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ORIGINAL ARTICLE

Altered processing of conflicting body representations in women with restrictive anorexia nervosa

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Abstract
Cognitive and affective impairments in processing body image have been observed in patients with Anorexia Nervosa (AN) and may induce the hypercontrolled and regulative behaviors observed in this disorder. Here, we aimed to probe the link between activation of body representations and cognitive control by investigating the ability to resolve body-related representational conflicts in women with restrictive AN and matched healthy controls (HC). Participants performed a modified version of the Flanker task in which underweight and overweight body images were presented as targets and distractors; a classic version of the task, with letters, was also administered as a control. The findings indicated that performance was better among the HC group in the task with bodies compared to the task with letters; however, no such facilitation was observed in AN patients, whose overall performance was poorer than that of the HC group in both tasks. In the task with body stimuli, performance among patients with AN was the worst on trials presenting underweight targets with overweight bodies as flankers. These results may reflect a dysfunctional association between the processing of body-related representations and cognitive control mechanisms that may aid clinicians in the development of optimal individualized treatments.

Keywords Anorexia nervosa · Body representation · Flanker task · Conflict processing · Cognitive control

Introduction

Body awareness is crucial for interaction with the environment and the social world (Berlucchi & Aglioti, 1997, 2010). Since certain clinical conditions may be associated with defective processing of body-related information, this represents a possible source of physical, psychological, and social distress. Anorexia Nervosa (AN) is a severe eating disorder characterized by (i) disturbance in processing information about body weight and shape, (ii) lack of recognition of one's own severely low body weight, and (iii) intense fear of gaining weight (DSM-V; APA, 2013). Among all psychiatric illnesses, AN constitutes one of the most common causes of death in young women and teenagers in Western industrialized cultures (Smink et al., 2012). Although the etiology of the disorder likely has its roots in the interactions between genetic, environmental, and psychosocial factors, its exact causes remain unknown (Treasure & Schmidt, 2013; Zipfel et al., 2015). From a clinical perspective, two subtypes of AN have so far been identified: the binge-eating/purging type, in which behaviors of recurrent food consumption are followed by purging episodes, and the restrictive type, in which weight loss is achieved by excessive dieting, fasting, and physical efforts (APA, 2013).

It is worth noting that the distortion of body image (i.e., the internal abstract self-representation based on sensorial and perceptual processing) is widely deemed to be a core symptom of the disorder (Dakanalis et al., 2016; Gadsby, 2017). Indeed, alteration of the body image dramatically affects an individual's ability to develop accurate representations of their body state and may lead to clinical outcomes

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that involve over-estimations of body weight and shape, impairment in multisensory integration, and proprioceptive deficits (Grunwald et al., 2001; Keizer et al., 2011; Madsen et al., 2013; Provenzano et al., 2019; Spitoni et al., 2015). Moreover, the selective representational distortion of body image that occurs in AN can affect an individual's cognitive and emotional processing, inducing false beliefs, cognitive biases, and negative attitudes towards their own (mis)perceived body (Skrzypek et al., 2001). These distortions may contribute to the promotion of loop-like regulatory and non-compensatory behaviors (e.g., excessive body monitoring, physical exercise, and restrictive dieting) that increase the patient's control over their body weight and shape (Tabri et al., 2015). The occurrence of such maladaptive hypercontrolled behaviors underlies the atypical functioning of the cognitive control system in AN during information processing (Vitousek & Hollon, 1990). In particular, neuroimaging studies have observed structural and functional alterations in crucial regions belonging to the frontal executive network, such as the anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex, which are implicated in performance monitoring and top-down control (Alfano et al., 2020; Simon et al., 2019; Steward et al., 2020). More specifically, the ACC is a key structure in monitoring of conflicting representations, detection of erroneous performance, driving of behavioral adjustments, and modulation of motivational and affective processing (Botvinick et al., 2001; Carter et al., 1998Stevens et al., 2011). Importantly, in patients suffering from AN, the ACC exhibits reduction in gray matter volume (Mühlau et al., 2007), blood perfusion (Naruo et al., 2001; Takano et al., 2001), and resting-state functional connectivity (Gaudio et al., 2015), likely reflecting the neurophysiological substrates of deficits relating to executive control (Hirst et al., 2017).

On this point, laboratory-based experimental studies have probed behavioral performance among patients with AN through the use of behavioral paradigms that typically tap into cognitive control, such as the Stroop task (Stroop, 1935) and the Flanker tasks (Eriksen & Eriksen, 1974). Studies employing an emotional Stroop task with salient stimuli (e.g., food- or body-related words) have generally observed an attentional bias in favor of body- or weight-related stimuli in participants with AN (Channon et al., 1988; Redgrave et al., 2008). For example, Johansson and colleagues (2005) conducted a meta-analysis of 27 studies in which performance in Stroop tasks using body- and food-related words was examined in groups of individuals with eating disorders (i.e., participants suffering from anorexia or bulimia nervosa), individuals with concerns about body weight, and healthy control participants. The results indicated that, across these studies, the Stroop effect (i.e., the response slowdown during color naming of relevant words) was larger in the clinical group compared to the other groups (Johansson et al., 2005). However, other studies reported no differences between patients with AN and neurotypical controls in processing of representational conflicts and cognitive interference during this type of emotional Stroop task (Dobson & Dozois, 2004; Mendlewicz et al., 2001). These discrepancies might be partially explained by sample heterogeneity (e.g., with respect to age or AN subtype), differences in sample sizes, and the use of behavioral paradigms that do not lead to definitive and generalizable conclusions (Dobson & Dozois, 2004; Faunce, 2002).

In contrast with the Stroop task, studies using the Flanker tasks seem to suggest that the hyper-control characteristic of AN symptomatology may facilitate patients' ability to deal with conflicting stimuli and reinforce top-down mechanisms. Flanker tasks induce competition between multiple possible responses during the rapid processing of conflicting stimuli, which consist of a central target displayed between similar or dissimilar laterally-presented distractors. In this type of task, participants are required to identify the central target as quickly and accurately as possible, while ignoring the (in)congruent lateral distractors (Eriksen & Eriksen, 1974). Pieters and colleagues (2007) have reported that, compared to control participants, AN patients are better at responding correctly after having made an error in a classical version of the Flanker task (i.e., with letters as stimuli), suggesting that they are more proficient in post-error adjustments and can exert greater cognitive control in comparison to healthy participants. Similarly, adolescents with AN exhibit less cognitive interference than control participants during a Flanker task presenting arrow stimuli, demonstrating a stronger ability to implement control strategies for achieving attentional orientation toward the central target and to reduce the impact of processing of the flankers (Weinbach et al., 2018). In turn, it is plausible that the continuous monitoring and control over the body that occurs in AN may facilitate the conflict resolution component of cognitive processing. Nevertheless, it is unclear whether and to what extent the distortion of body representation that occurs in AN may affect cognitive control and interact with patients' ability to process conflicting body-related stimuli. The present study aimed to fill this gap, hypothesizing that there is a direct link between altered body representation and conflict processing in AN.

Several studies have already demonstrated the suitability, in neurotypical populations, of the Flanker task as a way to measure cognitive control in coordinating response selection to complex visual stimuli potentially of specific relevance to AN pathology, such as high vs. low calorie foods (Forestell et al., 2012; Meule et al., 2012) and (in)congruent body-related representations (as conveyed, e.g., by hands, faces, or entire bodies; Fusco et al., 2022a; Mondloch et al., 2013; Oldratiet al., 2020; Petrucci & Pecchinenda, 2017). However, no study has yet implemented a Flanker task with body-related stimuli that may elicit evidence of altered conflict processing in populations of eating disorder patients. To this end, we developed a novel Body-Flanker (BF) task presenting images of underweight and overweight bodies as stimuli and administered it to a group of AN patients and a group of neurotypical control participants to obtain new insight into how impairments to body representation may affect conflict and top-down processing. Recently reported evidence has pointed toward possible cognitive differences between subtypes of AN (Tamiya et al., 2018; Van Autreve et al., 2013); although this is debated (Hirst et al., 2017; Wildes et al., 2013), we included only participants diagnosed with restrictive AN in the clinical sample to avoid spurious sample heterogeneity. Additionally, as a baseline measure of the ability to process cognitive conflicts, all participants also completed a classic Letter-Flanker (LF) task, in which conflicting stimuli with no relevance to AN pathology were presented.

In line with existing evidence that AN is associated with hypercontrolled, efficient behavioral response strategies and disturbed body representation, we expected that AN patients' overall performance (i.e., accounting for the covariation between response times and accuracy) compared to a matched control group of neurotypical participants would be better in the LF task and weaker in the BF task. Since configural processing appears to facilitate visual discrimination of body-related stimuli to a greater extent among healthy individuals compared to patients with AN (Urgesi et al., 2014), we also expected that the control group would exhibit a better performance in the BF than in the LF. Moreover, we hypothesized that the ability of AN patients to inhibit cognitive interference induced by task-irrelevant information (i.e., the flankers) and optimally resolve conflicts induced by incongruent stimuli might be affected specifically in the BF task by distorted cognitive and affective body-related representations. Indeed, bodies—especially overweight ones—might be processed as emotionally arousing stimuli, thereby impairing the resolution of competing responses during information processing.

Materials and methods

Participants

An a priori power analysis was conducted using MorePower 6.0.4 (Campbell & Thompson, 2012) to estimate the required sample size. For an alpha level (α) of 0.05, to achieve statistical power ($1-\beta$) of 0.80 at an effect size (η_p^2) of 0.15 (estimated on the basis of the effect size reported for the interaction between group and congruency effect in Weinbach et al., 2018), a sample of a total of 48 participants would be required. Thus, 50 young women were enrolled to participate in the study: of these, 25 were patients with AN (21.60 ± 1.20 [mean ± S.E.M] years, range 16–44; body mass index (BMI): 16.64 ± 0.21, range 14.53–18) and 25 were age-matched healthy controls (HCs; age: 24.31 ± 0.66 years, range 19–32; BMI: 20.35 ± 0.29, range 17.71–23.04). Patients were recruited at the UOSD Eating Disorder Unit of Santa Maria della Pietà hospital in Rome, Italy. Each patient had a diagnosis of AN of the restricting subtype, as defined according to the DSM-V criteria and confirmed by expert psychiatrists via clinical interviews and a test battery designed for the assessment of eating disorders and psychopathology. Additional inclusion criteria for participants in the AN group in the present study were a BMI below 18 and absence of psychotic disorders.

Nine participants in the patient group reported comorbidity of other disorders with their AN (depressive syndrome: $N=4$; anxious–depressive syndrome: $N=4$; borderline traits: $N=2$). None of the HC participants reported any neurological or psychiatric diseases, including any history of eating disorders. All participants had normal or corrected-to-normal visual acuity in both eyes and were naïve to the purposes of the study.

The experimental protocol was approved by the ethics committee of the Fondazione Santa Lucia and was carried out in accordance with the ethical standards of the 2013 Declaration of Helsinki. All participants provided their written informed consent to take part in the study.

Tasks and stimuli

Each participant was required to complete two versions of the Flanker task (Eriksen & Eriksen, 1974), namely the BF and LF tasks. In this type of task, a target stimulus is embedded in a string of four distractor stimuli (i.e., flankers, with two on each side); distractors are either similar to the target (the congruent condition; CC) or dissimilar from it (the incongruent condition; IC). These conditions are illustrated in Fig. 1. Typically, a *flanker effect* is observed, in which better performance is elicited by the CC than by the IC. In the BF task, the stimuli were female body silhouettes facing to the right, each depicting either an underweight or an overweight body (see Fig. 1A). In the LF task, target and distractors instead took the form of the letters H and S (see Fig. 1B).

On each trial, the participant was asked to respond as quickly and accurately as possible to the target stimulus, by pressing one of the two selected response keys on a keyboard (counterbalanced across participants). Following the presentation of a fixation cross for 100 ms at the center of a PC monitor (dimensions: 51 × 30 cm) at the start of each trial, the target and flankers were presented simultaneously on a gray background for 100 ms. The response time window was set individually for each participant (see Procedure section).

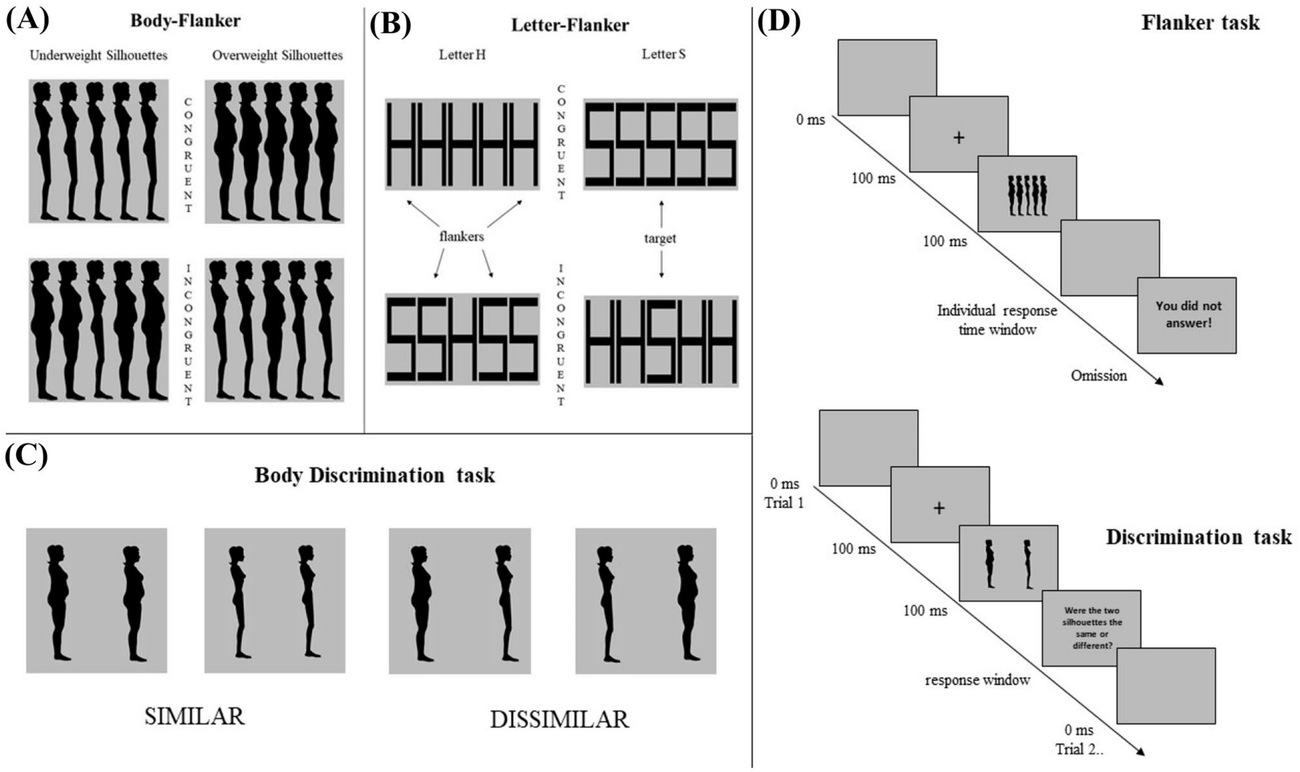

Fig. 1 Task and stimuli. **A**, **B** Show the stimuli and conditions characterizing the Body-Flanker and Letter-Flanker tasks, respectively. **C** Shows the stimuli administered during the Body Discrimination task. **D** Shows the timeline of individual trials in the Flanker tasks and the Discrimination task

However, if the participant did not provide any response within the allocated time, a visual feedback message was presented with the text "*Non hai risposto*" ("You did not answer"; Fig. 1D). Three consecutive blocks of trials were administered for each version of the Flanker, with a five-minute interval between blocks. Each block consisted of 160 trials (80 CC and 80 IC) presented in a random order, for a total of 480 trials.

Immediately after completing the Flanker tasks, each participant was also asked to complete a Body Discrimination task to confirm that the duration of stimuli presentation during the flanker tasks (100 ms) was sufficient to enable them to discern perceptually whether the target and flanker body silhouettes were similar or dissimilar under conditions involving no activation of conflicting responses. In this task, the participant was asked to specify whether two under- or overweight body silhouettes (the same stimuli as those presented in the BF task), presented on either side of a fixation cross positioned in the center of the screen, were similar or different (Fig. 1C). Specifically, they were instructed to look at the center of the PC screen. A fixation cross appeared for 100 ms and was then replaced by a pair of body silhouettes, which were presented for 100 ms. In total, 60 pairs were presented (30 similar and 30 dissimilar). The participant was instructed to respond as accurately as possible using the two keys on the keyboard (pressing key 1 if the silhouettes were similar and key 2 if they were dissimilar). There were no time constraints on participants' responses.

All the experimental tasks were constructed using the E-prime 2.0 professional software package (Psychology Software Tools Inc., Sharping, PA, USA).

Questionnaires and scales

To assess AN severity, psychiatric and psychological aspects of the personality traits associated with eating disorders, and body perception and distortion, the following clinical scales were administered to all participants: the Eating Disorder Inventory-2 (EDI-2; Garner et al., 1983), the Body Uneasiness Test (BUT-A and BUT-B; Cuzzolaro et al., 2006), and the Body Shape Questionnaire (BSQ; Cooper et al., 1987). The EDI-2 is a self-report questionnaire comprising 91 items that measure clinical and psychological aspects of AN, bulimia, and eating disorder not otherwise specified, with responses provided on a 6-point Likert scale. The questionnaire consists of 12 subscales: Drive for Thinness, Bulimia, Body Dissatisfaction, Low Self-Esteem, Personal Alienation, Interpersonal Insecurity, Interpersonal

Alienation, Interoceptive Deficits, Emotional Dysregulation, Perfectionism, Asceticism, and Maturity Fears. The BUT is a 71-item self-report questionnaire, with responses provided on a 6-point Likert scale, consisting of two parts: the BUT-A probes weight phobia, body image concerns, avoidance, compulsive self-monitoring, detachment, and feelings of estrangement from one's own body (depersonalization); and the BUT-B focuses on worries about specific body parts and bodily behaviors. Finally, the BSQ is a 34-item self-report questionnaire measuring how the respondent (negatively) evaluates their own body shape, with responses again provided on a 6-point Likert scale.

Additionally, since conflict and error processing could be modulated by motivation, anxiety, and cognitive closure (Amodio et al., 2008), participants also completed the Behavioral Inhibition and Activation Scales (BIS/BAS; Carver & White, 1994), the State and Trait Anxiety Inventory (STAI-Y; Spielberger, 2010), and the 16-item reduced form of the Need for Closure Scale (NFCS, Roets et al., 2015).

All scales were administered to participants in the AN group by an expert clinical psychotherapist in our research group (MP).

Procedure

At the start of the experimental session, the participant was invited to sit in a comfortable position on a chair 80 cm away from the PC screen in a dimly lit room. Each of the two Flanker tasks (the BF and LF) was completed by each participant; the order in which they were administered was counterbalanced across participants. To familiarize the participant with the task instructions and stimuli, each task began with a training phase, which consisted of two blocks containing 20 trials each (10 CC, 10 IC). Subsequently, to calibrate the task difficulty according to each participant's performance, a practice block of 60 trials (30 CC, 30 IC) was administered. On each of these trials, the participant was required to respond within a timeframe of 700 ms; additionally, if their response was provided between 501 and 700 ms after stimulus onset, the visual feedback message "*Più veloce!*" ("Faster!") appeared in the center of the screen. At the end of this practice block, the participant was asked to complete a form collecting their demographic details. In the meantime, the experimenter completed the task calibration by computing the participant's mean reaction time (RT) for correct trials during the practice block. This value plus 0.5 standard deviations was then adopted as the individually-calibrated response time window for that participant in the experimental task. This procedure was conducted to calibrate the task difficulty to elicit an accuracy level of approximately 75–80% (De Bruijn et al., 2004; Pieters et al., 2007) and to avoid possible ceiling or floor effects that might arise as a result of the task being too easy or too difficult for one of the participant groups.

The main experimental session began immediately after this calibration procedure. Each participant completed three experimental blocks for each Flanker task, with an inter-task interval of 15 min. Following the tasks, the participant was asked to complete one block of the Body Discrimination task and to respond to the questionnaires and scales.

Data processing

The data were checked for normality of distribution using the Kolmogorov–Smirnov test. Age, BMI, and scores on each of the scales and questionnaires were compared between groups using independent-samples Student's *t*-tests.

To account for both the temporal dynamics and the accuracy of participants' responses in a single behavioral variable that could be used to compare the two samples on their overall performance, we computed the RTs/ACC ratio for each participant in each condition; this functioned as an index of general performance in the Flanker task (Bowie et al., 2021; Fusco et al., 2018, 2022a; Oldrati et al., 2020). Specifically, the lower a participant's score on this behavioral index, the quicker and more accurate their responses were (i.e., the better their overall performance was).

Data were analyzed using mixed factorial repeated-measures analyses of variance (ANOVAs) reflecting a 2×2×2 design, with GROUP (AN vs. HC) as a between-participants factor and TASK (BF vs. LF) and CONGRUENCY (CC vs. IC) as within-participants factors. Additionally, to analyze the modulating effects of stimulus body size on cognitive processing of conflicting stimuli, further mixed factorial repeated-measures ANOVA(s) were computed over data from the BF task only, again reflecting a 2×2×2 design with GROUP (AN vs. HC) as a between-participants factor and body SIZE (underweight vs. overweight) and CONGRUENCY (CC vs. IC) as within-participants factors. Main effects and significant interactions identified via ANOVA were further analyzed using Duncan's multiple range post-hoc tests.

Since the data from the Body Discrimination task were not normally distributed, the Wilcoxon signed-rank test was conducted for within-group comparisons and the Mann–Whitney *t*-test for independent samples was used to compare accuracy scores between groups.

Finally, Pearson product-moment correlation coefficients (r^2) were computed between indices of behavioral performance in the BF task and subjective global scores collected via the clinical scales and subscales measuring dysfunction in eating behavior and concerns over body shape and weight (i.e., the EDI-2, BUT-A, BUT-B, and BSQ), as well as scores on the questionnaires measuring motivation, anxiety, and cognitive closure (i.e., the BIS/BAS, STAY-Y, and

NFCS). The correlational analyses, the separate analyses on the reaction times (RTs) and accuracy (ACC) and additional explorative analyses (i.e., sequential trial effects, set shifting) are reported in the supplementary materials.

Results

Subjective measures

The two groups were comparable in age, $t(48) = 1.999$; $p = 0.052$; $d = 0.552$. However, as expected, they differed significantly in BMI, $t(48) = 10.176$; $p < 0.001$; $d = 3.790$, and in scores on most of the clinical measures indexing AN symptomatology relating to the body (EDI-2: Drive for Thinness, Body Dissatisfaction, Interoceptive Awareness, Ineffectiveness, Maturity Fears, Perfectionism, Interpersonal Distrust, Ascetism, Impulse Regulation, and Social Insecurity; BUT-A: General Symptom Index, Weight Phobia, Body Image Concerns, Avoidance, Compulsive Self-Monitoring, Depersonalization; BUT-B: Positive Symptom Distress Index, Thighs, Legs, Harms; BSQ); see Table 1 for further details.

Body discrimination task

Accuracy (Acc, % correct responses)

To rule out the possibility that either group of participants were not able to distinguish over- and underweight body images at a presentation duration of 100 ms, we compared their performance in identifying such images in the congruent and incongruent conditions of the Body Discrimination task. Friedman ANOVAs used to compare the conditions within each group revealed that, in both groups, accuracy differed between these conditions (AN: $\chi^2 = 23.05$, $p < 0.001$, $W = 0.307$; HC: $\chi^2 = 24.78$, $p < 0.001$, $W = 0.330$). Specifically, Wilcoxon matched pair tests (Bonferroni corrected for six comparisons; threshold for significance: $p < 0.0083$) indicated that, in both groups, worse performance (i.e., lower accuracy) occurred in identifying overweight congruent stimuli in comparison to all other conditions. Among the HC group, accuracy differed in the overweight–overweight condition (93 ± 0.06 [median ± interquartile range]) from the overweight–underweight condition (100 ± 0.00), $T = 9.00$, $Z = 3.583$; $p < 0.001$, $r = 0.716$; from the underweight–underweight condition (100 ± 0.06), $T = 19.00$, $Z = 2.896$; $p < 0.004$, $r = 0.579$; and from the underweight–overweight condition (100 ± 0.06), $T = 0.00$, $Z = 3.516$, $p < 0.001$, $r = 0.703$. Similarly, among the AN group, accuracy differed in the overweight–overweight condition (93 ± 0.06) from the overweight–underweight condition (100 ± 0.00), $T = 19.00$, $Z = 3.210$, $p < 0.002$, $r = 0.642$; from the underweight–underweight condition (93 ± 0.13), $T = 58.50$; $Z = 1.981$, $p < 0.047$, $r = 0.396$; and from the underweight–overweight condition (100 ± 0.00), $T = 26.00$, $Z = 2.277$, $p < 0.006$, $r = 0.455$. Finally, from the same dataset, we conducted a Mann–Whitney *U* test to check for possible differences between the groups in their perceptual abilities relating to the identification of under- and overweight body representations. No significant differences emerged from the analysis.

Differences between AN patients and neurotypical participants in cognitive control during responses to conflicting body and letter stimuli

Overall performance Index (RTs/Acc)

The ANOVA over the ratio-based overall performance index indicated that there was a main effect of GROUP, $F(1,48) = 6.910$; $p = 0.011$; $\eta^2_p = 0.125$, reflecting overall better performance among participants in the HC group (4.89 ± 0.07) compared to those in the AN group (5.42 ± 0.10). There was also a significant interaction TASK × GROUP, $F(1,48) = 5.695$; $p = 0.021$; $\eta^2_p = 0.106$, reflecting better performance among participants in the HC group in processing of conflicting body images (4.72 ± 0.04) compared to letter stimuli (5.07 ± 0.12; $p < 0.001$), and better performance in both these tasks among participants in the HC group compared to those in the AN group (BF task: 5.39 ± 0.16; $p = 0.003$; LF task: 5.43 ± 0.14; $p = 0.002$). Importantly, among AN patients, there was no significant difference in performance between the two tasks ($p = 0.728$; Fig. 2), suggesting that the processing of cognitive conflicts was not facilitated when the stimuli were body images, as was the case among participants in the neurotypical group. The ANOVA also indicated that there was a significant interaction TASK x CONGRUENCY, $F(1,48) = 172.603$; $p < 0.001$; $\eta^2_p = 0.782$, confirming that a flanker effect was present in both the BF task (CC: 4.96 ± 0.12; IC: 5.15 ± 0.17; $p < 0.001$) and the LF task (CC: 4.63 ± 0.09; IC: 5.85 ± 0.11; $p < 0.001$). Participants also performed better on trials in the CC of the LF task compared to either the CC ($p = 0.001$) or the IC ($p < 0.001$) of the BF task, as well as performing more poorly on trials in the IC of the LF task than on trials in either in the CC ($p < 0.001$) or the IC ($p < 0.001$) of the BF task.

Table 1 Mean (standard deviation) scores on all administered scales (and their subscales), effect sizes (*d*) and *t* values representing comparisons between the healthy control (HC) group and participants with anorexia nervosa (AN)

	NT	AN	t	*d*
Age	24.36 (3.38)	21.6 (6.02)	1.999	0.552
BMI	20.42 (1.51)	16.65 (1.07)	10.176**	3.790
EDI-2 (Drive for Thinness)	2.2 (4.06)	13.6 (7.69)	– 6.556**	1.853
EDI-2 (Bulimia)	1.48 (2.95)	1 (2.43)	0.629	0.177
EDI-2 (Body Dissatisfaction)	6.96 (5.02)	13.8 (8.91)	– 3.345**	0.945
EDI-2 (Interoceptive Awareness)	3.36 (5.05)	11.52 (8.79)	– 4.026**	1.138
EDI-2 (Ineffectiveness)	5.28 (5.27)	9.52 (7.35)	– 2.343*	0.663
EDI-2 (Maturity Fears)	3.24 (2.91)	8.44 (5.09)	– 4.435**	1.254
EDI-2 (Perfectionism)	3.12 (3.62)	6.16 (3.50)	– 3.019**	0.853
EDI-2 (Interpersonal Distrust)	3.6 (3.88)	5.76 (4.58)	– 1.799	0.508
EDI-2 (Ascetism)	2.16 (2.75)	6.4 (4.15)	– 4.257**	1.204
EDI-2 (Impulse Regulation)	2.96 (5.17)	5.72 (6.14)	– 1.719	0.486
EDI-2 (Social Insecurity)	4.16 (4.32)	7.12 (5.09)	– 2.218*	0.627
BUT-A (General Symptom Index)	1.21 (0.73)	2.5 (1.20)	– 4.526**	1.298
BUT-A (Weight Phobia)	1.73 (0.95)	3.26 (1.15)	– 5.117**	1.450
BUT-A (Body Image Concerns)	1.45 (0.83)	2.5 (1.27)	– 3.332**	0.978
BUT-A (Avoidance)	0.67 (0.78)	1.61 (1.23)	– 3.181**	0.912
BUT-A (Compulsive Self-Monitoring)	1 (0.77)	2.54 (1.40)	– 4.807**	1.363
BUT-A (Depersonalization)	0.87 (0.72)	2.32 (1.47)	– 4.433**	1.252
BUT-B (Positive Symptom Total)	17.52 (8.44)	23.08 (11.78)	– 1.918	0.542
BUT-B (Positive Symptom Distress Index)	1.87 (0.49)	2.49 (1.08)	– 2.605*	0.739
BUT-B (Mouth)	1.1 (0.78)	1.38 (1.25)	– 1.261	0.268
BUT-B (Face Shape)	0.59 (0.58)	1.17 (1.40)	– 1.908	0.541
BUT-B (Thighs)	1.18 (0.85)	2.6 (1.57)	– 3.935**	1.124
BUT-B (Legs)	0.86 (0.85)	1.76 (1.39)	– 2.729**	0.781
BUT-B (Harms)	0.70 (0.68)	1.76 (1.42)	– 3.343**	0.952
BUT-B (Moustache)	1 (0.74)	0.87 (1.04)	0.503	0.144
BUT-B (Skin)	1.16 (0.94)	1.35 (1.50)	– 0.522	0.151
BUT-B (Blushing)	1.06 (0.80)	1.43 (1.32)	– 1.216	0.339
BSQ	80.08 (29.05)	115.57 (42.01)	– 3.427**	0.982
STAI-Trait	49.08 (2.89)	48.57 (3.36)	0.571	0.162
STAI-State	46.24 (11.31)	51.82 (6.65)	– 2.061*	0.601
BIS	14.44(3.04)	14.26 (5.31)	0.953	0.041
BAS (Reward Responsiveness)	10.8 (2.35)	11.48 (4.49)	– 0.663	0.189
BAS (Drive)	11 (1.91)	11.22 (3.10)	– 0.294	0.085
BAS (Fun Seeking)	11.2 (3.27)	12.17 (3.49)	– 0.999	0.286
NCC	48.04 (7.27)	54.52 (6.96)	– 3.151**	0.91

BMI body mass index, *EDI-2* Eating Disorder Inventory–2, *BSQ* Body Shape Questionnaire, *STAI* State and Trait Anxiety Inventory, *BIS/BAS* Behavioral Inhibition and Activation Scales, *NFCS* Need for Closure Scale

Single asterisks (*) denote comparisons where $p < 0.05$; double asterisks (**) denote those where $p < 0.01$

Differences between AN patients and neurotypical participants in cognitive control relating specifically to the shape (weight) of conflicting body images

Overall performance index (RTs/Acc)

The analysis revealed that there was a significant three-way interaction GROUP x SIZE x CONGRUENCY, $F(1,48) = 4.230$; $p = 0.045$; $\eta_p^2 = 0.081$; Fig. 3. Specifically, there was a pronounced impairment among participants in the AN group in responding to trials in the IC in which an underweight target was flanked by overweight distractors; performance by participants in this group was poorer in this condition (5.78 ± 0.28) compared to the underweight CC (5.30 ± 0.23; $p < 0.001$), and to both overweight

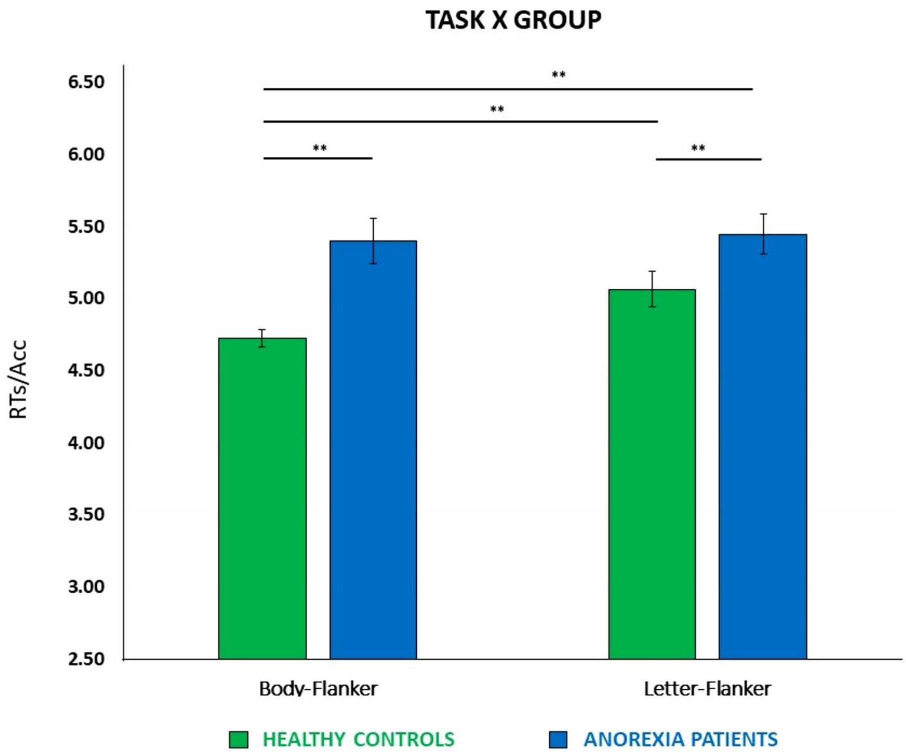

Fig. 2 Bar plot representing difference in performance in the two versions of the Flanker task (with bodies and with letters) between the experimental group (patients with anorexia nervosa; blue bars) and the control group (neurotypical participants; green bars. Double asterisks (**) denote comparisons where $p < 0.01$

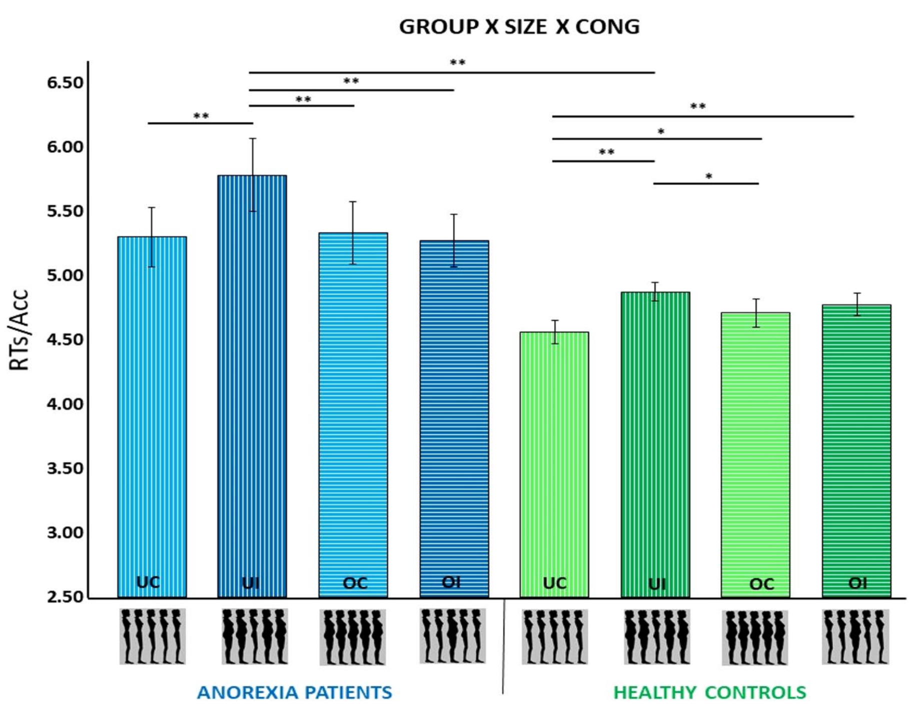

Fig. 3 Bar plot illustrating the significant three-way interaction between Group (anorexia nervosa patients vs.; healthy controls), Size (underweight vs. overweight), and Congruency (congruent vs. incongruent). Asterisks (*) denote comparisons where $p < 0.05$; double asterisks (**) denote those where $p < 0.01$. *UC* underweight congruent, *UI* underweight incongruent, *OC* overweight congruent, *OI* overweight incongruent

conditions (overweight CC: 5.33 ± 0.24; $p < 0.001$; IC: 5.27 ± 0.20; $p < 0.001$), although there was no difference between the latter in the performance of participants in this group ($p = 0.462$). Similarly, performance among participants in the AN group did not differ between the underweight and overweight CCs ($p = 0.669$). Moreover, the performance of AN patients on trials presenting underweight incongruent stimuli was poorer than that of participants in the HC group on trials with underweight stimuli that were either congruent (4.56 ± 0.09; $p = 0.002$) or incongruent (4.87 ± 0.07; $p = 0.018$). Along the same lines, participants in the HC group performed more poorly in response to trials in the underweight IC compared to the CC with either underweight ($p < 0.001$) or overweight (4.71 ± 0.11; $p = 0.033$) stimuli. Additionally, performance among HC in the underweight CC differed from their performance in the overweight CC ($p = 0.045$) and IC (4.77 ± 0.09; $p = 0.006$). Interestingly, in both samples, there was no significant effect of congruence in the case of underweight silhouette flankers, suggesting that body images of this type may exert a milder effect as distractors, producing insufficient cognitive interference to impair task performance.

Discussion

The present behavioral study aimed to compare the ability to process cognitive interference and resolve competing responses between a sample of healthy women (the HC group) and patients suffering from anorexia nervosa (the AN group). Two primary results emerged from the investigation. First, participants in the AN group exhibited impaired overall performance in both the Flanker tasks compared to the HC sample, who exhibited greater proficiency in resolving conflicts elicited by body images compared to those elicited by letters. Second, although both the groups were sensitive to the presence of overweight flankers on incongruent trials (that is, these flankers interfered with their processing of an underweight target), the effect was stronger among AN patients. This suggests that the clinical sample might have oriented more cognitive resources towards the overweight body distractors harbor a potential attentional bias that altered conflict resolution.

Conflict and error processing in Anorexia Nervosa (AN)

To handle with representational conflicts and avoiding errors efficiently are two fundamental cognitive skills that allow individuals to control and adjust their goal-directed behaviors under challenging circumstances. In recent years, cognitive and clinical neuroscience have displayed a growing interest in the investigation of the behavioral, neural, and neurophysiological underpinnings of conflict and error processing in clinical populations that typically exhibit deficits in cognitive control, such as obsessive–compulsive disorder, addiction, and Parkinson's Disease (Endrass & Ullsperger, 2014; Luijten et al., 2014; Pezzetta et al., 2021).

In the field of eating disorders, particular attention has been paid to AN, a psychiatric disease characterized by distorted processing of body representation and over-controlled behaviors. Atypicalities of the anterior cingulate cortex have been widely observed in patients with AN, suggesting that dysfunctional activity in this frontal region could represent a plausible neurophysiological marker of their impaired cognitive control (Gaudio et al., 2015; Mühlau et al., 2007; Naruo et al., 2001; Takano et al., 2001; Wierenga et al., 2014). Nevertheless, behavioral paradigms investigating conflict and error processing in AN have produced inconsistent findings. For example, studies using classical flanker tasks with letters or arrows as stimuli have observed that participants with AN exhibit a stronger ability to process cognitive conflict and improved top-down control in comparison to HC samples. On the one hand, Pieters and colleagues (2007) have observed reduced error-related negativity ERN amplitudes among participants with both AN and high trait perfectionism compared to HC participants in a Flanker task with neutral letter stimuli. Despite this apparent impairment in detecting motor–perceptual errors at the neurophysiological level, participants in the AN group also exhibited greater behavioral accuracy in providing correct responses to trials following errors (i.e., better behavioral adjustment) compared to the HC group. This dissociation may arise from the recruitment of other brain regions belonging to the frontoparietal network for the optimization of cognitive control (Pieters et al., 2007). On the other hand, improved top-down processing has also been observed among adolescents with AN in a Flanker task with arrow stimuli (Weinbach et al., 2018). In this case, AN participants have been found to be less affected by the competition between responses elicited by trials with incongruent targets and distractors (i.e., the congruency effect is small) compared to neurotypical participants in a control group, highlighting the improved abilities of AN patients to inhibit task-irrelevant information (Weinbach et al., 2018).

In the present study, in contrast to our hypotheses, we observed that although AN patients performed equally in both versions of the Flanker task administered, they exhibited general impairment in comparison to the HC group in resolving conflicts. Crucially, performance among HC participants revealed that cognitive interference was more readily processed in the BF task compared to the LF task, suggesting a facilitatory effect of body stimuli: that is, these stimuli provided better support for the resolution of conflict compared to letters. This information processing facilitation was absent among participants in the AN group, which can probably be attributed to the distortion of body-related representations underpinning AN symptomatology (Gadsby, 2017) and the impairment in configurational or holistic processing of body stimuli associated with the disorder (Reed et al., 2006; Urgesi et al., 2014). Moreover, it is possible that AN patients were more susceptible to the affective content of body representations, which might have caused their weaker performance in the task involving these. In this case, we cannot exclude the possibility that the under- and overweight silhouettes may have activated an emotional response among participants in the AN group that impacted their conflict processing and contributed to the impairment of conflict resolution.

Corroborating evidence for this interpretation can be found in studies adopting the emotional variant of the classic Stroop task, in which participants are required to identify the color of words that are either emotionally salient (e.g., "slim," "fat," "snack") or neutral (e.g., "car," "pen," "house"). In this type of task, the semantic representational content of the salient words can interfere with the processing of their perceptual features that is required to name the relevant color, thereby impairing behavioral performance. Interestingly, patients with AN of the binge-eating/purging subtype exhibit slower response times when asked to respond to the color of stimuli representing the words "fat" or "thin" compared to meaningless neutral words (Redgrave et al., 2008). A similar pattern of results has been observed among participants with eating disorders in a version of the emotional Stroop task presenting body images ranging from extremely underweight to extremely overweight (Walker et al., 1995). Nevertheless, while some studies involving food- and body-related words have reported impaired performance among participants with AN (Channon et al., 1988; Redgrave et al., 2008), others have found no difference between these participants and the neurotypical population (Dobson et al., 2004; Mendlewicz et al., 2001). Discrepancies between experimental studies, such as differences in recruitment criteria, individual and clinical variability (e.g., sample size, age, AN subtype) may partially explain these heterogeneous results (Dobson & Dozois, 2004; Faunce, 2002). Furthermore, neuroimaging evidence indicates that patients with AN show structural and functional alterations in the extrastriate body area (EBA; Suchan et al., 2010; Uher et al., 2004), a lateral occipito-temporal cortical region specializing in the processing of body-related stimuli (Downing et al., 2001; Gandolfo & Downing, 2019; Moro et al., 2008; Urgesi et al., 2007). Therefore, it is plausible that, in the present study, the activation of body-related representations might have had a facilitatory effect on processing among participants in the HC group as a result of the preserved functional contribution of the EBA. In turn, this may explain this group's better perceptual ability to process body silhouettes compared to AN patients.

Finally, the finding in the present study that participants with AN exhibited impaired general performance in resolving competition between possible responses contrasts with those of previous studies providing evidence for greater top-down control among patients with AN (Pieters et al., 2007; Weinbach et al., 2018). We may speculate that the administration of two tasks (i.e., the LF and BF tasks) relying on processing of stimuli with different perceptual properties (letters vs. bodies) and imposing different response rules (i.e., which key to press) during the same session, despite the logical similarity of the tasks, may have had an impact on conflict processing. As evidence for this possibility, behavioral studies employing paradigms measuring executive functions have reported that AN patients exhibit perseverative errors associated with set-shifting deficits (Galimberti et al., 2012; Roberts et al., 2007; Tchanturia et al., 2012). Therefore, to test this hypothesis in relation to the present study, we conducted several further exploratory analyses (see the supplementary materials). We reasoned that, if set-shifting effects may have occurred and altered participants' conflict processing, we would observe better general performance in the first task completed by any given participant compared to the second, independently of which type of stimuli were presented in it. The results revealed that this was not the case, ruling out the potential role of fatigue in accounting for the observed impairments. Indeed, participants did not exhibit greater ability to resolve conflicting stimuli in either the BF task or the LF task when it was administered first. Moreover, in our study, the rate of error commission did not differ significantly between the two participant samples. This suggests that the impaired performance reflected by the index computed on the basis of the ratio between RTs and accuracy was not influenced by perseverative errors caused by a possible set-shifting effect among participants with AN; instead, it was probably attributable to an altered overall capacity to process rapidly-arising perceptual–motor conflicts.

Attentional bias toward body-related representations

A further behavioral result emerging from the present study highlighted the fact that the strongest cognitive conflict occurred in processing of those stimulus strings in which an underweight target was flanked by overweight distractors. Although the conflict elicited by this stimulus was more pronounced among the participants with AN, performance on this type of trial was also altered among participants in the HC sample. Moreover, the interference found in responding to underweight incongruent targets was boosted by having previously responded to overweight congruent bodies. Interestingly, such an effect resulted associated with variables expressing concerns on body image (see the supplementary materials for more details on the analysis for trial sequence and correlations). Possible interpretations of this pattern may be suggested by the findings of studies investigating attentional bias (i.e., attentional orienting toward salient and emotional stimuli) during processing of body-related features (Cass et al., 2020; Faunce, 2002). It has been shown that exposure to images of overweight bodies may induce gaze avoidance in neurotypical women (Cho et al., 2013) and activation of brain regions involved in emotional regulation, such as the prefrontal cortex and the amygdala (Kurosaki et al., 2006). These results appear to reflect a physiological response to the aversive or negative valence of overweight bodies (Cho et al., 2013; Kurosaki et al., 2006). Several studies have employed a dot-probe task (MacLeod et al., 1986) to examine attentional processing of body-related stimuli more directly. In this paradigm, a probe replaces one of two stimuli that are presented simultaneously on a screen: a salient stimulus (e.g., an image of a body or a body-related word) and a neutral one (e.g., a tree or an object-related word). Participants are required to quickly indicate the location of the probe by pressing the corresponding key; fast responses indicate attentional allocation or bias toward the stimulus matched with the probe. Behavioral evidence from this type of paradigm has indicated that both women who are both dissatisfied with their weight and those who are satisfied with their weight tend to respond more rapidly to probes appearing in the same location as fat-related words, demonstrating selective attention toward overweight body representations (Gao et al., 2011). Similar findings have been obtained among populations with bulimia and AN in paradigms presenting words and images of bodies (Rieger et al., 1998; Shafran et al., 2007). Interestingly, Gilon Mann and colleagues (2018) have observed an attentional bias or avoidance strategy toward weight-related words in a dot-probe task among patients with AN of the restrictive and binge-eating/purging subtypes (Gilon Mann et al., 2018).

Overall, in relation to the findings of the present study, we may speculate that in trials in which the overweight body depictions were presented as flankers, these were likely perceived as threatening stimuli. Consequently, they captured attentional resources, thereby weakening the processing of targets taking the form of underweight bodies and increasing cognitive interference. Moreover, the possible attentional bias toward overweight body representations may have had an impact on trials in the IC in which an overweight target was flanked by underweight distractors. In this case, the bias toward overweight bodies appears to have outweighed the flanker effect. In line with this possibility, no differences were observed between incongruent and congruent trials in which the target was an overweight body image and thus the aforementioned representational interference was absent, suggesting that a facilitatory attentional effect in target processing may have improved conflict resolution in these trials.

Finally, it is necessary to address several limitations of the present study. First, it is possible that the perceptual salience and the semantic and emotional content of the over- and underweight bodies presented as stimuli made distinct contributions to response selection during conflict processing. Future investigations might disentangle these two components by administrating a control Flanker task with conflicting stimuli that are perceptually similar but not body-related (e.g., neutral elliptical shapes presenting a similar wide vs. narrow contrast). Furthermore, the behavioral results obtained from the sample of participants in this study, all of whom had a diagnosis of restrictive AN, might not be generalizable to patients with the binge-eating/purging subtype of AN; thus, further replication studies are needed to compare these two clinical subgroups on their performance, which could shed light on important differences about top-down control mechanisms related to the processing of body representations.

Conclusion

The ability to deal with conflicting representations is fundamental for perception of the external world and in driving goal-directed behaviors. This competence might be impaired in certain clinical conditions, contributing to worsening of symptoms and delays in recovery. Individuals with AN may experience conflict arising from their distorted representation of their own body, resulting in the implementation of excessive self-monitoring and hypercontrolled behaviors. In this study, we attempted to experimentally show a link between conflict processing, and body representation, through the use of a new version of the Flanker task in the form of the Body-Flanker paradigm, in which conflicting stimuli depicting under- and overweight silhouettes are presented. Unlike neurotypical participants, patients with restrictive AN did not show any facilitation of their performance in this Flanker task (compared to a traditional Flanker task with letters) arising from the specific presentation of body-related stimuli, which may have a facilitatory effect in conflict resolution. On this regard, it would be useful to employ neurophysiological measures to investigate altered patterns of electrocortical activity (e.g., N200, ERN, theta oscillations) that may potentially underlie this type of effect in the processing of conflicting body representations. The evidence provided by the present study may inform clinicians of the need to consider the dysfunctional interaction between cognitive control and body image for a better understanding of AN symptomatology and for the development of efficient and targeted treatments. For example, it has recently been reported that the application of transcranial alternating current stimulation (tACS) can modulate electrocortical activity to promote synchronization between distal areas that are implicated in conflict monitoring (e.g., the mediofrontal cortex) and perceptual encoding of body-related stimuli (e.g., the EBA; Fusco et al., 2022a). Similar non-invasive neuromodulation protocols (Fusco et al., 2022b) might have the potential for use in patients with AN as a prospective way to restore dysfunctional oscillatory patterns associated with top-down control and body representation processes.

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Data availability statement The present data will be made publicly available upon request and will be stored at the Department of Psychology, Sapienza University of Rome, Italy.

Declarations

Conflict of interest None.

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