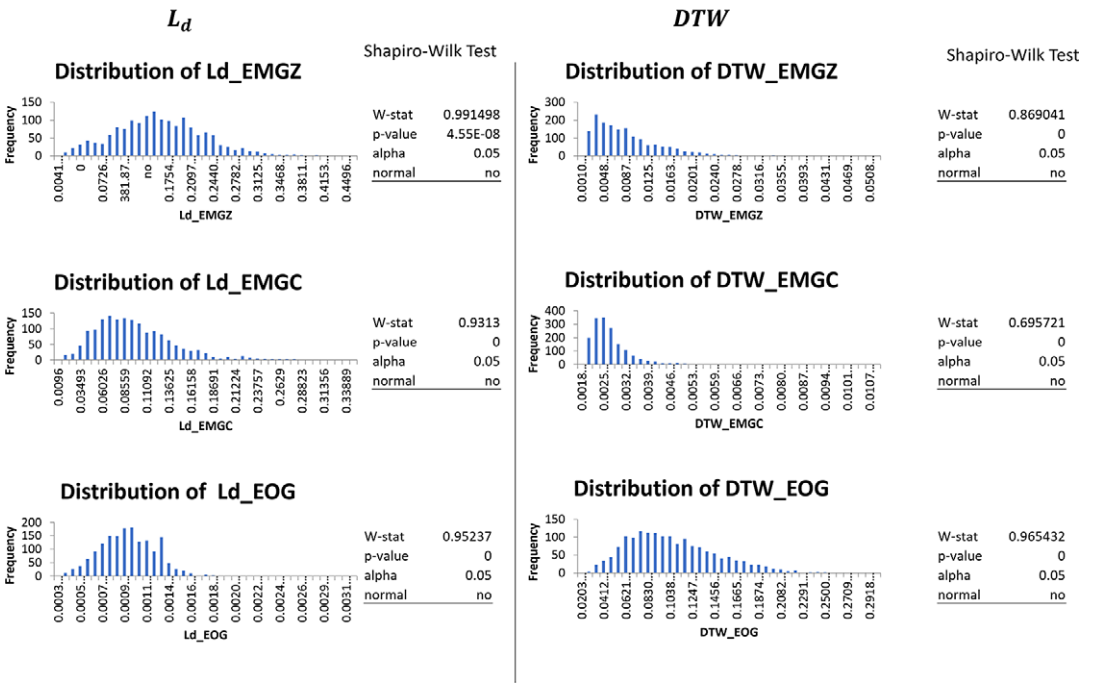


Figure A1. Distribution of Ld and DTW data with associated Shapiro–Wilk test.

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Figure A2. Creative outputs of task 2.

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