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Attachment and borderline personality disorder as the dance unfolds: A quantitative analysis of a novel paradigm

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ABSTRACT

Current research on personality disorders strives to identify key behavioural and cognitive facets of patient functioning, to unravel the underlying root causes and maintenance mechanisms. This process often involves the application of social paradigms — however, these often only include momentary affective depictions rather than unfolding interactions. This constitutes a limitation in our capacity to probe core symptoms, and leaves potential findings uncovered which could help those who are in close relationships with affected individuals. Here, we deployed a novel task in which subjects interact with four unknown virtual partners in a turn-taking paradigm akin to a dance, and report on their experience with each. The virtual partners embody four combinations of low/high expressivity of positive/negative mood. Higher scores on our symptomatic measures of attachment anxiety, avoidance, and borderline personality disorder (BPD) were all linked to a general negative appraisal of all the interpersonal experiences. Moreover, the negative appraisal of the partner who displayed a high negative/low positive mood was tied with attachment anxiety and BPD symptoms. The extent to which subjects felt responsible for causing partners' distress was most strongly linked to attachment anxiety. Finally, we provide a fully-fledged exploration of move-by-move action latencies and click distances from partners. This analysis underscored slower movement initiation from anxiously attached individuals throughout all virtual interactions. In summary, we describe a novel paradigm for second-person neuroscience, which allowed both the replication of established results and the capture of new behavioural signatures associated with attachment anxiety, and discuss its limitations.

1. Introduction

Borderline personality disorder (BPD) is a debilitating clinical condition spanning a diverse range of symptoms in the interpersonal, affective, cognitive, and behavioural domains (circa 0.5-2.5 % of the population are affected) (Maier et al., 1992; Gunderson et al., 2011; Gunderson, 2009; Skodol et al., 2002; Leichsenring et al., 2011). Diagnosis of BPD currently relies on clinical interviews and questionnaires, lacking quantifiable, non-verbal markers. Here, we introduce a novel task to better understand BPD through the "cognitive-emotional fingerprinting" of subjects' interactions with virtual others. A decisive consideration in the design of the task and the associated data analyses was that attachment disturbances and the ensuing continual patterns of interpersonal dysfunction are defining themes of the aetiology and maintenance of BPD, respectively (Agrawal et al., 2004; Gunderson, 2007; Fossati et al., 1999; Johansen et al., 2004; Lieb et al., 2004). Subjects with a BPD diagnosis frequently have intense and unstable intimate relationships and typically exhibit shifts between idealisation and devaluation of the other as well as aggression and extreme distress at perceived threats of abandonment (APA, 2013; WHO, 2004).

Research in experimental psychology pays due attention to the identification of core cognitive endo- and eco-phenotypes of BPD underpinning the interpersonal domain, for instance in so-called "static" tasks such as mental state discrimination, (Fertuck et al., 2009; Frick

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et al., 2012; Anupama et al., 2018; Berenson et al., 2018) facial emotion recognition, (Lowyck et al., 2016; Ritzl et al., 2018) or reactivity to emotion induction (Renneberg et al., 2005). There have also been growing efforts to investigate aspects of aberrant appraisal of social interactions, such as in paradigms of social exclusion and rejection, (Domsalla et al., 2014; De Panfilis et al., 2015) idealisation and devaluation, (Michael et al., 2021) or behavioural trust games (King-Casas et al., 2008; Unoka et al., 2009; Xiang et al., 2012). Other accounts have provided characterisations of differentiable biases in social vs. non-social (i.e. physical) learning in BPD patients (Timothy et al., 2008; Fineberg et al., 2018a; Henco et al., 2020).

However, there is a growing agreement that novel paradigms should be devised to elicit a more proximal range of dysfunctional appraisal mechanisms (and ensuing behaviours) that arise ecologically in BPD - moving towards settings in which participants engage with the closer "you" rather than the distant "them", (Schilbach et al., 2013; Fineberg et al., 2017) and moving from verbal to non-verbal measurements (Westermann and Sibilis, 2022). A promising approach is to use virtual environments in which social interactions take place with computer-controlled avatars (McCall, 2015; Fineberg et al., 2017; Michael et al., 2021; Sevgi et al., 2020; Westermann and Sibilis, 2022; Lin et al., 2023; Riem et al., 2019). The use of avatars allows experimenters to design participant behaviors, social algorithms, and situations to probe internal computing models that underpin interpersonal dysfunction (Barakova et al., 2009).

As a step in this direction, we developed the "dancing task", a paradigm that enabled us to describe and decompose the appraisal of virtual interpersonal interactions. This allowed us to relate both the reported quality of this experience and objective measures of behaviour to the spectrum of borderline symptomatology and attachment styles. The dancing task was inspired by a seminal but somewhat underexploited approach which uses visual animations to elicit attributions of actions, interactions and mental states to others (Fritz et al., 1944). It makes use of minimal avatars (smiley-frowny faces) in a 2D space (a computer screen), where subjects get to know (or rather "dance" with) four different partners, which vary in their "personalities" (i.e., the bias and range of their facial expression, which lies on a continuum from smiling to frowning). The adequacy of this choice of minimal smiley-frowny avatar is supported by evidence that analogous patterns of neural activity related to emotional processing occur when people are exposed even just to simple text emoticons (Yuasa et al., 2006; Aldunate and González-Ibáñez, 2017). Subjects were informed that maintaining a comfortable interpersonal distance during the interaction was crucial for keeping their partner's avatar smiling. This choice was motivated by the difficulties in psychological distance regulation among BPD patients, and evidence linking BPD with altered emotional responses (with mixed results) (Renneberg et al., 2005; Matzke et al., 2014; Bertsch et al., 2018; Mitchell et al., 2014). However, the dancing task goes beyond prior efforts in eliciting emotional responses by offering higher ecological validity – due to the element of agency in eliciting facial expressions as opposed to passive appraisal.

Our study analysed the overall experience derived from all dances and its relation with clinical scales quantifying BPD symptoms and attachment style. Our primary hypothesis was that increased severity of borderline personality disorder (BPD) symptoms and attachment difficulties would correlate with a more negatively biased overall experience evaluation. Additionally, we analysed questionnaire items to individuate emergent, interpretable factors describing covert experience with all partners, and subsequently probed the relationship between these and our clinical measures. We further provide a comprehensive link between all items describing covert experience (including partner-personality specific items) and all clinical scales and sub-scales. While we did not have substantial hypotheses regarding specific aspects of covert experience relevant to different clinical dimensions, we hypothesized sparsity (i.e. the presence of only few meaningful relationships) in the relevance of partner-specific questionnaire items and clinical scales. Finally, we present an investigation of move-by-move measurements of click distances from partners and action latencies, which involved the construction of simplified linear models and subsequent exploration of the relationship between these subjective, model-based quantities and questionnaire measures.

2. Methods

2.1. Participants and procedure

Fourty-eight subjects diagnosed with borderline personality disorder and 38 healthy controls took part in the study. Participants diagnosed with BPD were recruited from specialist personality disorder services across various London mental health trusts. The diagnosis of BPD was confirmed using the Structured Clinical Interview for DSM-IV (SCID-II) (First et al., 1997). Individuals with a history of psychotic episodes, severe learning disability or neurological illness/trauma were excluded. Healthy control participants were recruited from the community. They did not have a history of mental illness or neurological illness/trauma and did not have any current diagnosis. The absence of personality disorder in healthy controls was confirmed by screening participants with the Standardized.

Assessment of Personality, Abbreviated Scale (SAPAS) (Paul et al., 2003). Any individual scoring above 4 on the SAPAS was subsequently interviewed with the SCID-II and excluded if they scored above threshold on any personality disorder. All participants were included on the basis of English language fluency. Participants attended research appointments at University College London. All participants provided signed informed consent. The study was approved by the Research Ethics Committee for Wales (REC reference number 12/WA/0283).

2.2. Questionnaires

2.2.1. Personality assessment inventory for borderline traits (PAI-BOR)

The PAI-BOR is a self-report questionnaire assessing traits associated with BPD (Charles Morey, 1991). Across 24 items, participants are asked to indicate how much each question describes them from 0 ("False") to 3 ("Very True"). Combining all items gives a total score (PAI-BOR). Additionally, there are four subscales relating to core BPD features: affective instability (PAI-BOR-A), negative relationships (PAI-BOR-N), identity problems (PAI-BOR-I), and non-suicidal self-harm (PAI-BOR-S). PAI-BOR-S merges impulsive behaviours and self-harm. For all scales, a higher score indicates more severe pathology.

2.2.2. Experiences of close relationships-revised (ECR-R)

The ECR-R is a self-report questionnaire measuring adult attachment tendencies towards romantic partners in terms of how anxious or avoidant they are (Fraley et al., 2000). Subjects answered 36 questions asking them to indicate how much they agree with a given item on a range from 1 ("Strongly Disagree") to 7 ("Strongly Agree"). This results in scores for two subscales: Anxious-Attachment and Avoidant-Attachment. A higher score represents a higher level of anxious or avoidant attachment.

2.3. Task design

The dancing task consisted of a JavaScript-coded game (a trial version with reduced overall durations is available online at https://ba5r373hms.cognition.run/— jspsych code can be found at https://github.com/fedmanci/dancing-task-1.0). The game involved a series of dancing episodes between the subject's avatar and each of four virtual partners, all shown as circular smiley-frowny faces on a blank canvas (the 'dance floor'). The four partners differed in their personalities, defined by the individual range of moods they were able to express through their mouth and eyes. Partners could be identified by their colours. The subject's avatar's facial expression (i.e., the expression of the smiley face representing the participant's position in the virtual space) was kept neutral.

2.3.1. Task structure

After registering their preferred username, subjects faced a short training dance (1 min) to familiarise themselves with moving their avatar (which we call *S* for brevity). Once this was completed, four coloured circles (the new dancing partners) made their appearance. When these were not selected, they were simply shown as plain, numbered (1–4) circles, each of a different colour. Subjects simply pressed the corresponding key (1–4) to select a partner for a dance. When a partner was selected (we call the selected partner *P*) it turned from a plain circle into a smiley-frowny face. Subjects could then see the partner's facial expression (neutral before the first move) and the dance began when the subject first moved their avatar. From this point onwards, P's mood was a function of distance to the subject's avatar. Specifically, the update of the selected partner's mood during the dance was determined by a simple differential equation (described in Fig. 2 in Supplementary Materials), which dictated that mood improved when *S* struck a *good distance* from *P* (not too close, nor too far), and deteriorated otherwise (Fig. 1). While the mood change per unit time was the same for all partners, the range of moods displayable by each was unique (see Fig. 2). During the dances, participants and virtual partners swayed back and forth in a synchronized manner. While subjects had the flexibility to choose their next position with a left mouse click at any point during the interaction, the coordinated movement of the subject and partner occurred at regular intervals of every 3 s. Dances could be interrupted at any moment (after a minimum of 3*s*) by pressing the space bar. Subjects knew that they must dance with all partners at least once; to enforce this, partners could not be re-selected before all had been given one dance first. However, once all partners had been given one dance, subjects were free to re-select whichever dancer they preferred. Subjects had 14 min to get to know all partners, after which they filled a questionnaire which probed their impressions of each.

2.3.2. Dancing task questionnaire

We developed the Dancing Task Questionnaire (DTQ), a comprehensive survey administered immediately after the completion of the dances. This consisted of the same set of 9 items concerning each of the four partners (36 items in total). Subjects responded via a JavaScript visual analogue scale which allowed for finely graded responses (0, 'Not at all', to 100, 'Very much').

We included three main sets of items. The first centered on affective outcomes, investigating the degree of (1) liking, (2) trust in the partner, and the extent to which the interaction induced feelings of annoyance or irritation (5). The second set delved into the behavioural and emotional assessment of the partner, probing how unpredictable their dance was (7), and how unstable their mood was perceived to be (8). The third set prompted a reflective analysis of the participant's role in the interaction, particularly regarding how they perceived their impact on the partner. These items are crucial, given that the task implies the other person's mood depends on the participant's actions; they quantified the extent to which the participant caused the partner to be (3) happy, (4) sad, how much (6) effort was invested in the interaction overall, and whether (9) they felt responsible for their partner's mood. The items are listed below, with a relevant label in quotes and italic to facilitate reference.

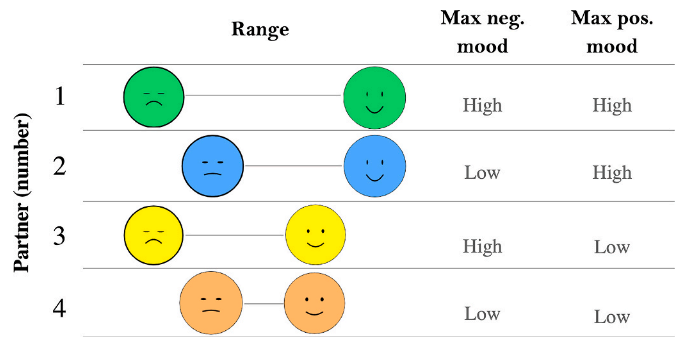

Fig. 2. Personalities of partners. Dancing partners differ in their range of facial expressions. Partners can reach 'High' (1,2) and 'Low' (3,4) positive (smile) expressions, as well as 'High' (1,3) and 'Low' (2,4) negative (frowning) expressions, resulting in four unique partners.

1. How much did you like this dancer? ("*Likeable*")
2. How much did you trust this dancer? ("*Trustworthy*")
3. Do you think you made this dancer happy? ("*Made Happy*")
4. Do you think you made this dancer sad? ("*Made Sad*'')
5. How much did you get irritated or annoyed with this dancer? ("*Irritating*")
6. How much effort did you invest in understanding which distance this dancer liked? ("*Effort*")
7. How unpredictable was their dance? ("*Unpredictable*")
8. Did you feel that their mood was unstable? ("*Unstable*")

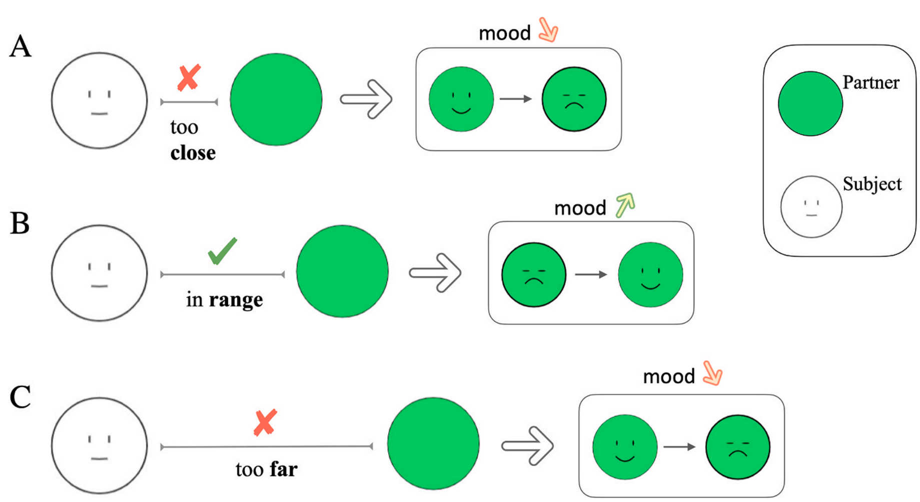

Fig. 1. The evolution of partner's mood as a function of distance. This figure provides a simple illustration of the relationship between dancing distance and the evolution of partner's mood. The transition between facial expressions is governed by a differential equation, which makes it gradual (see Supplementary Materials). In **A** the subject is too close to the partner, so that their mood deteriorates; in **B**, the subject strikes a good distance from the partner, corresponding to a certain interval (i.e., between 55 and 200 pixels), improving their mood; in **C**, the subject is too far, causing a deterioration as in A.

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9. Did you feel this dancer's mood depended on what you were doing? ("*Locus*")

An earlier version of the questionnaire only contained 8 questions per partner, so for some subjects (27), "*Trustworthy*" ratings (item 2) were unavailable. In our factor and canonical correlations analyses, we addressed this by imputing the missing values using the "3 nearest neighbors" method, chosen for its balanced trade-off between accuracy and preservation of data structure (Beretta and Santaniello, 2016). In our correlation-based analyses, we only utilised data from subjects for whom the scale was originally present.

2.4. Analyses

2.4.1. Structure of clinical scales

We initially studied the inherent structure or our clinical measures. We obtained Chronbach's α measures to tap the internal consistency of each scale, and subsequently performed sparse canonical correlations analysis (sCCA; PMA package) (Witten et al., 2009) to explore the relations between BPD symptoms and attachment measures.

2.4.2. Dancing Task Questionnaire

The bulk of our analyses concerned the ways in which the impression gained about each partner, measured via the DTQ, varied with BPD symptoms severity and attachment style. The DTQ was designed so that the same set of 9 questions was asked about each dancing partner. Thus, we first analysed questionnaire responses marginalizing across partners, and studied the covariance structure of these partner-independent measures, identifying underlying (oblique) factors through Factor Analysis (FA) (Charles, 1961). Scores along these partner-independent dimensions would reflect prior notions about people *in general* (regardless of personality) and the factors obtained, as a DTQ pre-processing step, would inform us as to the underlying dimensionality of DTQ responses, and enhance our power to find links with our measures. We used parallel analysis to establish the number of meaningful underlying factors (Horn, 1965).

In a second step, we adopted a model-based approach using sparse (i.e., regularized) canonical correlations analysis (sCCA; PMA package) (Witten et al., 2009) to determine the main mode through which DTQ and clinical questionnaire measures relate to each other. This approach was chosen to reflect our agnosticity about the relevance of each of the nine items towards our clinical scales. The method captures a critical linear combination of (1) questionnaire measures and (2) all ratings for items in the DTQ, which maximises their correlation, and provides a measure for the relative contribution of each clinical subscale and DTQ item towards maximising the relationships between the two sets. We used sparse CCA for robustness and to avoid overfitting. We assessed the out-of-sample performance of the sCCA model (i.e., the expected strength of the association between dancing questionnaire and PAI and ECR-R scales) via cross-validation. We split our dataset into five folds. For each of five iterations, one fold was held out as the remaining four were merged and used as training set. Here, we used the native permutation scheme implemented in the PMA package to extract the best penalization parameters (denoted λ; i.e., the L1 norm upper-bounds on the CCA weight vectors), which were then used to compute a correlation coefficient between latent dimensions in the held-out set. Out-of-sample correlations were averaged to yield stability. Lastly, we took the median of five repetitions. In Supplementary Materials, we complement our sCCA analysis with a full report of conventional (Bonferroni-Holmes corrected) pairwise correlations.

2.4.3. Overt behaviour

Our exploration of overt behaviour was inherently novel, as (to the best of our knowledge) similar measurements have not been previously undertaken within a comparable task and cohort. Our analysis included (1) putative proxies for indecision, measured through action latencies (Donald Richard John Laming, 1968), (2) proxies for preference in interpersonal distance and reactions to spatial intrusion (Jeremy et al., 2003) (specifically, the log-transformed click distance from the interacting partner at each individual move), and (3) the proportion of interaction time allocated to each partner. In analyses (1) and (2) potential influences on action latencies and click distances could come from two factors: (i) the distance between subject and partner; and (ii) the current mood of the interacting partner. Our candidate models for both action latencies and click distances included the addition of these predictors, as well as the two taken individually. Subject-wise estimates were incorporated as random effects. We compared models using the Widely Applicable Information Criterion (WAIC) (Watanabe, 2013) (using BRMS, version 2.19, and LOO, version 2.5.1, within R). Only after establishing the most parsimonious linear model according to WAIC, we would carry out Bonferroni-Holmes corrected comparisons with our clinical scales, to assess a possible relationship between our clinical measures and the subjective estimates obtained. For all analyses, we considered measures obtained both during the exploratory phase (in which subjects must dance with all partners at least once) and the subsequent phase, in which choice of the next dancing partner is unconstrained.

2.4.4. Data pre-processing

The synchronization of movements occurred at regular intervals of every 3 s; as a result, action latencies were quantified as the (negative) time preceding the synchronized execution of the next move. To ensure that this measurement truly captured a decision-making process rather than, for example, a delayed decision to move in the previous turn that eventually manifested as a quick decision in the current turn, we opted to only include decisions made within 2500 ms. of the occurrence of the next move. Given the presence of heavy tails in click distances, we took a twofold approach. First, we retained only distance measurements below 600 pixels and then log-transformed them. Of note, participants utilised identical monitor configurations, enabling us to utilize pixel-wise measurements for our analyses without the need for additional adjustments.

3. Results

ECR-R and PAI-BOR scales were unavailable for four and two subjects respectively. In the two cases where PAI-BOR scales were missing, ECR-R scales were also unavailable. Data from the two subjects with entirely missing scales were excluded from all analyses, while data from the remaining two were used for the analyses involving PAI-BOR.

We identified three outliers when inspecting the histogram of subject-wise largest time spent with a single partner (S1: 81% of time spent with one partner, +3.7 sd from the mean; S2: 79%, +3.47 sd from the mean; S3: 78%, +3.45 sd from the mean). These subjects were excluded from all analyses, on two accounts - first, to mitigate potential adverse effects on the correlations in our results related to proportionate time spent with partners; second, these participants would only very briefly have interacted with other entities, making the ratings provided about these other partners less reliable and thereby also impacting our questionnaire-based analyses. One of these subjects had already been excluded due to missing questionnaire data, so only the data from the other two subjects constituted an additional exclusion. Ultimately, our analyses focused on a final sample of 80 subjects with available ECR-R scales and 82 subjects with PAI-BOR scales.

3.1. Clinical questionnaires

We found that both the PAI-BOR and ECR-R questionnaire sub-scales have very good internal consistencies (Cronbach's α; PAI-BOR-A: 0.92, PAI-BOR-N: 0.82, PAI-BOR-I: 0.83, PAI-BORS: 0.90; ECR-R-Anxiety: 0.93, ECR-R-Anxiety: 0.93). We then performed sCCA on the full dataset, as anticipated in methods, to link the primary latent dimensions of (1) the four PAIBOR subscales and (2) the two ECR-R sub-scales. The foreshadowed relationship between the two latent dimensions was found to be very strong (R = 0.84). This analysis highlights a link between attachment anxiety (ECR-R-Anxiety) and identity problems (PAI-BOR-I) in our sample, with lower contributions from the other PAI-BOR subscales, and a substantially lower contribution from attachment avoidance. Results from this analysis are illustrated in Table 1.

3.2. Dancing task questionnaire: partner-independent results

Bonferroni-Holmes corrected correlations of our scales against marginalised items substantiate our primary hypothesis, indicating that PAI-BOR and ECR-R scales serve as predictors for a general negative appraisal of interactions with all partners. Elevated scores on these scales corresponded to perceptions of interacting entities as less likable, less trustworthy, and perceiving one's own impact on the partner as less beneficial ("*Made Happy*" item; see Table 2). We then identified the underlying factors for marginalised items using FA. Our parallel analysis identified three meaningful components of our FA on marginalised DTQ items. These components cumulatively explained a variance of 53% (1^{st}component: 21%, 2^{nd}component: 18%, 3^{rd}component: 14%). The resulting factors were readily interpretable (see Table 2). In the first dimension, positive scores were associated with positively oriented items, i.e. "*Likeable*", "*Trustworthy*","*Made Happy*" whereas two negatively oriented items were associated with negative scores (e.g. "*Irritating*", "*Unstable*"). The second dimension saw positive contributions to just the negative items, with only item "*Made Sad*" having a low loading. The third dimension indicated the subjective tendency to report making partners sad (and unhappy) and feeling responsible for it. Simply put, the primary dimension encodes a *positive* overall impression; the second a *negative* overall impression; and the third, the degree of feeling responsible to have caused partners to be sad or unhappy (again see Table 2). The first dimension anti-correlated with summed PAI-BOR scores and all subscales (PAI-BOR: $r = -0.39$, $p < 0.001$, $CI_{95\%}$ $[-0.55, -0.17]$, subscales: all $r < -0.28$, all $p_{adj} < 0.05$), and both ECR-R subscales, though the strength of the association was note worthier for the anxiety subscale (see Fig. 3; anxiety: $r = -0.49$, $p_{adj} < 0.001$, $CI_{95\%}$ $[-0.68, -0.21]$; avoidance: $r = -0.33$, $p_{adj} = 0.02$, $CI_{95\%}$ $[-0.57, -0.04]$). Interestingly, ECR-R Anxiety ratings were the only ones to anti-correlate with the third dimension (post correction for multiple comparisons – see Fig. 3; $r = +0.39$, $p_{adj} = 0.002$, $CI_{95\%}$ [0.10,0.62])). There were no significant correlations involving the second factor.

3.3. Dancing task questionnaire: sCCA analysis

We now move on to the exploratory analysis of the full questionnaire and clinical scales, the goal of which was to identify key partner-specific items linked with borderline symptomatology and its sub-domains. To obtain a quantitative link between dancing questionnaire and PAI-BOR subscales, we adopted a predictive approach using sparse canonical correlations analysis (sCCA) (Witten et al., 2009; Witten and Tibshirani, 2009) in which, for simplicity, we only retained the first mode. We registered a good out-of sample performance for sCCA (median out-of-sample correlation coefficient = 0.32, min = 0.15, max = 0.41). When applied to the whole dataset, sCCA found a strong relationship between latent dimensions of the two sets of variables ($r = 0.59$, $p < 0.001$, $CI_{95\%} = [0.41, 0.71]$), leaving the weight of dancing items nearly intact ($\lambda = 0.91$), and somewhat penalising questionnaire scales ($\lambda = 0.7$). Consistent with our previous analysis, the relative weights of items for partner 3 (biased in the negative range of expression) were most prominent (average of weights: 0.21; see Fig. 4, inset D). Partner 1 followed with a lower contribution (0.14), and partners 2 and 4 were the least informative with even smaller average contributions (both 0.1). The importance of weights appears to follow closely the mood displayed by the partner over the course of the dance, in which the maximally negative mood observed weighs more than positive mood towards the ultimate judgement. Items "*Trustworthy*" and "*Made Happy*" for partner 3 had the largest sCCA weights across all questionnaire items (i.e. −0.35 for both items). The most important clinical scale, on the other hand, was the ECR-R-Anxiety sub-scale (scca weight: 0.73). In terms of PAI-BOR subscales, PAI-BOR-I (Identity problems) and PAI-BOR-S (Self-harm and Impulsivity) featured lower yet still sizeable contributions (0.50, and 0.46 respectively). We illustrate all sCCA results in Fig. 4. In the Supplementary Materials, we report the Bonferroni-Holmes corrected pair-wise correlations between all dancing questionnaire items and PAI and ECR-R sub-scales. Here, we just note that the only correlation to survive correction for multiple comparisons was the anticorrelation between PAI-BOR-S (Self-harm), and "*Made Happy*" ratings for partner 3 ($r = -0.39$, $p_{adj} = 0.05$, $p_u < 0.001$, $CI_{adj95\%} = [-0.68, -0.003]$). In Supplementary Materials, we further report an ulterior (unplanned) analysis which investigated whether there were partner-dependent items associated with our clinical questionnaires when considering healthy controls and patients separately.

Table 1
Relationship between attachment scores and PAI borderline scales. This table quantifies the relationship found through sCCA between PAI subscales (top four rows), and attachment style as measured by ECR-R along dimensions of anxiety and avoidance (bottom two rows). The relationship found was strong (R = 0.84), with only minor penalisations on both sides (PAI: $\lambda = 0.97$, ECR-R: $\lambda = 0.79$), and highlighted a prominent role of attachment anxiety in relation to borderline features - with substantial focus on identity problems (PAI-BOR-I).

PAI	sCCA weights
PAI-BOR-A (Affective Instability)	0.46
PAI-BOR-N (Negative relationships)	0.49
PAI-BOR-I (Identity problems)	0.66
PAI-BOR-S (Self-harm)	0.32
ECR-R	
Anxiety	0.98
Avoidance	0.17

Table 2
General analysis of items marginalised across partners. Columns specify the correlation coefficients between items marginalised across partners and PAI-BOR (col. 1), ECR-R-Anxiety (col. 2) and ECR-R-Avoidance (col. 3) questionnaire scores (**: $p < 0.001$; *: $p < 0.05$; p-values are Bonferroni-Holmes corrected for multiple comparisons). The three rightmost columns showcase the loadings along the three FA dimensions found. In the case of "*Trustworthy*" ratings, only data from subjects for whom these ratings were directly obtained (not imputed) were included, totaling 55 subjects for PAI-BOR, and 54 for ECR-R scales. Scores along the first dimension are significantly associated with PAI-BOR and ECR-R sub-scales. The ECR-R-Anxiety subscale holds the strongest association with single items and, in turn, with the primary FA dimension. It also correlates strongly with the third FA dimension, which embodies a sense of being responsible to have caused partners to be unhappy.

Item	PAI-BOR	ECR-R		FA loading		
		Anxiety	Avoidance	dim.1	dim.2	dim.3
Likeable	−0.39**	−0.48**	−0.39**	0.7	−0.07	−0.08
Trustworthy	−0.45**	−0.45**	−0.34*	0.87	−0.06	0.05
Made Happy	−0.28*	−0.36*	−0.23	0.39	0.06	−0.54
Made Sad	0.21	0.35*	0.15	0.05	0.07	0.83
Irritating	0.28*	0.36*	0.29	−0.36	0.47	0.17
Effort	−0.06	−0.09	0.02	0.42	0.45	−0.18
Unpredictable	−0.03	−0.03	0.12	0.07	0.79	0.04
Unstable	0.14	0.13	0.05	−0.22	0.71	0.04
Locus	−0.06	−0.02	0.02	0.41	0.01	0.44

3.4. Overt behaviour

3.4.1. Action latencies

To explore inter-personal factors affecting action latencies, we constructed three linear models as outlined in Methods. The best model for action latencies included population-wise and subject-wise intercepts

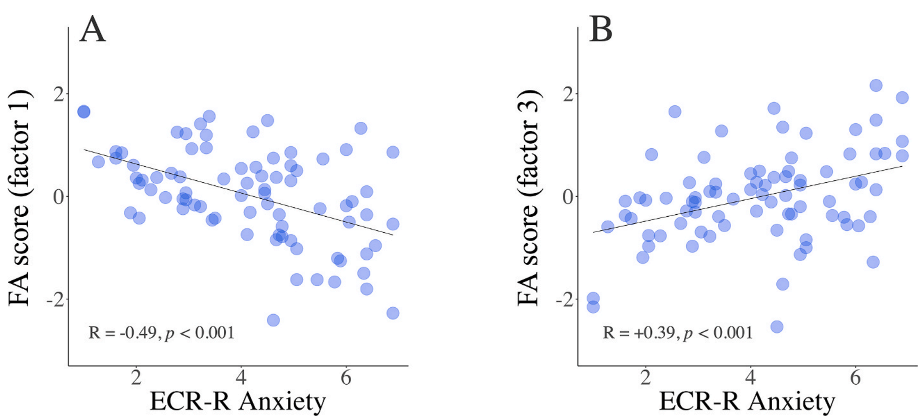

Fig. 3. FA results for attachment anxiety. The first FA factor was linked to both severity of borderline features as measured by PAI-BOR, but even more strongly to attachment Anxiety, which is the measure we report here (ECR-R-Anxiety scores; inset **A**). Our measure of attachment anxiety was also linked to the third factor, which points to a feeling of agency linked to making partners sad (inset **B**). Further analyses on the partner items underlying these effects revealed that partner 3 is the one to highlight these relationships to the highest extent.

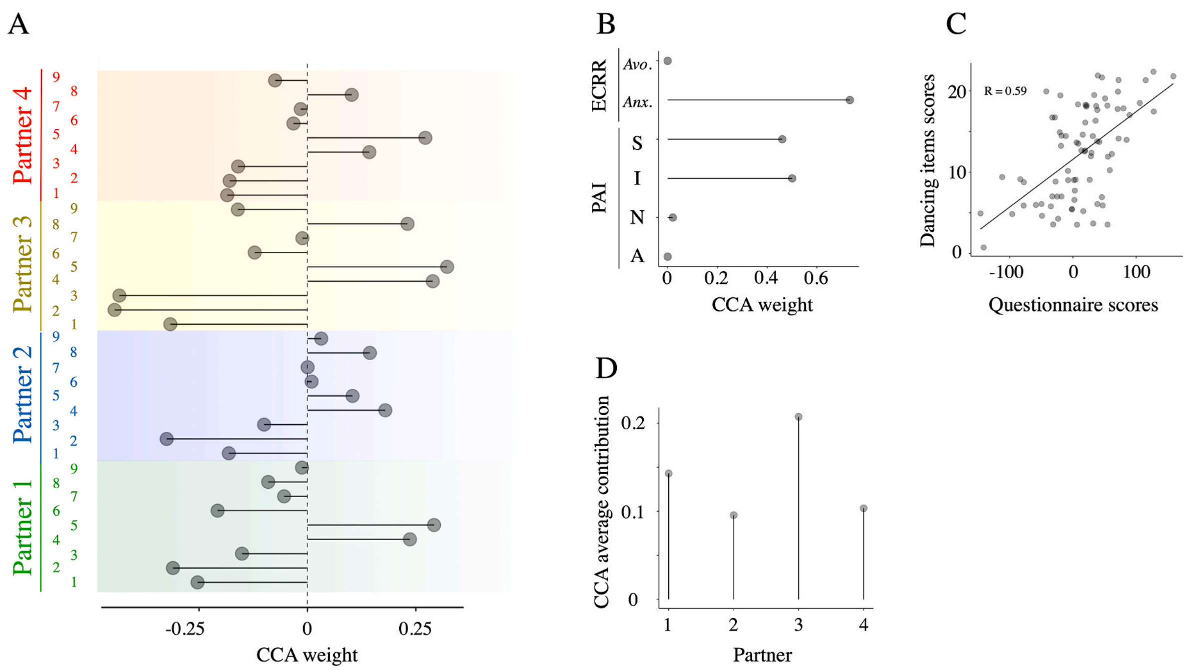

Fig. 4. Results of sCCA. This figure summarises the results of our sCCA analyses. Inset **A** specifies the weights associated to each of the dancing questionnaire items. These are enumerated as described in the Methods, i.e. 1 : "*Likeable*"; 2: "*Trustworthy*"; 3: "*Made Happy*"; 4: "*Made Sad*"; 5: "*Irritating*"; 6: "*Effort*"; 7: "*Unpredictable*"; 8: "*Unstable*"; 9: "*Locus*". Consistent with FA analyses over marginalised items (and pairwise correlations reported in Supplementary Materials) positive weights are weighed negatively, and negative ones positively. Inset **B** indicates the weights assigned to the questionnaire sub-scales which are the counterpart to the dancing questionnaire in our sCCA analysis. There is a salient contribution from attachment anxiety scores, followed by PAI-BOR-I (Identity problems) and PAI-BORS (Self-harm) with similar contributions. Attachment anxiety and PAI-BOR-I are strongly correlated in our sample (see Table 1). However the weight assigned to the former is larger. Inset **C** indicates the relationship between scores over the latent dimensions discovered. Finally, inset **D** includes a plot of the relative contribution of each individual partner in terms of sCCA weights (average of the absolute values of weights as depicted in A). The plot indicates a leading role of partner 3, followed by partner 1, which is in turn closely followed by partners 2 and 4 (the most uninformative).

(indicating the general propensity to move faster or slower), as well as the main effects of distance and partner mood before the move ($WAIC_{D+M} = 178{,}167, WAIC_D = 178{,}340, WAIC_M = 178{,}229$). Analysis of the population-wise effects revealed that latencies increased overall as the distance between subject and partner increased ($\beta = 37.96$, $CI_{95\%}$ [23.25,52.89]), and highlighted a substantial contribution from mood, whereby negative moods prompted quicker responses – perhaps reflecting the urge to quickly correct a mis-distancing which would have happened on the preceding move ($\beta = 91.97$, $CI_{95\%}$ [65.57,118.36]). Our analyses of the relationship of subject-level parameters and our clinical scales revealed a strong correlation between subject-level intercepts and anxiety scores ($r = 0.36$, $p_{adj} = 0.01$, $p_u < 0.001$, $CI_{adj95\%} = [0.14, 0.53]$) the only one to survive Bonferroni-Holmes correction for multiple comparisons (see Fig. 5).

3.4.2. *Click distance from partner*

In alignment with findings related to action latencies, the best model here also integrated both primary influences of distance and mood preceding the move ($WAIC_{D+M} = 11{,}874, WAIC_D = 12{,}008, WAIC_M = 13{,}058$). Analysis of population-level effects revealed that, in general, larger distances implied larger click distances ($\beta = 0.13$, $CI_{95\%}$ [0.11,0.15]). This can simply be attributed to subjects' efforts to

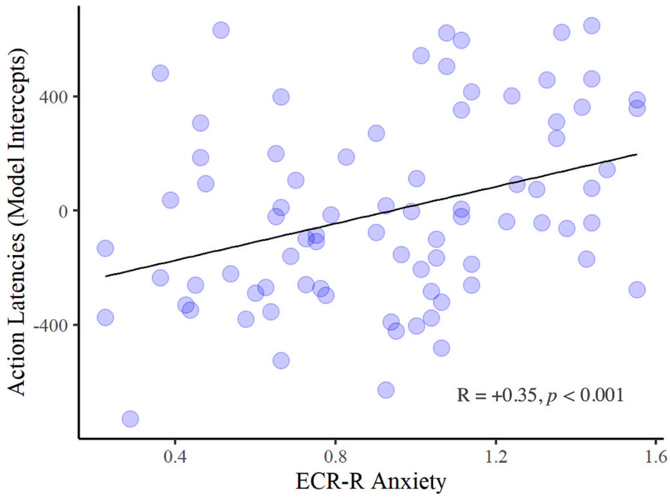

Fig. 5. ECR-R Anxiety and response latencies. The scatter plot showcases the positive relationship between action latencies (as exemplified by intercepts in the winning model, i.e. $D + M$) and ECR-R Anxiety scores.

gradually approach or distance themselves from the interactive agent, resulting in larger (smaller) click distances when initiating from a greater (closer) distance. Further, subjects exhibited greater distancing in the presence of more negative moods ($\beta = -0.06$, $CI_{95\%}$ [−0.08, −0.04]; recall, from Methods, that negative moods are expressed as negative numbers, and positive moods as positive numbers; thus, a negative beta coefficient in this context signifies an augmentation in distancing behaviour). Our exploration of the relationship of subject-level parameters and our clinical scales only indicated a trending correlation between subject-level intercepts and PAI-BOR scores ($r = 0.19$, $p_{adj} = 0.38, p_u = 0.08$, $CI_{adj95\%} = [-0.03, 0.39]$) which does not survive Bonferroni-Holmes correction for multiple comparisons.

3.4.3. Proportionate time spent with partners

A longer time spent with a given partner is indicative of a higher appreciation for such partner (see Table 2 in Supplementary Materials). We calculated pairwise correlations between PAI-BOR scores and time spent with each partner - and found notable anti-correlations between PAI-BOR scores and time spent with partner 3 ($r = -0.21$, $p_u = 0.05$, $p_{adj} = 0.12$, $CI_{95\%} = [-0.45, 0.05]$) and a similar trend for partner 4 ($r = 0.19$, $p_u = 0.08$, $p_{adj} = 0.12$, $CI_{95\%} = [-0.07, 0.43]$). However, our study is under-powered for these sort of effect sizes - and these relationships do not survive correction for multiple comparisons.

4. Discussion

We have introduced a novel paradigm which takes us toward a second-person neuroscience (Schilbach et al., 2013). With this paradigm, we described the experience retained from a brief series of social interactions with previously unknown virtual partners. These differed in their ability to convey high and low, positive and negative moods, giving rise to four distinct virtual personalities. Our analyses were based on post-task questionnaires and behaviour throughout the task. The questionnaire-based analyses determined the general and partner-specific items which were most strongly tied with the dimensional measures of BPD symptom severity and attachment style.

In terms of the intrinsic relationships within our clinical scales of choice, sCCA analyses foregrounded, in our sample, a prevalent association between attachment anxiety and the identity problems subdomain of borderline pathology. This confirms previous findings (Crawford et al., 2007) and aligns with the mentalizing perspective on personality disorder — in which identity problems (caused by an interplay between dispositional factors, ill-functioning child-primary caregiver relationships and/or trauma) can lead to patterns of anxious attachment and emotional dysregulation.

Our factor-analysis-based analyses of the DTQ revealed that scores along a primary factor of appraisal (denoting a positive overall impression) of social interaction were negatively associated with all measures of attachment anxiety (ECR-R-Anxiety), avoidance (ECR-RAvoidance) and borderline symptoms (PAI-BOR and subscales). As a key novel finding, attachment anxiety was further linked to a *third* factor which embodied perceived responsibility to have caused partners to be unhappy. Our dimensionality reduction-based results align with a large body of work indicating that BPD patients hold negatively biased evaluations of others (Fertuck et al., 2013, 2019; Arntz and Veen, 2001; Barnow et al., 2009; Meyer et al., 2004; Nicol et al., 2013). The stronger relationship found for attachment anxiety and scores along the first factor (see Fig. 3) is somewhat surprising, since attachment anxiety is traditionally associated with valence-independent increased vigilance, rather than biased appraisal of others' behaviour. For instance, in a widely known paradigm bearing some analogy to ours in terms of the appraisal of morphing facial ex-pressions (a modified version of the "morph movie" task) (Niedenthal et al., 2000, 2001), Fraley and colleagues found that anxiously attached individuals were more sensitive to (i.e., were quicker to detect) variations in *all* emotional facial expressions. They however reported smaller effect sizes for happy facial expressions, especially in terms of the transitions from neutral to happy emotional states (Chris Fraley et al., 2006). Our results are in line with previous literature indicating that anxiously attached individuals perceive more conflict in relationships and are hyper-vigilant about *negative* outcomes such as waning affection, or signs of potential withdrawal from their partners (Collins, 1996; Campbell et al., 2005) - and even experience more 'phantom vibrations' on their mobile phones when they "are concerned about something that [they] might get a call/message about" (Kruger and Djerf, 2016). In terms of mentalizing, the hyper-vigilance of anxiously attached individuals can be understood as an attempt to compensate for a reduced ability to mentalize with a propensity to engage in phenomenologically distinct, yet ineffective, hyper-mentalizing. The reduced ability to mentalize could also underlie the novel relationship of attachment anxiety with scores along factor 3 (feeling responsible for making the partner sad/unhappy, or failing to make them happy), as anxiously attached individuals may fail to moderate their appraisal of the other's emotional state, not taking into account that this might arise from other (inherent and independent) causes rather than one's own actions.

Our more granular sCCA analyses revealed that items concerning Partner 3 were those which most strongly associated with PAI-BOR and ECR-R sub-scales overall. Notably, this was the partner who manifested the most negative range of affect. Partners 2 and 4 contributed substantially less to these associations while Partner 1 provided an intermediate contribution (Fig. 4). Echoing the results from our Model-based sCCA approach, the most prominent and only significant partner specific correlation, involved item "*Made Happy*" involving Partner 3. This association ties with previous work suggesting that some forms of mental ill-health might be best characterized by a relatively impoverished — or possibly 'unbiased' — way of updating affective beliefs and experiences of lack of agency (Gordon Willard Allport, 1955; Taylor and Brown, 1988; Sharot, 2011).

The positive relationship between BPD severity and larger distancing is only a trend, but aligns with previous studies which found that BPD patients have a larger preferred interpersonal distance (Fineberg et al., 2018b; Abdevali et al., 2021) and altered face processing in response to simulated intrusion of subjects' own personal space (Schienle et al., 2015).

A number of limitations concerning the present study must be pointed out. First, our DTQ was a purpose-built questionnaire which will need further validation. Our factor analysis approach requires subsequent confirmatory factor analyses (CFA) to validate the identified factor structure. Second, our sCCA analyses involved imputed

“Trustworthy” items, and although we employed a robust imputation method, the highlighted results (especially the weights concerning “*Trustworthy*” ratings) should be substantiated in future iterations using actual ratings. Third, while the potential diagnostic significance of the “*Made Happy*” item (specifically with respect to partner 3) is intriguing, confidence in its special merit awaits further task iterations. It is conceivable that this item’s relevance is specific to our sample, perhaps due to the notably high dependency observed between PAI-BOR and attachment anxiety scores. The robustness of this result across diverse samples remains to be established. Furthermore, our exploratory analyses of overt behaviour were approached conservatively, by first building a simplified, linear model for these quantities, and only establishing relationships with clinical questionnaires with the quantities thus found a posteriori. Future task developments (one such development is currently being analysed) will make it possible to give more comprehensive explanations of microscopic (motor) decision-making, through the use of normative computational models - the use of which could bring us closer to more mechanistic insights. Finally, the task may be too short, which entails that we can not reliably measure some aspects of behaviour. For instance, our results on proportion of time spent with Partners 3 and 4 indicate only a trend. Failure to observe a more robust effect may be due to the fact that subjects had only 14 min to play, and were made to play with all partners at least once. Future iterations of our study using longer versions of this task might offer more variability in the proportion of time spent with partners, allowing a stronger relationship to surface. Finally, a more ecological manipulation would be to add a socially goal-directed component to the task - such that the interactions offered are not purposeless, but are needed to establish trust - for instance to reach an ultimate decision about whose advice to trust. One option would be to provide affective value to the act of touching - such that when the subject and partner’s avatars touch, subjects become vulnerable to them. As an example, the partner avatar might then give or take away money from the participant.

Taken together, our results support the notion that even very simple, second-person tasks can measure known and unknown aspects of healthy and ill-functioning social appraisal. Our task operationalised partner personality in a straightforward way – by manipulating the range of the interacting partner’s facial expression – and speak for an asymmetric weighing of negatively valued expressions, because of the high relevance of Partner 3 that emerges from the sCCA analysis. We know of no previous paradigms which have studied the impact of co-occurring positive and negatively valued stimuli when appraising a novel acquaintance, especially in a clinical population known to be vulnerable to compromised attribution of intentions. We have provided robust evidence that higher ratings in terms of attachment disturbances and borderline symptoms tie with a negatively biased appraisal of novel social interactions, and added to this result by observing a somewhat novel, powerful explanatory role for attachment anxiety. Future work should of course replicate our initial findings - and further refine and expand this paradigm.

CRediT authorship contribution statement

Federico Mancinelli: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tobias Nolte:** Writing – review & editing, Validation, Methodology, Data curation, Conceptualization. **Julia Griem:** Writing – review & editing, Validation, Methodology, Data curation, Conceptualization. **Terry Lohrenz:** Writing – review & editing, Project administration, Funding acquisition. **Janet Feigenbaum:** Writing – review & editing, Project administration, Funding acquisition. **Brooks King-Casas:** Writing – review & editing, Project administration, Funding acquisition. **P. Read Montague:** Writing – review & editing, Project administration, Funding acquisition. **Peter Fonagy:** Writing – review & editing, Project administration, Funding acquisition. **Christoph Mathys:** Writing – review & editing, Project administration.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpsychires.2024.03.046.

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