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RESEARCH ARTICLE

Body shape rather than facial emotion of others alters interpersonal distance in patients with anorexia nervosa

Alice Cartaud¹  | Philibert Duriez^{2,3}  | Johanna Querenghi¹  |
Jean-Louis Nandrino¹  | Philip Gorwood^{2,3}  | Odile Viltart^{1,2}  | Yann Coello¹ 

¹University of Lille, CNRS, UMR 9193 - SCALab - Sciences Cognitives et Sciences Affectives, Villeneuve d'Ascq, France

²Université Paris Cité, Institute of Psychiatry and Neuroscience of Paris (IPNP), INSERM U1266, Paris, France

³GHU Paris Psychiatrie et Neurosciences, Hôpital Sainte-Anne, CMME, Paris, France

Correspondence

Yann Coello, University of Lille, UMR SCALab 9193, 59653, Villeneuve d'Ascq, France.

Email: yann.coello@univ-lille.fr

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Abstract

Objective: The study investigated interpersonal distance in patients with anorexia nervosa (AN), focussing on the role of other's facial expression and morphology, also assessing physiological and subjective responses.

Method: Twenty-nine patients with AN and 30 controls (CTL) were exposed to virtual characters either with an angry, neutral, or happy facial expression or with an overweight, normal-weight, or underweight morphology presented either in the near or far space while we recorded electrodermal activity. Participants had to judge their preferred interpersonal distance with the characters and rated them in terms of valence and arousal.

Results: Unlike CTL, patients with AN exhibited heightened electrodermal activity for morphological stimuli only, when presented in the near space. They also preferred larger and smaller interpersonal distances with overweight and underweight characters respectively, although rating both negatively. Finally, and similar to CTL, they preferred larger interpersonal distance with angry than neutral or happy characters.

Discussion: Although patients with AN exhibited behavioural response to emotional stimuli similar to CTL, they lacked corresponding physiological response, indicating emotional blunting towards emotional social stimuli. Moreover, they showed distinct behavioural and physiological adjustments in response to body shape, confirming the specific emotional significance attached to body shape.

KEYWORDS

anorexia nervosa, body shape, electrodermal activity, emotional facial expression, interpersonal distance

Highlights

- Patients with anorexia nervosa (AN) show a regulation of interpersonal distances to social emotional stimuli similar to healthy controls (CTL) but lack the corresponding physiological response.

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- Patients with AN, not CTL, prefer shorter interpersonal distance with underweight social stimuli and larger interpersonal distance with overweight ones and show increased physiological response to both of them.
- Patients with AN show a bias towards morphological rather than emotional cues when processing information to optimise social interaction.

1 | INTRODUCTION

Anorexia nervosa is a chronic eating disorder characterised specifically by voluntary food restriction, intense fear to gain weight, vigorous physical activity (Achamrah et al., 2016; Rizk et al., 2020), and endocrine and metabolic alterations (Duriez et al., 2019; Schorr & Miller, 2016; Viltart et al., 2018). This complex psychiatric disorder, predominantly affecting young women, is attributed to a combination of risk factors encompassing genetic, biological, psychological and social elements (Gorwood et al., 2016; Guy-Rubin & Gorwood, 2016; Treasure et al., 2015). These factors collectively contribute to heightened social anxiety and impairments in social cognition (Bulik et al., 2022; Treasure et al., 2020; van Elburg et al., 2021; Watson et al., 2019), such as difficulties in recognising emotions, particularly emotional facial expressions (Blomberg et al., 2021; Caglar-Nazali et al., 2014; Dapelo et al., 2016; Duriez et al., 2022). Furthermore, AN is also associated with body image disturbance, where individuals with AN often perceive their bodies as larger than they are (Clarke et al., 2016; Cserjési et al., 2010; Guardia et al., 2010). This distorted body image, coupled with cognitive-affective disturbances, contributes to affective and cognitive impairments, potentially leading to inappropriate social behaviours and ongoing social dysfunction (Treasure et al., 2015).

Among the social behaviours entailed in interpersonal dynamics, a pivotal aspect is the regulation of interpersonal distances (IPD, Hall, 1966). This distance refers to the appropriate space maintained between oneself and others during formal social interactions (Coello & Cartaud, 2021; Iachini et al., 2014). According to the homeostatic theory of social interactions (Coello & Cartaud, 2021), IPD would be based on the representation of the peripersonal space (PPS), which corresponds to the multisensory interface between the body and the environment that is dedicated to motor actions directed towards stimuli within reach (Previc, 1998; Rizzolatti et al., 1997). IPD also incorporates an additional “safety margin” to protect the integrity of the body during social interactions. However, an IPD that is too large may not be suitable for social interaction. Conversely, a too short IPD may generate a feeling of discomfort (Hayduk, 1978;

Kennedy et al., 2009; Lloyd, 2009; Sommer, 1959), associated with a pronounced physiological response leading, in most cases, to defensive behaviour (Cartaud et al., 2018, 2020; Kennedy et al., 2009; Vieira et al., 2020; Watson et al., 2019). In line with this view, Cartaud et al. (2018, 2020) demonstrated that the physiological response (or threat level) triggered by a social stimulus in the PPS is predictive of the selected IPD with the same social stimulus. Hence, the physiological responses to social stimuli in reference to PPS (or their anticipation) would represent the signal used to specify appropriate IPD (Coello & Cartaud, 2021). Thus, because IPD is sensitive to the affective dimension of social interaction, it is flexible and dependent broadly on the level of anxiety of individuals (Iachini et al., 2015).

As evidence, Nandrino et al. (2017) showed that although PPS did not differ when comparing patients with AN and control population, the patients showed an atypical increase of IPD in usual social interactions. This preference for larger IPD is believed to be linked to the heightened anxiety they experience in social situations. In addition, their inclination towards larger IPD seems particularly sensitive to deviation of others' weight from the ideal weight for individuals with AN (Welsch et al., 2020). Interestingly, individuals with AN reported also higher perceived arousal upon encountering social stimuli (De Sampaio et al., 2015), although not associated with higher physiological arousal (Couton et al., 2022; Nandrino et al., 2011). Thus, a distorted evaluation of physiological responses (or interoceptive awareness) could be associated with a specific increase in IPD within this population (Ambroseccchia et al., 2017). However, despite the expanding literature on this topic in healthy controls (Cartaud et al., 2018; Lebert et al., 2024; Ruggiero et al., 2017), no study has specifically examined the impact of emotional facial expressions on physiological responses or the regulation of IPD among patients with AN. Assuming that anxiety-dependent social deficits in AN involve body image as well as emotional disturbance, the present study examined preferred IPD and physiological responses in patients with AN when interacting with virtual characters having different body shapes and facial expressions, taking into account body mass index (BMI) and individual psychological characteristics. The main objective was to gain insights into how the interplay

between body image disturbance, emotional disturbance, and social anxiety might manifest in the preferred interpersonal distance of individuals with AN. In relation to literature, we predicted that patients with AN would prefer larger IPD, especially in the presence of negatively perceived social stimuli (e.g., negative emotion or overweighted, Welsch et al., 2020), without specific variation of the physiological response to social stimuli in comparison to healthy controls (Couton et al., 2022; Nandrino et al., 2011). More precisely, larger IPD in AN should be particularly influenced by the subjective feeling triggered by the social stimuli (e.g., emotional valence and arousal), rather than the underlying physiological responses.

2 | METHODS

2.1 | Participants

The minimum sample size by group was determined a priori to 28 participants for Bayesian inference with a medium effect size ($d = 0.6$) and mildly informative priors ($\mu = 0$, $\sigma = 1$). The sample included 29 adult females with AN and 30 female control participants (CTL), who agreed to participate in the study and had no current or past eating disorder. Patients were recruited at the Clinique des Maladies Mentales et de l'Encéphale (CMME), an expert care center for eating disorders (Hôpital Sainte-Anne, GHU Paris, France), after entering specific treatment programs. CTL were matched to patients with AN according to sex, age, and education level. Exclusion criteria for all participants were: age <18 , experience of neurological disease, or hearing or visual impairments. All participants gave their written informed consent to participate in the study, after a detailed explanation of its aim and procedure.

All patients were diagnosed with AN by clinicians as outlined in the fifth edition of the DSM-V (American Psychiatric Association, 2013) based on the Mini-International Neuropsychiatric Interview (MINI, Lecrubier et al., 1997). Fourteen (48.3%) of them had the diagnostic criteria of the restricting type, eight (27.6%) had the binge eating/purging type, the other seven (24.1%) had atypical AN. No patient with AN had a diagnosis of schizophrenia or psychosis, or current major depressive episode or bipolar disorder.

2.2 | Stimuli

Social stimuli consisted of male and female virtual characters taken from the ATHOS database (Cartaud &

Coello, 2020), presented with an idle stance, in an empty room created using Unity (version 2019.4.20f1, Figure 1). Three characters of each gender had normal-weight (BMI: 19–25 kg/m²) and either an angry, happy, or neutral facial expression (six emotional stimuli). Another set of three characters of each gender had a neutral facial expression and was either normal-weight, underweight (BMI: 12–16 kg/m²), or overweight (BMI: 26–30 kg/m²), leading thus to six morphological stimuli. For each participant, the attribution of a specific character to a specific category (emotion or morphology) was random within each gender.

2.3 | Psychological assessment

Healthy controls and patients with AN were evaluated using a set of questionnaires. Eating disorder symptoms were assessed using the Eating Disorder Inventory-2 (EDI-2, Garner, 1991). The EDI-2 consists of 91 items rated on a 6-point scale measuring 11 psychopathological dimensions (Table 1). Anxiety trait and state were measured with the STAI-YB (Spielberger et al., 1983). The level of anxiety across each dimension was evaluated through a set of 20 items. Depression was assessed with the short version of the Beck Depression Inventory-13 (BDI, Beck & Beck, 1972) consisting of 13 items rated on a 4-point Likert scale. Empathy was assessed using the Interpersonal Reactivity Index (IRI, French version, Gilet et al., 2013), consisting of 28 items rated on a 7-point Likert scale (Table 1).

2.3.1 | Procedure

At the beginning of the experiment, the participants gave their informed consent to take part in the experiment and were seated in front of a 24" computer screen. They were then equipped with Ag-AgCl electrodes from a Biopac MP36 on the non-dominant hand (electrodermal activity recording). In all tasks, participants had to represent themselves being inside a virtual room, at the forefront of the scene (*i.e.*, the position of the camera). The social stimuli were social characters which could have either different emotional facial expressions (*emotional* stimuli) or different morphological body sizes (*morphological* stimuli). The participants had to perform two successive tasks in two different experimental sessions: a reachability judgement task and an interpersonal distance judgement task, conducted separately with emotional stimuli and morphological stimuli.

In the reachability judgement task, participants were instructed to observe the virtual character presented at



FIGURE 1 Examples of the characters used in the experiment (shown at 115 cm from participants). The male is presented with a normal-weight and an angry (top left) and happy (top right) emotional facial expression and the female, with a neutral facial expression and an underweight (bottom left) or an overweight morphology.

TABLE 1 Clinical characteristics of the population with and without anorexia nervosa (AN) (mean and standard deviation, contrast, confident interval and averaged R-Squared of the fits).

| Evaluation | AN | CTL | Contrast | 95% CI | R-Squared |
|--------------------------------|----------------|----------------|----------|---------------|-----------|
| Age | 27.15 (9.59) | 24.79 (6.27) | -0.09 | [-1.57, 1.41] | 0.01 |
| BMI | 18.61 (3.6) | 22.35 (3.45) | -2.6 | [-3.8, -1.22] | 0.13 |
| BDI | 12 (6.72) | 6.35 (5.3) | 5.41 | [2.13, 8.6] | 0.17 |
| STAI state | 47.17 (12.34) | 34.32 (11.62) | 12.58 | [6.35, 18.59] | 0.23 |
| STAI trait | 55.62 (10.55) | 49.52 (11.07) | 5.37 | [0.09, 10.85] | 0.07 |
| IRI | 141.72 (17.48) | 141.52 (16.77) | -0.79 | [-9.79, 8.3] | 0.02 |
| EDI-2 | 87.38 (47.06) | 46.74 (37.96) | 36 | [14.9, 56.34] | 0.16 |
| <i>Drive for thinness</i> | 11.52 (6.85) | 2.81 (4.67) | 7.34 | [4.49, 9.98] | 0.30 |
| Bulimia | 4.14 (5.79) | 2.13 (3.7) | 0.47 | [-1.44, 2.38] | 0.01 |
| <i>Body dissatisfaction</i> | 15.31 (9.07) | 6.39 (7.06) | 7.4 | [3.47, 11.09] | 0.19 |
| <i>Ineffectiveness</i> | 10.72 (7.97) | 4.58 (5.74) | 5.88 | [2.74, 8.96] | 0.16 |
| Perfectionism | 9.45 (5.1) | 6.81 (4.62) | 1.96 | [-0.56, 4.33] | 0.05 |
| Interpersonal distrust | 4.93 (3.83) | 3.68 (3.76) | 1.43 | [-0.39, 3.3] | 0.05 |
| <i>Interoceptive awareness</i> | 8.38 (6.2) | 4.58 (6.03) | 3.88 | [0.97, 6.87] | 0.10 |
| Maturity fears | 5.07 (5.06) | 4.23 (4.46) | 0.45 | [-1.81, 2.7] | 0.01 |
| <i>Asceticism</i> | 6.97 (4.26) | 3.58 (2.73) | 3.08 | [1.35, 4.9] | 0.16 |
| Impulse regulation | 4.48 (4.14) | 3.77 (5.33) | 0.89 | [-1.24, 3.1] | 0.02 |
| <i>Social insecurity</i> | 6.62 (4.14) | 4 (4.43) | 3.07 | [0.98, 5.24] | 0.12 |

Note: The contrasts between the two groups are credible if the 95% CI excludes 0 (in italics).

Abbreviations: AN, group of patients with anorexia nervosa; BDI, Beck Depression Inventory; CI, Credibility interval; CTL, Control group; EDI2, Eating Disorder Inventory; IRI, Interpersonal Reactivity Index; STAI, State-Trait Anxiety Inventory.

different distances and to judge whether he/she was reachable with the dominant arm or not, without moving the arms or the body. Participants were randomly presented with one of the six characters (depending on the session) either in the participants' PPS (35 cm), extrapersonal space (EPS, 205 cm), or at the boundary of the PPS (115 cm, evaluated in a pilot study). The character remained on the screen for 6.0–6.5 s then was replaced by a question mark prompting the participants to respond (reachable: right arrow of the computer keypad; unreachable: left arrow of the computer keypad, counterbalanced across the participants). Then, an empty room was presented for 4–5.5 s before another trial started. Participants performed a total of 18 trials per session (3 spaces \times 6 characters). In this task, the electrodermal activity was recorded.

In the interpersonal distance judgement task (IPD), the virtual character was presented either in PPS (30 cm) or in the EPS (250 cm) and the task for the participants was to adjust the distance until they felt comfortable to interact with, using the left and right arrow of the computer keypad to increase or decrease the IPD (key assignment was counterbalanced across the participants). Using a staircase adaptive method (Cornsweet, 1962), the step between the different distances was initially set at 40 cm and remained constant until the participants changed their response. When this change occurred, the step between the different distances was divided by two and the same procedure (distance adjustment) was used until the step reached 5 cm, which corresponded to 4 successive changes in the response. The preferred IPD corresponded to the distance at which the fifth response change occurred. The order of presentation of the 12 trials per session (2 initial distances \times 6 characters) was random.

At the end of each experimental session, participants evaluated each character, presented randomly, in terms of valence (0: very negative, 10: very positive) and arousal (0: not arousing, 10: very arousing) using a slider. No numerical feedback was provided.

2.4 | Data analysis

In the reachability judgement task, the electrodermal activity was analysed using Matlab (version 2013b, MathWorks) and the Ledalab toolbox (Benedek & Kaernbach, 2010), depending on the space and character in each experimental session. The signal was first down sampled at 20 Hz, then smoothed using a 50-sample gaussian window filter. We extracted the average phasic driver (curve integral) within a 0.5–5 s response window after the stimulus onset through a deconvolution of the electrodermal signal. This index can be seen as a proxy of

the sudomotor nerve activity. In addition, we measured the proportion of “reachable” responses. In the IPD judgement task, we measured the preferred distance which corresponded to the final distance selected. We also analysed the valence and arousal ratings provided by the participants, as well as the scores at the clinical assessments collected through the questionnaires.

With respect to the questionnaires, we performed a correlation analysis between the dimensions of the EDI-2, BDI, IRI and State-Trait Anxiety Inventory for “trait” and “state” scores. Since questionnaire scores were correlated (Supporting Information Table 1), we performed a principal component analysis to integrate the components to the statistical analyses. This analysis revealed that three components meet Kaiser criterion (*i.e.*, eigenvalues greater than 1), explaining 74.8% of the total variance. The first component (PC1, 55.01%), mainly relied on “Psychological stability”. The clinical tests involved in PC1 were negatively related to this component (*i.e.*, the higher the deficits, the lower the PC1 scores). The second component (PC2, 11.81%) was more related to a “Negative body image”, through a positive relationship with the tests, and the third component (PC3, 8.01%) to “Interpersonal skills”, for which a high score suggested good skills (see Table 2).

Statistical analysis was performed using R software (version 4.1.3, R Core Team, 2018) and RStudio (version 2022.12.0, RStudio Team, 2020). Five Bayesian mixed-effects models were fitted using the brms package (Bürkner, 2017; Gelman & Hill, 2006), one per dependent variable of interest (*i.e.*, preferred IPD, electrodermal response, proportion of “reachable” response, valence, and arousal ratings). In addition, we tested for a Group effect on the clinical assessments. We applied mildly informative prior information ($M = 0$, $SD = 1$) to each regression. The posterior distribution (*i.e.*, the combination of the priors and the data) was approximated using 8000 Markov chain Monte Carlo iterations (with 4000 warm-up samples), divided into 4 chains. Convergence of the chains was validated by computing the Rhat statistic and visual inspection.

In our analysis, we performed the comparison between two conditions by evaluating the contrast between their respective posterior distributions, which are derived from posterior draws generated during the fitting process. Bayesian mixed models with appropriate priors deal with issues related to multiple comparisons (Gelman & Hill, 2006). A contrast is judged as credible (equivalent to “significant” in frequentist inference) when its posterior 95% credibility interval (*i.e.*, plausible ranges of parameter values based on the observed data and the prior information, 95% CI) does not include 0. Conversely, if the 95% CI of that contrast includes the 0 value, the null

TABLE 2 Principal component analysis of the clinical evaluation for each participant.

| | PC1 (55.01%) | PC2 (11.81%) | PC3 (8.01%) |
|-------------------------|-----------------|-----------------|----------------|
| BDI | −0.3 | . | . |
| STAI state | −0.25 | . | . |
| STAI trait | −0.31 | . | . |
| IRI | . | . | 0.77 |
| EDI-2: | . | . | . |
| Drive for thinness | . | 0.44 | . |
| Bulimia | . | 0.47 | . |
| Body dissatisfaction | . | 0.44 | . |
| Ineffectiveness | −0.32 | . | . |
| Perfectionism | −0.29 | . | . |
| Interpersonal distrust | . | . | −0.49 |
| Interoceptive awareness | −0.31 | . | . |
| Maturity fears | −0.25 | . | . |
| Asceticism | −0.26 | . | . |
| Impulse regulation | −0.27 | . | . |
| Social insecurity | −0.29 | . | . |

Abbreviations: BDI, Beck Depression Inventory; EDI2, Eating Disorder Inventory; IRI, Interpersonal Reactivity Index; PC1, psychological stability; PC2, negative body image; PC3, interpersonal skills; STAI, State-Trait Anxiety Inventory.

hypothesis cannot be rejected. We report in the results section the contrast between two conditions and the associated [95% CI]. Each regression followed the same model, except for the electrodermal response and the proportion of “reachable” response models, which also included the space (PPS, PPS boundary, EPS, in italic in the model) as a categorical independent variable, and its interaction with the stimulus category and the group. More precisely, we tested the effect of the group (AN, CTL), the stimulus category (angry, happy, neutral, or underweight, normal-weight, overweight), the participants’ BMI and the three different components resulting from the clinical assessment (PC1, PC2, PC3). In addition, we controlled for the effect of the gender of the character (male, female). We added the subject level as a random effect to consider the interindividual variability. The regression model used for statistical analysis was:

$$\text{Dependent Variable} \sim \text{Group} * (\text{Stimulus category} * \text{Space} + \text{BMI} + \text{PC1} + \text{PC2} + \text{PC3} + \text{Gender}) + (1 | \text{Subject})$$

3 | RESULTS

3.1 | Clinical assessments

The clinical evaluations and the associated statistics of both the AN and the CTL groups are presented in Table 1. As expected, the AN group had a lower BMI than the CTL group, and patients with AN were more depressed and more anxious than CTL participants. EDI-2 scores also showed higher scores for the AN group for the drive for thinness, body dissatisfaction, ineffectiveness, interoceptive awareness, asceticism, and social insecurity dimensions.

3.2 | Subjective rating of the stimuli

3.2.1 | Valence rating

The analysis of the valence ratings (averaged R-Squared of the fit: $R^2 = 0.55$ [0.51, 0.58]) revealed no evidence for an overall difference between the two groups (AN – CTL: -0.27 [−0.74, +0.19], Supporting Information Figure 1) and no effect of BMI (-0.02 [−0.07, +0.03]). However, we found an effect of the components “psychological stability” (PC1: -0.09 [−0.16, −0.03] and “negative body image” (PC2: -0.28 [−0.33, −0.03]). Participants scoring high on dimensions associated with “psychological stability” and “negative body image” rated the stimuli less positively.

As expected, both the AN group and the CTL group rated the happy characters as more positive than the angry (+4.70 [+4.20, +5.18] and +5.12 [+4.60, +5.60] respectively) and the neutral ones (+1.41 [+0.88, +1.92] and +1.18 [+0.64, +1.69] respectively). Both groups also rated the angry characters less positively than the neutral ones (AN group: -3.28 [−3.73, −2.77]; CTL group: -3.95 [−4.47, −3.47]). However, no difference emerged between the two groups concerning the character’s emotional facial expression (AN – CTL for angry characters: +0.41 [−0.27, +0.93]; happy characters: -0.03 [−0.68, +0.64]; neutral characters: -0.27 [−0.95, +0.37]).

Regarding stimuli with varying morphology, no difference emerged between the two groups when focussing on normal-weight (-0.48 [−1.17, +0.15]) or underweight characters (-0.15 [−0.81, +0.47]). However, the AN group rated the overweight characters less positively than the CTL group (-1.10 [−1.76, −0.45]). More precisely, the AN group rated the normal-weight characters more positively than the overweight (+1.07 [+0.56, +1.61]) and underweight ones (+1.43 [+0.89, +1.95]), whereas the CTL group rated the underweight characters less

positively than the normal-weight (-1.76 [$-2.22, -1.20$]) and overweight ones (-1.32 [$-1.83, -0.82$]). No other difference emerged.

3.2.2 | Arousal rating

The analysis of arousal ratings (averaged R-Squared of the fit: $R^2 = 0.26$ [$0.21, 0.31$]) revealed no evidence for an overall difference between the two groups (AN - CTL: -0.62 [$-1.37, +0.13$], Supporting Information Figure 1) and no effect of BMI (-0.05 [$-0.14, +0.04$]). However, we found an effect of the component “interpersonal skills” (PC3: -0.41 [$-0.67, -0.15$]). The lower the score on PC3, the more arousing participants rated the stimuli.

The AN group rated the angry characters (-0.98 [$-1.92, -0.16$]) and the happy characters (-1.00 [$-1.95, -0.02$]) as less arousing than the CTL group. Moreover, both the AN group and the CTL group rated the happy characters ($+1.29$ [$+0.62, +2.02$] and $+1.33$ [$+0.65, +2.05$] respectively) and the angry characters ($+1.13$ [$+0.49, +1.70$] and $+1.15$ [$+0.46, +1.79$] respectively) as more arousing than the neutral ones.

When focussing on the character's morphology, no difference emerged between the two groups (AN - CTL for normal-weight: -0.92 [$-1.91, +0.04$]; overweight: $+0.03$ [$-1.04, +0.93$]; underweight: $+0.15$ [$-0.85, +1.14$]). However, although the AN group rated both the overweight characters ($+0.95$ [$+0.29, +1.66$]) and underweight characters ($+1.13$ [$+0.43, +1.81$]) as more arousing than the normal-weight ones, no difference emerged for the CTL group.

3.3 | Behavioural performances

3.3.1 | Interpersonal distance judgement

With respect to IPD (averaged R-Squared of the fit: $R^2 = 0.62$ [$0.60, 0.64$]), we found no evidence for an overall difference between the two groups (AN - CTL: -0.02 m [$-0.24, +0.27$], Supporting Information Figure 2) or for an effect of the components (PC1: $+0.03$ m [$-0.01, 0.07$], PC2: $+0.001$ m [$-0.09, +0.08$], PC3: $+0.08$ m [$-0.17, +0.01$]), or BMI [-0.01 [$-0.03, +0.03$]).

Both groups maintained larger IPD with the angry characters than with the happy (AN group: $+0.15$ m [$+0.08, +0.22$]; CTL group: $+0.29$ m [$+0.22, +0.36$], Figure 2) and neutral characters (AN group: $+0.17$ m [$+0.10, +0.24$]; CTL group: $+0.29$ m [$+0.22, 0.36$]). No difference emerged between happy and neutral characters in either the AN ($+0.02$ m [$-0.05, +0.09$]) or CTL (-0.003 m [$-0.07, +0.06$]) groups.

Patients with AN preferred to keep further away the overweight characters than the normal-weight ($+0.08$ m [$+0.01, +0.16$]) and the underweight ones ($+0.21$ m [$+0.14, +0.28$]). They also preferred shorter distances with the underweight characters than the normal-weight ones (-0.13 m [$-0.20, -0.06$]) whereas no effect of morphology appeared in the CTL group (normal-weight - underweight: -0.02 m [$-0.09, +0.04$], normal-weight - overweight: -0.07 m [$-0.13, +0.00$], underweight - overweight: -0.04 m [$-0.11, +0.02$]). No difference emerged between the two groups.

3.3.2 | Reachability judgement

For both groups, the percentage of “reachable” response was higher when the characters were presented in PPS than, on the one hand, in the EPS (AN group: $+96.63\%$ points [$+94.39, +98.15$]; CTL group: $+99.07\%$ points [$+98.00, +99.65$]) and than, on the other hand, at the boundary of PPS (AN group: $+42.90\%$ points [$+21.01, +64.79$]; CTL group: $+36.37\%$ points [$+16.84, +59.60$], averaged R-Squared of the fit: $R^2 = 0.78$ [$0.77, 0.80$]). When presented at the boundary of the PPS, the characters were also judged more often as reachable than when presented in the EPS (AN group: $+54.05\%$ points [$+31.39, +75.32$]; CTL group: $+62.62\%$ points [$+39.82, +81.45$]).

3.4 | Electrodermal activity

The electrodermal response did not differ between the two groups for either the emotional or morphological stimuli (averaged R-Squared of the fit: $R^2 = 0.18$ [$0.14, 0.23$], Supporting Information Table 2). Concerning the emotional stimuli, patients with AN only showed a stronger response to happy characters than to angry ones when presented at the boundary of the PPS ($+1.91E-4$ μS , [$+0.03E-4, +4.76E-4$], Figure 3). However, the electrodermal response of the CTL group to angry and to happy characters was stronger when the latter were presented in the PPS than at the boundary of the PPS (respectively, $+1.48E-4$ μS [$+0.08E-4, +3.18E-4$]; $+2.83E-4$ μS [$+0.95E-4, +5.48E-4$]).

Both the underweight and the overweight characters triggered a stronger electrodermal response than the normal-weight ones when presented in the PPS of the AN group ($+2.40E-4$ μS [$+0.66E-4, +5.11E-4$] and $+1.65E-4$ μS [$+0.01E-4, +3.86E-4$] respectively). The underweight characters also triggered a stronger electrodermal response than the normal-weight ones when presented at the boundary of the PPS ($+1.41E-4$ μS [$+0.022E-4,$

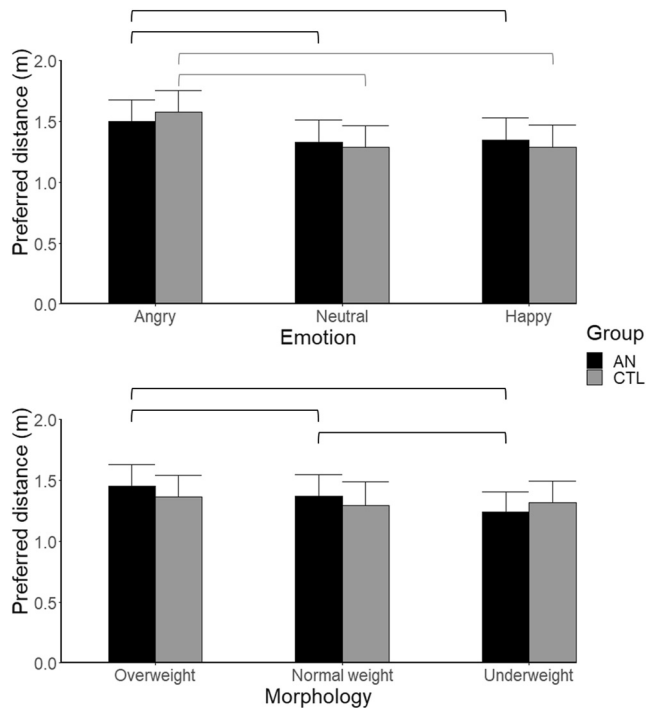


FIGURE 2 Posterior mean of the preferred distance and 95% Credibility interval (CI) as a function of the Group and Stimulus category. AN: participants with anorexia nervosa (black bars); CTL: control participants (grey bars). Horizontal bars represent credible contrasts.

+3.34E-4]). The response to the underweight characters was also higher when presented in the PPS compared to the EPS of the AN group (+2.78E-4 μ S [+0.88E-4, +5.47E-4]), and the response to the overweight characters was stronger when presented in their PPS than at the boundary of PPS (+1.18E-4 μ S [+0.18E-4; +3.86E-4]). Finally, the underweight characters triggered a stronger response in the CTL group than the normal-weight ones when presented in the EPS (+1.97E-4 μ S [+0.18E-4, +4.43E-4]).

4 | DISCUSSION

Based on previous studies, we investigated whether the preference for larger IPD observed in patients with AN (Nandrino et al., 2017) depended on a stronger physiological activation, stemming from higher discomfort with near body social stimuli (Cartaud et al., 2018), or depended on a stronger subjective evaluation of these social stimuli (Nandrino et al., 2011), taking into account BMI and individual characteristics. We also investigated whether these specific spatial adjustments depended on body shape and emotional information

from others. The main outcomes of the study are that patients with AN revealed a specific pattern of social behaviour with extended IPD for overweight virtual characters and contracted IPD for underweight ones, while they performed as the controls with the emotional characters, preferring larger interpersonal distances with angry characters, than happy and neutral ones.

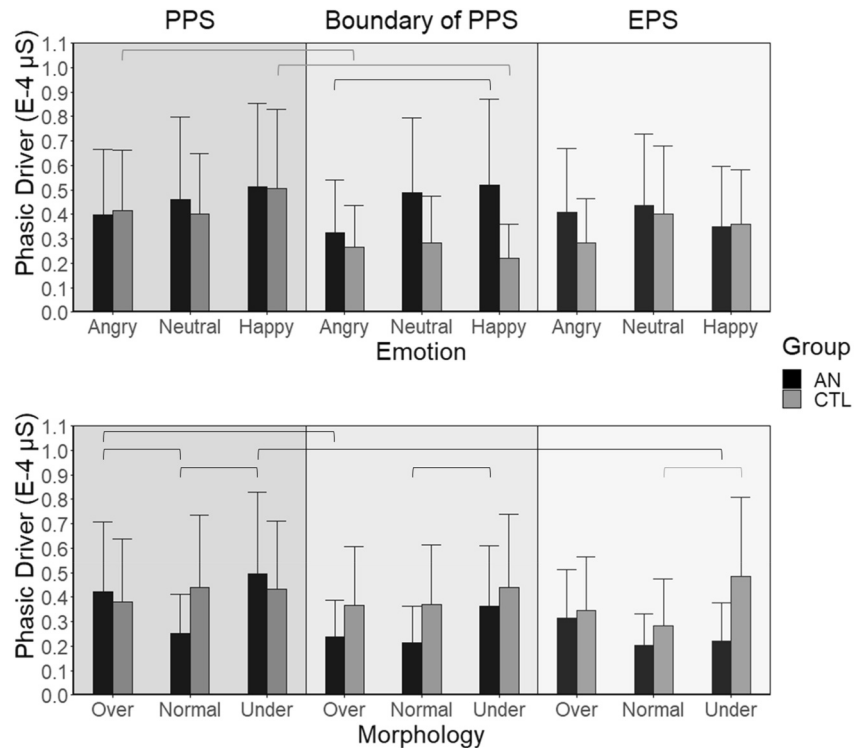
4.1 | Morphological stimuli

While no effect of morphology appeared in the control group, patients with AN preferred larger distance with the overweight than with the normal-weight characters, confirming previous report (Ambrosecchia et al., 2017; Welsch et al., 2020), and shorter distance with the underweight than the normal-weight characters. These effects, however, contrasted with those obtained for the valence ratings. Indeed, individuals with AN rated the underweight and overweight characters more negatively than the normal-weight characters, whereas control participants rated only the underweight characters more negatively. These results suggest that although individuals with AN evaluated negatively underweight body shapes, in accordance with social expectancies, they preferred to be close to them.

This interpretation fits with the physiological and the subjective arousal measures since individuals with AN showed a stronger electrodermal response to the proximity of the overweight and the underweight than the normal-weight characters, which was not observed in the control group. Moreover, the electrodermal response with underweight characters was more pronounced when presented in the PPS than the EPS. This latter finding suggests that, in patients with AN, a near body exposure to underweight morphology is experienced positively whereas the exposure of an overweight morphology is experienced negatively, in line with previous observations (Clarke et al., 2016; Cserjési et al., 2010). Furthermore, the subjective arousal reported by patients with AN was higher in the presence of underweight and overweight characters compared to the normal-weight characters, which was not observed in the control group. This effect might stem from the negative relationship between this subjective evaluation and social relationship abilities (PC3: “interpersonal skills”).

Finally, we observed a difference between the two groups in the valence assessment of the overweight characters: the AN group rated them more negatively

FIGURE 3 Posterior mean of the electrodermal response and 95% Credibility interval (CI) as a function the Group, Stimulus category and Space (PPS: peripersonal space – darkest background; Boundary of PPS – medium background; EPS: extrapersonal space – lighter background; Over: overweight; Normal: normal-weight; Under: underweight. AN: patients with anorexia nervosa (black bars); CTL: control group (grey bars). Horizontal bars represent credible contrasts.



than the CTL group, as this was previously reported (Cserjési et al., 2010). This result is consistent with the negative relationship observed between the valence rating of overweight characters and the alteration of body representation (PC2 “negative body image”). Altogether these results, the main finding with respect to patients with AN is the presence of a decoupling between estimated valence to underweight social stimuli on the one hand and the physiological and behavioural responses on the other hand, which was not observed in the CTL group. Such a decoupling was not observed when considering overweight social stimuli.

4.2 | Emotional stimuli

With regard to the emotional social stimuli, both groups preferred larger distances with angry characters than with neutral and happy ones. Furthermore, both groups rated angry characters less positively than neutral ones, which in turn were rated less positively than the happy ones. Previous studies reported a similar finding in terms of affective valence judgements, suggesting that individuals with AN, despite experiencing difficulties in emotion recognition (Blomberg et al., 2021; Martini et al., 2023), perceive and evaluate affective valence similarly to individuals without AN (De Sampaio et al., 2015). Moreover, affective valence appears to be particularly sensitive to the altered body

representation (PC2 “negative body image”), as revealed by the negative relationship.

Concerning the physiological activity, we observed that patients with AN did not show any change in the electrodermal response whatever the emotional facial expression of the character or its spatial location, except between the angry and happy characters when located at the boundary of the PPS. These results contrasted with the CTL group, for which both angry and happy characters triggered a stronger electrodermal response when located in the PPS. This observation is congruent with previous studies that have reported a stronger physiological activity to emotional stimuli when presented close to the body (Cartaud et al., 2018, 2020). Moreover, this pattern of results in patients with AN echoes the emotional blunting observed in the presence of emotional social stimuli, that was already suggested (Blomberg et al., 2021; Leppanen et al., 2017). These data are also coherent with the arousal rating, since although both groups rated the angry and the happy characters more arousing than the neutral ones, the patients with AN rated them as less arousing than the control group. Taken together, these results suggest that, unlike what was observed in the control group, the regulation of IPD is more related to subjective experience (valence and arousal rating) than physiological response in patients with AN when interacting with emotional social stimuli.

5 | CONCLUSION AND LIMITS

The outcomes of the present study suggest that patients with AN may experience an emotional activation, expressed through physiological response, specific to variations of morphological features and not variations of facial expressions. We thus observed a bias in the selection of the social cues used to process emotional information and optimise social interactions, with body shape prevailing over facial expression. This statement is supported by the change in IPD with overweight and underweight stimuli that is not observed in the control group. This also confirms the specific emotional value of others' body shape, in particular at the physiological level, that characterises patients with AN. Accordingly, patients with AN revealed a physiological blunting towards emotional stimuli (facial expressions) that triggers no specific response despite the variations of the stimuli valence. However, despite this emotional blunting, IPD remains affected by the valence of social stimuli, as controls, which indicates that facial expressions are recognized and used in social interactions. The observed dissociation between objective and subjective responses to facial expression in relation to IPD should therefore be the subject of further investigations. Finally, and unexpectedly, IPD was not overall larger in the patients with AN than in controls, contrary to observations made in previous studies (Nandrino et al., 2017; Welsch et al., 2020). One possible interpretation for such discrepancy in the findings is that the present study used virtual human characters instead of real humans, which could have reduced the social stakes of the interaction. Another possible interpretation is that the present study deviated from the typical approach by not employing a stop-distance paradigm as is customary (Ambroseccchia et al., 2017; Nandrino et al., 2017; Welsch et al., 2020), but instead a staircase adaptive method. While this psychophysical method offers a more implicit evaluation of IPD regulation, it might be less attuned to the approach/avoidance behaviours seen in real-life situations, behaviours that patients with AN seem to be particularly sensitive to (Welsch et al., 2020). Yet another interpretation is that the virtual environment used was not immersive enough to trigger a strong feeling of social presence. Another possible explanation is that the virtual environment used was not immersive enough to trigger a strong feeling of social presence. Although these interpretations might have reduced the effect of anxiety, characterising patients with AN, on the adjustment of IPD, further studies would be necessary to disentangle these interpretations. This lack of effect might also stem from the ongoing weight

recovery in some patients with AN. This interpretation should also be the subject of future studies. If confirmed, the role of weight recovery in the regulation of interpersonal distances in patients with AN presents a promising prospect towards more regular social interactions. Another limitation of this study is that it was not pre-registered. However, we ensured transparency by reporting all results, including those contradicting our hypotheses. Overall, these findings indicate that social interactions in patients with AN is specifically impaired, characterised by a biased focus towards the size of the body, thus neglecting the usual emotional cues conveyed by the face, which should be considered in clinical interventions.

AUTHOR CONTRIBUTION

Alice Cartaud: conceptualisation; data curation; formal analysis; methodology; visualisation; writing—original draft. Philibert Duriez: writing—review and editing. Johanna Querenghi: conceptualisation; data curation; writing—review and editing. Jean-Louis Nandrino: writing—review and editing. Philip Gorwood: writing—review and editing. Odile Viltart: conceptualisation; writing—review and editing. Yann Coello: conceptualisation; formal analysis; methodology; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest with respect to the authorship of the publication of the article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Zenodo at <https://doi.org/10.5281/zenodo.10231192>, reference number 10.5281/zenodo.10231192.

ORCID

Alice Cartaud  <https://orcid.org/0000-0002-0918-8869>
 Philibert Duriez  <https://orcid.org/0000-0001-7321-6820>
 Johanna Querenghi  <https://orcid.org/0009-0009-2989-3504>
 Jean-Louis Nandrino  <https://orcid.org/0000-0003-2339-9432>
 Philip Gorwood  <https://orcid.org/0000-0003-1845-3676>
 Odile Viltart  <https://orcid.org/0000-0002-4801-3586>
 Yann Coello  <https://orcid.org/0000-0002-7148-0561>

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