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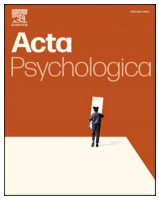

Distorted body representation in adolescent girls with anorexia nervosa

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ABSTRACT

Background: A core symptom of anorexia nervosa (AN) is a distorted body representation. AN often has an onset in puberty. Therefore, it is pivotal to gain a better understanding of these distortions in adolescents with AN. This study aimed to capture the multidimensional perspective of body representation and investigate to what extent adolescent girls with AN differ from adolescent girls without AN on five domains of body representation, namely bodily cognitions and attitudes, body checking and body avoidant behaviors, visual perception, tactile perception, and affordance perception.

Methods: Thirty-one adolescent girls with AN and 33 without AN (aged 14–18 years) were included in this study. Body representation was measured using questionnaires (Body Attitude Test, Body Appreciation Scale-2, and Body Checking and Avoidant Questionnaire) and experimental tasks (visual, tactile, and affordance estimation tasks).

Results: Findings demonstrated a difference on all domains of body representation; adolescent girls with AN self-reported to experience more negative cognitions and attitudes toward their bodies, self-reported to engage in more body checking and body avoidant behaviors, and showed higher percentages of visual, tactile, and affordance overestimation compared to adolescent girls without AN.

Conclusions: Adolescent girls with AN appear to have a more severely distorted body representation when compared to adolescent girls without AN, and may benefit from intensifying body-oriented interventions.

1. Introduction

Anorexia nervosa (AN) is a severe mental disorder that typically starts developing during adolescence or young adulthood (Campbell & Peebles, 2014; Herpertz-Dahlmann, 2009). A key feature of AN is a distorted experience of one's own body size, shape, and weight (American Psychiatric Association, 2013). The disturbed experience of body size in AN is central to the disorder. Individuals with AN have an incorrect notion of their body's weight and shape which is also represented in an overestimation of their body size (e.g., Glashouwer et al., 2019; Sattler et al., 2020). This is often referred to as a body image disturbance or as a disturbance in body representation that includes bodily cognitions and attitudes, body checking and avoidant behavior, visual perception, tactile perception, and affordance perception of the own body (Farrell et al., 2005; Gaudio & Quattrocchi, 2012).

The way in which individuals with AN perceive and experience their body size has been linked to a worse prognosis (Boehm et al., 2016) and higher levels of relapse (Carter et al., 2004). Moreover, the incidence rate of AN among 10- to 14-year-old girls has increased significantly over four decades while in other age groups the incidence rate remained stable (van Eeden et al., 2023). Therefore, investigating the adolescent AN population seems crucial as it will provide clinically relevant information on the distorted body representation in this group. Yet even though a distorted body representation is considered a core symptom of AN, studies researching the full spectrum of body representation relevant to adolescent girls with AN within the same sample have not yet been carried out. The main aim of this paper is therefore to provide a systematic investigation within a number of domains of body

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representation in adolescent girls with AN in comparison with adolescent girls without AN.

The concept body representation is widely used in the field of neuropsychology and cognitive neuroscience (for an overview of different theoretical approaches and definitions see e.g., de Vignemont, 2010, Moseley et al., 2012; Vallar, 2024). The definition of body representation that we adopt in the current paper is that body representation refers to the internal model, or blueprint, of the body that is stored in the brain. The brain continuously receives multimodal information about the body (e.g., perceptual experiences that are triggered when the body is touched or while moving through a room full of obstacles). All this (abstract) information is processed and then stored in the body representation. As such, the body representation contains a wealth of body-related information and is by definition multisensory in nature (de Vignemont, 2010; de Vignemont, 2018; Gallagher, 2005; Haggard & Wolpert, 2005). Information stored in the body representation is for instance related to where the body is located in space, knowledge regarding the body, but also to how the body looks, and to where the skin is touched (e.g., de Vignemont, 2018).

In relation to AN, it is hypothesized that especially metric information (i.e., information related to the size and shape of the body) in the body representation is disturbed, and that this affects behavior at several levels (e.g., cognitive-affective, visual perception, tactile perception, and affordance perception) (Keizer & Engel, 2022). Indeed, previous work with adult women with AN show altered performance in tasks and experiments in which metric information from the body representation is assumed to play a role: they overestimate their body on visual and tactile body size estimation tasks, and, they demonstrate a disturbance in the way they plan and execute a movement of the body (affordance perception) in comparison to women without AN (Cash & Deagle, 1997; Guardia et al., 2012; Keizer et al., 2013: Metral et al., 2014; Spitoni et al., 2015; Waldman et al., 2013). It is important to mention here that patients with AN do not show a distortion on all aspects of body perception. Specifically, aspects of body representation that are *not* related to metric information about body size have been found to be comparable in healthy adult women and adult women with AN (e.g., object-related multisensory integration measured with a size weight illusion; Engel et al., 2022). A recent review (Brizzi et al., 2023) showed that individuals with AN appear to exhibit abnormalities in the ability to combine inputs from different sensory domains. They further suggested this incapacity may be associated with an inability to integrate sensory information from multiple domains into a coherent percept. In the past decade, research in adult women has been fruitful and insightful as findings indeed underline the clinical observations of patients describing feelings of being fat and fear of weight gain despite their low body weight, estimating their body size in a way that is consistent with their false percept of a wider body. Additionally, results from a study by Engel and Keizer (2017) revealed the existence of overestimations of body size in adult women, even after recovery from AN. These findings suggest that current treatment programs for AN may require a stronger focus on targeting a disturbed body representation.

Remarkably, research on the full scope of disturbed body representation in adolescent girls with AN is still limited. Although a recent review by Sattler et al. (2020) provided a solid and comprehensible study overview, this review also demonstrated that most studies have mainly focused on only two domains of body representation: the cognitive-affective domain (what do adolescent girls think about their body), and the visual perception domain (how do they visually perceive their body size). Research that includes investigating other domains of body representation, such as body checking (e.g., measuring the size of their thighs with their hand) and body avoidant behavior (e.g., wearing dark, muted clothing to detract attention from their figure), tactile percept (how they estimate the distance between two tactile stimuli presented on their skin), and affordance percept (how they perceive the possibility to interact with one's environment) within the same sample has not yet been carried out in adolescent girls with AN. Addressing this gap in knowledge on these five domains of body representation may provide a more comprehensive insight in the nature of a distorted body representation in adolescent girls with AN.

Among researchers and clinicians, there is indeed consensus that bodily cognitions and attitudes are strongly affected in adolescents with AN (Bauer et al., 2017; Brown et al., 2021; Legenbauer et al., 2013; Sattler et al., 2020). In contrast, body checking and body avoidant behaviors in adolescent girls with AN are still an understudied topic within the field of body representation. Only few studies reported higher levels of body checking in adolescent girls with AN when compared to adolescent girls without AN (Brown et al., 2021; for a review see Sattler et al., 2020). Studies on body avoidant behavior in adolescents with AN are lacking. Although one could argue that these body related behaviors are not body representations in themselves but rather stem from (distorted) body representations, they may impact body representations (Möllmann et al., 2024). Cognitive behavioral models suggest that body checking and body avoidance may serve as safety behaviors (Fairburn et al., 1999), reducing anxiety and distress in the short-term but worsening body image and eating behaviors in the long run (Bailey & Waller, 2017). Furthermore, dysfunctional body-related checking and avoidance may also contribute to the maintenance of a distorted body representation as it prevents positive and corrective body-related experiences (Shafran et al., 2004).

Visual perception, tactile perception, and affordance perception are often grouped together under the umbrella term of perceptual body representation. Several studies on the visual perception domain of body representation have indeed shown that adolescents with AN visually overestimate their body size (Boehm et al., 2016; Brown et al., 2021; Castro et al., 2004; Dalhoff et al., 2019; Sattler et al., 2020). However, studies show that investigating only the visual perception may be too limited in demonstrating the full scope of the distorted perceptual body representation (e.g., Keizer & Engel, 2022). Including tactile perception and affordance perception may further advance our understanding of a distorted body representation in adolescent girls with AN.

Regarding tactile perception, previous work often used tactile size estimation tasks (Keizer et al., 2011; Spitoni et al., 2015). In such tasks individuals are instructed to estimate the distance between two tactile stimuli presented on their skin. Tactile information is initially processed by the somatosensory cortex and because of difference in tactile receptor density between body parts, this results in highly distorted somatotopic maps. Accurate tactile distance estimations therefore require subsequent rescaling using metric information about the physical size of body parts from the stored body representation (see e.g., Longo et al., 2010; Taylor-Clarke et al., 2004). If the metric representation of the body part that is touched is disturbed, this could result into abnormal performance when estimating the distance between two tactile stimuli presented on the skin. In adult women with AN, it was found that individuals indeed overestimated the distance presented on the skin when compared to control subjects (Hasenack et al., 2021; Keizer et al., 2011; Risso et al., 2020; Spitoni et al., 2015). This finding supports the notion that the disturbance in body representation in AN takes the shape of an overweight and wider body (Gadsby, 2017).

Affordance perception is described as perceiving the possibility to interact with one's environment (Gibson, 1979) and is assessed by investigating motor planning and bodily action (body–scaled action). In order to move our body safely through the environment, our brain must have access to up to date information on for instance the exact location of our body but also to a highly accurate metric representation of the size of our body (Gibson, 1979; Warren & Whang, 1987). Generally, people are able to move around seemingly effortlessly in the external world, without bumping into obstacles. However, several studies report an abnormal affordance perception in adult women with AN, suggesting that they move their body as if it were larger than their current body size, either in reality (Keizer et al., 2013), or imagined and anticipated (Guardia et al., 2010).

To summarize, no previous studies have yet looked at a full range of a

disturbed body representation within the same sample of adolescent girls with AN. The current research sought to fill this gap in knowledge. Specifically, in the present study we systematically investigated the entire spectrum of body representation in adolescent girls with AN and compared their results to those of girls without AN. We will specifically assess five domains of body representation: bodily cognitions and attitudes, body checking and body avoidant behaviors, visual perception of body size, tactile perception, and affordance perception. Following previous findings of studies on bodily cognitions and attitudes and body checking, and body avoiding, we expected adolescent girls with AN to have more negative bodily cognitions and attitudes, and more dysfunctional body checking and body avoidant behaviors, relative to adolescent girls without AN (Brown et al., 2021; Dion et al., 2015; Legenbauer et al., 2013). Following previous findings regarding body size and affordance perception in adolescents with AN (only visual body size: Boehm et al., 2016; Dalhoff et al., 2019; Sattler et al., 2020) and studies in adults with AN (e.g., Hasenack et al., 2021; Spitoni et al., 2015), we hypothesized that adolescent girls with AN showed a larger percentage of overestimation on visual perception of body size, tactile distance perception, and affordance perception.

2. Methods

2.1. Participants and procedure

Thirty-one adolescent girls with AN and 33 adolescent girls without AN between the ages of 14 and 18 participated in the study. Before participating, participants were fully informed about the procedure and were given the opportunity to ask questions about the study. Participants who then signed the informed consent form were enrolled in the study. Participants younger than 16 years old were required to have their parents sign the informed consent form as well. Furthermore, participants received a gift voucher of €10 at the end of the study. This study was approved by the Medical Ethical Committee of Utrecht (METC NL72565.041.20) and by the Committee Scientific Research of Altrecht Mental Health Institution (CWO 2121).

All AN patients were recruited from Altrecht Eating Disorders Rintveld in Zeist. Here, AN patients were receiving eating disorder treatment at the time of the experiment (e.g., Family Based Treatment; Lock & Le Grange, 2013). All patients met the diagnostic criteria of AN (Diagnostic and Statistical Manual of Mental Disorders-5th ed., APA, 2013). Adolescent girls without AN (control subjects) were recruited through a Dutch secondary school in Utrecht. In line with our exclusion criteria, control subjects were required not to self-report any eating disorder pathology at the time of recruitment. Before scheduling the experiment, control subjects were asked to complete The *Eating Disorder Examination Questionnaire* (EDE-Q; Fairburn & Cooper, 1993). The EDE-Q is widely used and is considered a so called golden standard for assessing eating disorder pathology. The clinical cut off score of the EDE-Q is 4.00 (Rø et al., 2015). Importantly, this questionnaire was only used to screen control subjects for possible symptoms of eating disorder pathology. If the participants scored below the cutoff score, the experiment was conducted. In this study, none of the participants scored above this clinical cut off point. As the data was only used as a screen tool, the collected data of the EDE-Q was not used in the statistical analyses of this study. Besides this exclusion criterium for the control subjects we also had several exclusion criteria for all participants such as any conditions that affect the ability to hear and/or see and any conditions that influence the task performance.

There was no significant difference between the age of AN patients ($M = 16.07$, $SD = 1.23$) and control subjects ($M = 15.97$, $SD = 1.19$), $t(56) = -0.23$, $p = .822$ (see Table 1). AN patients had a significantly lower body mass index (BMI) than control subjects, $t(62)$ -0.4.75, $p < .001$. The average BMI in adolescents with AN was 17.51 ($SD = 2.68$), placing the BMI-for-age at the 10th percentile, just within the range of a healthy weight (below the fifth percentile is indicative for underweight; https://www.cdc.gov). BMI of the patient group is relatively high, which is likely caused by the fact that all patients were undergoing treatment aimed at weight restoration at the time of testing. Moreover, previous work has shown that in AN patients BMI is independent of the severity of body representation disturbances (Keizer et al., 2011). In individuals who have recovered from AN, body representation disturbances were still present (Engel & Keizer, 2017), even though these individuals were weight restored. The average BMI in adolescents without AN was 21.22 ($SD = 0.50$), placing the BMI-for-age at the 58th percentile which also falls within the range of a healthy weight. Furthermore, a significant difference was found between the AN group and the control subjects regarding the scores on both the EDI-2 ($t(58.18) = 10.53$, $p < .001$; Garner, 1991), and the DASS-21 (Lovibond and Lovibond, 1995; $t(56) = 11.23$, $p < .001$). Both measurements are indicative for a clinical description of the population (García-Grau et al., 2010; Szabó, 2010). Both scales demonstrated a Cronbach's alpha of 0.98, which indicates an excellent reliability.

Table 1
Means and standard deviations of demographic and clinical characteristics.

	AN ($N = 31$)		HC ($N = 33$)	
	M	*SD*	*M*	*SD*
Age	16.07	1.23	15.97	1.19
BMI	17.51	2.68	21.22	3.50
Age of onset	13.89	1.66	–	–
Duration of illness (months)	11.89	16.06	–	–
EDI-2	247.79	40.18	140.25	39.44
DASS-21	56.26	11.17	26.84	8.76

Note. BMI = Body Mass Index; DASS-21 = Depression Anxiety and Stress; EDI-2 = Eating Disorder Inventory.

2.2. Procedure and measures

The experiment started with the Visual Estimation Task (adapted from Keizer et al., 2013), the Tactile Estimation Task (adapted from Keizer et al., 2011), and the Hoop Task (adapted from Keizer et al., 2019). At the end of the experiment actual width of the shoulders, waist, and hips was measured. The height and weight of the control subjects were also recorded, to confirm that they had a healthy weight. For AN patients information on height and weight was obtained from their electronic patient file. The questionnaires were completed via an online platform (*Qualtrics*), participants completed the surveys in their own time but within 3 days after the experiment.

2.2.1. Bodily cognitions and attitude questionnaires

Positive attitudes toward the body were assessed using the *Body Appreciation Scale* (BAS-2; Tylka & Wood-Barcalow, 2015). This questionnaire consists of ten items (e.g., "I feel that my body has at least a few good qualities") to which participants respond on a 5-point Likert scale, ranging from 1 (*never*) to 5 (*always*). A higher total score on the BAS-2 reflects a more positive body attitude.

Negative body attitudes were assessed with the Body Attitude Test (BAT; Probst et al., 1995). The BAT consists of 20 questions (e.g., "I have a strong desire to be thinner") that are scored on a 6-point Likert scale ranging from 0 (*never*) to 5 (*always*). A high total score on the BAT is indicative of a stronger negative body attitude. An example item of the negative appreciation subscale of body size is "Some parts of my body look swollen." An example item of the lack of familiarity with one's own body subscale is "My body appears to be numb object." An example item of the general dissatisfaction subscale is "I envy others for their physical appearance." Both the BAS and BAT have been shown to be reliable and valid (Probst et al., 1995; Tylka & Wood-Barcalow, 2015). In the present study, both the BAS-2 ($\alpha = 0.98$) and the BAT ($\alpha = 0.95$), had an excellent internal consistency. The subscales of the BAT, negative appreciation of body size, lack of familiarity with one's own body, and

general dissatisfaction demonstrated a Cronbach's alpha between 0.93 and 0.95, indicating an excellent reliability.

2.2.2. Body checking and body avoidance questionnaire

The *Body Checking and Avoidance Questionnaire* (BCAQ; Legenbauer et al., 2017) is a 30-item questionnaire to measure eating-disorder-related psychopathological forms of body checking, body avoidance, and reassurance seeking behaviors on three subscales. An example of an item of the body checking subscale is "I assess whether I can reach around my wrists and ankles with one hand." An example of an item of the body avoidance subscale is "I don't wear any clothing which show my feminine curves, e.g., jeans or tight tops." Items are rated on a 4-point Likert scale ranging from 1 (*not at all true*) to 4 (*very true*). Higher scores are indicative for more body checking and body avoidant behavior. In the present study, the BCAQ had an excellent internal consistency ($\alpha = 0.97$). The subscales of the BCAQ, body checking and body avoidance, respectively showed a Cronbach's alpha of 0.96 and 0.93, indicating an excellent reliability.

2.2.3. Visual estimation task

In the *Visual Estimation Task* (VET; adapted from Keizer et al., 2013), participants were asked to indicate the width of their shoulders, abdomen, and hips by placing two adhesive markers on a white wall. They did this once for every body part. Participants were not allowed to look at themselves while placing the markers. After the markers were placed, the participant looked away while the distance between the markers was measured. The order in which the different body parts had to be estimated was counterbalanced between participants. The difference between the subjective width estimation and actual width was used to calculate a misestimation percentage for each body part. An average misestimation score was subsequently computed for each of the body parts separately. A positive score is regarded an overestimation whereas a negative score is considered an underestimation.

2.2.4. Tactile estimation task

We measured tactile perception using the *Tactile Estimation Task* (TET; adapted from Keizer et al., 2011). Participants had to estimate the distance between two tactile stimuli. These stimuli were presented with a caliper on the abdomen (horizontally) and arm (vertically). The distance between the two tactile stimuli varied between 50 mm, 60 mm, and 70 mm. Each distance was presented five times on each body part. Thus, in total, participants completed fifteen trials on the arm (emotionally neutral body part) and fifteen trials on the abdomen (emotionally salient body part). The order of these trials within each body part was randomized. Participants had to keep their eyes closed during this task. After each trial, they were asked to indicate the distance between the two tactile stimuli by separating their thumb and index finger on a touchscreen tablet. Each distance estimation was recorded with a MATLAB-based program. The average percentage of misestimation was calculated for the arm and abdomen separately, using the difference between the estimation and actual distance. A positive score is regarded an overestimation whereas a negative score is an underestimation. The present sample has a Cronbach's alpha of 0.96 on the arm and a Cronbach's alpha of 0.96 on the abdomen, indicating an excellent reliability for each trial.

2.2.5. Hoop task

We measured affordance perception using the *Hoop Task* (adapted from Keizer et al., 2019), participants were presented with fifteen different hoops. Each hoop differed in size (ranging from 24 cm to 52 cm with 2 cm increments) and each hoop was presented to the participants three times in a randomized order. Participants had to turn around after the presentation of each hoop, preventing them to see the researcher taking away the previous hoop and putting the following on the ground. For each hoop, the participants had to make an estimation whether they could fit through the hoop. If participants estimated that it was possible, they had to step inside the hoop and pull the hoop over their heads. When in doubt about whether the hoop would fit, participants were not allowed to try the hoop. The choices made by the participants were recorded, and the smallest hoop through which they estimated would fit was calculated. After completing all trials, the researcher assessed what the smallest hoop was that the participants could actually fit through. Based on the difference between the estimated and actual smallest hoop size through which they could fit, the percentage of misestimation was calculated. A higher positive percentage was indicative for a higher overestimation.

2.3. Statistical analyses

For analyzing the data, IBM SPSS Statistics version 28 (IBM Corp., 2021) was used. An a-priori sample size power calculation was carried out, using G*Power (Faul et al., 2009). The calculation was based on performing a mixed repeated measures ANOVA, as the means of two groups would be compared. We based the effect size *f* on the mean body image disturbance results we found in our previous study (Keizer et al., 2016) as this study included similar tasks measuring domains of body representation in adults with AN. In order to obtain a power of 0.95, with alpha set at 0.05, and *f* at 0.333 (Keizer et al., 2016), a total of 34 participants was required (17 in each group) to detect a statistically significant effect. Furthermore, a power calculation was performed to estimate the required number of participants needed for post hoc analyses in order to break down the interaction effect. The power calculation for independent samples *t*-test was based on an anticipated large effect size (Keizer et al., 2011), an alpha level of 0.05, and a desired power of 0.8. The results of this calculation indicated a required number of 52 participants, 26 for each group. To ensure adequate power, we aimed to recruit 30 participants per group.

Subsequently, we assessed whether AN patients and control subjects differed in task performance on bodily attitudes and cognitions, self-reported bodily behaviors, visual perception, tactile perception, and affordance perception. Firstly, independent *t*-tests were used to analyze differences between the AN group and the control subjects on the BAT, BAS-2, and the BCAQ.). Secondly, a 2×3 repeated measures ANOVA with group (AN and control subjects) versus body part (shoulders, waist, and hips) was carried out for the Visual Estimation Task. Subsequently, a 2×2 repeated measures ANOVA with group (AN and control subjects) versus body part (arm and abdomen) was used for the Tactile Estimation Task. Post hoc analyses consisted of independent *t*-tests with Bonferroni correction for the for the percentage of misestimation on the Visual Estimation Task and the Tactile Estimation Task Lastly, independent *t*-tests were used to examine differences between the AN group and the control subjects on the Hoop Task (affordance estimation task). Hedges' *g* will be reported as a measure of effect size (small = 0.2, medium = 0.5, large = 0.8; Hedges, 1981). The alpha level was set at $p < .05$ and p – values between 0.05 and 0.10 were denoted as marginally significant.

3. Results

3.1. Bodily Cognitions and Attitude Questionnaires

Adolescent girls with AN reported a significantly higher score ($M = 71.72$., $SD = 17.83$) on the total scale of the BAT than control subjects ($M = 18.19$, $SD = 9.76$), $t(42.760) = 14.29$, $p < .001$), in line with our hypothesis in which we expected that adolescent girls without AN would report a stronger negative attitude toward their body. The effect size was $g = 1.72$, indicating a large effect.

Additionally, adolescent girls with AN reported a significantly lower score ($M = 17.43$, $SD = 6.65$) on the BAS-2 than control subjects ($M = 40.56$, $SD = 5.33$), $t(58) = -14.95$, $p < .001$, in line with our hypothesis in which we expected that adolescent girls without AN would report a stronger positive attitude toward their body. The effect size was $g = 3.87$, indicating a large effect.

3.2. Body Checking and Avoidance Questionnaire

Furthermore, adolescent girls with AN reported a significantly higher score ($M = 2.50$, $SD = 0.56$) on the BCAQ than control subjects ($M = 1.32$, $SD = 0.24$), $t(36.075) = 10.31$, $p < .001$, in line with our hypothesis in which we expected that adolescent girls without AN would self-reported significantly higher levels of both body checking and avoidant behavior. The effect size was $g = 2.77$, indicating a large effect.

Taken together, and in line with our hypotheses, these results show that adolescent girls with AN demonstrate higher scores on the BAT (measuring negative attitude toward their bodies) and show higher scores on the BCAQ (measuring body checking and body avoidant behavior) when compared to adolescent girls without AN.

3.3. Visual estimation task

Percentages of misestimations of width of shoulders, waist, and hips were compared between groups. A 2 × 3 repeated measures ANOVA with group (AN and control subjects) and body part (shoulders, waist, and hips) showed a significant main effect for body part $F(1, 9) = 67.54$, $p < .001$ and a significant main effect for group $F(1, 62) = 15.04$, $p < .001$. Furthermore, a trend toward an interaction effect between group and body part was found $F(1.9) = 3.09$, $p = .053$. Post hoc Bonferroni-corrected independent sample t-tests showed that adolescent girls with AN reported a larger percentage of misestimation on the shoulders, $t(62) = 3.07$, $p = .003$, $g = 0.77$, indicating a large effect. A larger percentage of misestimation on the waist was also found in adolescent girls with AN, $t(62) = 4.28$, $p < .001$, $g = 1.07$, indicating a large effect. The misestimation percentage of the hips did not differ between adolescent girls with and without AN, $t(62) = 2.36$, $p = .07$ (See Fig. 1). Adolescent girls with AN had a mean percentage of misestimation for shoulders of 7.65 ($SD = 22.57$), for waist of 43.37 ($SD = 29.20$), and for hips of 18.38 ($SD = 27.38$). Adolescent girls without AN showed a mean percentage for shoulders of −9.44 ($SD = 21.94$), for waist of 17.11 ($SD = 19.13$), and for hips of 5.16 ($SD = 16.40$).

* $p < .05$.

In summary, in line with our hypothesis, the results from the Visual Estimation Task demonstrated differences between girls with AN and those without AN. Adolescent girls with AN showed higher percentages of overestimation on the size of their shoulders and the waist, but not of the width of their hips, when compared to adolescent girls without AN.

3.4. Tactile estimation task

A 2 × 2 repeated measures ANOVA with group (AN and control subjects) and body part (arm and abdomen) showed a no main effect for body part $F(1, 53) = 0.12$, $p = .73$, but a significant main effect for group was found, $F(1, 53) = 6.49$, $p = .01$, indicating that AN patients overestimate tactile distances on their arms with a mean percentage of 11.02 ($SD = 31.41$) and on their abdomen with a mean percentage of 10.89 ($SD = 29.27$), compared to control subjects. Adolescent girls without AN had a mean percentage of misestimation on their arm of −3.02 ($SD = 21.39$) and on their abdomen of = −5.28 ($SD = 19.12$). The effect size for arm was $g = 0.52$ and the effect size for abdomen was $g = 0.67$. Both effect sizes indicate a medium effect. The interaction between group and body part was not significant, $F(1, 53) = 1.32$, $p = .26$. Taken together and in line with our hypothesis, when compared to control subjects, adolescent girls with AN showed an overestimation of the distance between two tactile stimuli, independent of which body part was tested.

3.5. Affordance estimation task

An independent sample t-test was carried out and showed that adolescent girls with AN reported a larger affordance misestimation percentage on the Hoop Task when compared to HC, $t(35.27) = 5.32$, $p < .001$. The effect size was $g = 1.37$, indicating a large effect. These findings suggest that adolescent girls with AN demonstrate a larger mean percentage of misestimation of 22.97 ($SD = 4.13$) for affordance perception when compared to the mean percentage of −0.42 ($SD = 1.23$) of adolescent girls without AN, which was in line with our hypothesis.

4. Discussion

The current study aimed to systematically investigate multiple domains of body representation in adolescent girls with AN and compare findings to those in adolescent girls without AN. To the best of our knowledge, we are the first to assess body representation in five different domains within the same sample of adolescent girls, namely bodily cognitions and attitudes, self-reported body checking and body avoidant behaviors, visual perception, tactile perception, and affordance perception. It was hypothesized that adolescent girls with AN would self-report stronger negative bodily cognitions and attitudes, report more body checking and body avoidant behavior, show higher percentages of visual, tactile, and affordance overestimations when compared to adolescent girls without AN.

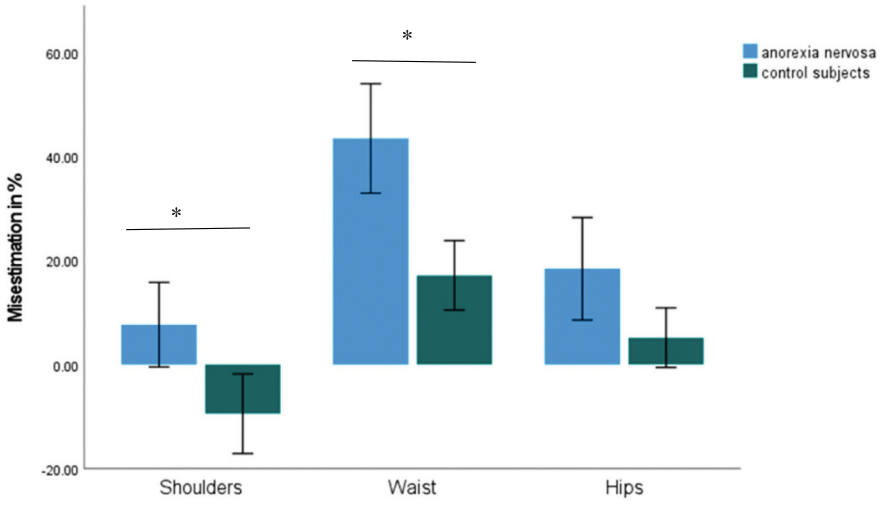

Fig. 1. Percentage of misestimations of shoulders, waist, and hips by adolescent girls with anorexia nervosa and control subjects.
Note. Percentage of misestimations of shoulder -, waist -, and hip width by adolescent girls with anorexia nervosa group and control subjects. Error bars depict SD.

A key finding of the present study is a distorted body representation in adolescent girls with AN in *all* investigated domains. In general, findings were in line with previous research in adult AN patients (e.g., Engel & Keizer, 2017; Hasenack et al., 2021; Spitoni et al., 2015; Waldman et al., 2013) and in adolescent AN patients (e.g., Boehm et al., 2016; Brown et al., 2021). As hypothesized, we indeed found higher levels of negative bodily cognitions and attitudes and higher levels of self-reported body checking and body avoidant behavior compared to adolescent girls without AN. In line with our hypotheses on the perceptual domain of body representation, results showed that adolescent girls with AN visually perceived their body as bigger than it actually is. These findings are in line with previous work in adolescents with AN by Boehm et al. (2016) and Dalhoff et al. (2019). Moreover, for the first time we showed that this group also demonstrated a larger overestimation of the distance between two tactile stimuli touching their skin, similar to previous findings in adults with AN (Keizer et al., 2012; Spitoni et al., 2015). Lastly, adolescent girls with AN demonstrated a larger percentage of misestimation for affordance perception when compared to adolescent girls without AN. The current study is first in showing a disturbed body representation within the full spectrum that is relevant to adolescent girls with AN. In other words, oversized bodily experiences in adolescents with AN are not only limited to thinking that they are fat, they also feel fatter than they actually are. They even literally feel touch on their body as bigger and they estimate their body size and what this affords them to do in a way that is consistent with their false percept of a wider body.

Compared to adolescent girls without AN, patients with AN scored significantly higher on the BAT (Probst et al., 1995) and lower on the BAS-2 (Tylka & Wood-Barcalow, 2015), suggesting higher levels of negative body attitudes on the one hand and lower positive body attitudes on the other. These findings add to a large body of evidence demonstrating that bodily cognitions and attitudes are indeed strongly affected in both adolescents and adults with AN (e.g., Bijsterbosch et al., 2021; Brown et al., 2021; Hasenack et al., 2021; Legenbauer et al., 2013). In addition, findings of the present study show that adolescent girls with AN frequently engage in dysfunctional body-related behaviors. Levels of both body checking and body avoidance were significantly higher in adolescents with AN compared to those without AN. The reported levels were in line with a recent study in adult women (Bijsterbosch et al., 2022). Although it is still undecided whether the behavioral domain could be regarded part of body representation (Möllmann et al., 2024), it is generally accepted that these behavioral manifestations of the overevaluation of weight and shape are potential etiological and maintenance factors in eating disorder pathology (Fairburn et al., 1999). These behaviors seem to hold an anxiolytic function (Mountford et al., 2006). As such, they may prevent positive and corrective body-related experiences (Shafran et al., 2004). These corrective experiences may in turn contribute to a general impairment of updating the actual body size information in their body representation after for example significant weight loss.

Findings on the visual perceptual domain of body representation revealed a significant difference between adolescent girls with AN and those without AN. Adolescents in the AN group demonstrated a significantly larger overestimation on their shoulders and waist when compared to adolescent girls without AN. These results are in line with previous findings in both adolescents and adults (Boehm et al., 2016; Brown et al., 2021; Castro et al., 2004; Engel & Keizer, 2017; Gila et al., 1998; Hasenack et al., 2021; Sattler et al., 2020). However, findings on the size estimation of the hips revealed a marginally significant difference between both groups. Possible, estimating the actual width of the hips is more challenging to adolescent girls *in general* as developmental changes to this particular body part may contribute these challenges. Nevertheless, this finding may also result from the smaller sample size and needs further replication. Notably, a direct comparison between findings of other studies is rather complicated as measuring the domain of visual percept is rarely carried out using the same methods (see Keizer & Engel, 2022). Nonetheless, findings of the present study contribute to the notion that in general adolescent girls with AN show a larger percentage of visual overestimation of their body (parts) when compared to adolescent girls without AN.

Findings on tactile and affordance perception represent a novel addition to the work on body representations in adolescent girls with AN. The tactile estimation task demonstrated significant differences at a group level; adolescent girls with AN overestimated the size of tactile distances on both their arm and their abdomen when compared to control subjects. These results suggest that the metric representation of a touched body part is disturbed which may reflect that the size of the touched body part is bigger in the mental representation of the body than in reality. This finding is line with previous studies in adults with AN (Keizer et al., 2011; Risso et al., 2020; Spitoni et al., 2015), suggesting a more generalized trend that AN patients perceive all aspects of the body as wider. Although tactile distance estimations have been used previously as a measure of metric body representation in clinical groups (Hasenack et al., 2021; Keizer et al., 2011), results have not yet been conclusive. Current results are in contrast with findings of other studies among adults with AN (Engel & Keizer, 2017; Engel et al., 2020), who did not find differences in tactile estimation between AN and control subjects.

Regarding affordance perception, adolescent girls with AN showed a larger percentage of overestimation on the hoop task when compared to adolescent girls without AN. In other words, adolescent girls with AN demonstrated greater difficulties estimating whether their body would fit through a specifically sized hoop and stopped stepping into a larger sized hoop although they would easily fit through. This contrasted with findings in adolescent girls without AN, who were capable of making almost correct estimations. Results were in line with a previous study in adult women with AN (Hasenack et al., 2021). Interestingly, in an anticipated body scale study by Guardia et al. (2010), participants were instructed to imagine themselves walking through an aperture. The study showed a positive correlation between the passability ratio (i.e., the critical aperture size to shoulder width ratio) and the duration of illness was found. The greater the passability ratio, the longer the period since onset of AN. Patients with a duration of illness of 10 years demonstrated the largest percentage of overestimation. They suggested that the passability ratio is particularly affected in long-duration of AN. The authors explained this by suggesting that AN patients possibly did not update the actual body size information in their body representation since the rapid weight loss at the onset of the illness. The current results do not seem to fit this line of reasoning. We studied a sample of adolescent girls, reporting an average duration of illness of only 12 months (in contrast to an illness duration of 10 years) and still found a significant overestimation. It should however be noted here that the task we used is different from that of Guardia et al. (2010). In our study participants received direct feedback on whether a hoop would fit around their body, if they reported that they thought that they would fit through the hoop. For hoops that they judged to be too small for their body, they did not receive this feedback. An important suggestion for future research is therefore to be consistent in giving feedback on whether participants fit through the hoops, this should either be done in each trial or in none of the trials.

Taken together, the results of the present study show a significant difference in how the body is experienced within a clinical and a non-clinical group of adolescent girls. Findings may at least indicate that adolescent girls with AN appear to exhibit abnormalities in the ability to combine inputs from multimodal information about the body within their mental body representation (e.g., Brizzi et al., 2023; Keizer & Engel, 2022). However, at this point it is still unclear what causes a distorted body representation in adolescent girls with AN and how perceptual body representations function (Gadsby, 2019). On the one hand, one could suggest that possibly these distortions are already present and slowly start emerging during the onset of AN. On the other hand, other processes may have an increasing impact on body

representation, particularly during adolescence. Generally, adolescence is known as a high-risk developmental period for the emergence and exacerbation of anxiety symptoms (Beesdo-Baum & Knappe, 2012). Individuals with predisposing trait of anxiety tend to feel easily overwhelmed which may exacerbate the experience of the changing body throughout adolescence. Furthermore, AN is characterized by the experience of very high levels of anxiety (e.g., Pallister & Waller, 2008).

An anxiety- related process specifically relevant for these pubertal bodily changes may be intolerance of uncertainty (IU), which is a personality characteristic common to adolescents with AN (Bijsterbosch et al., 2021; Frank et al., 2012; Sternheim et al., 2024). Those high in IU experience distress in face of uncertainty (Carleton et al., 2007). Puberty is acknowledged as a pivotal period in the development of a positive or a more negative way of experiencing (biological driven) changes of your body. Uncertainty about these bodily changes is inherent to the pubertal transition of the female body. For example, adolescent girls may wonder what their adult body will look like, or they may question what is expected from them when they grow breasts. These feelings of uncertainty may provoke high levels of anxiety and may explain why although all girls go through puberty, only few of them ultimately develop a severely distorted body representation that is characteristic of AN. Preliminary findings confirm that anxiety and difficulties tolerating uncertainty are indeed involved in several domains of body representation in AN patients (Bijsterbosch et al., 2021; Frank et al., 2012; Hasenack et al., 2021; Øverås et al., 2014). A better understanding of these anxiety related processes in relation to the experience of the body may advance our comprehension of the complex nature of a distorted body representation in adolescents with AN.

The present results have potential implications for clinical practice. Current treatment options for adolescents with AN are mostly restricted to psychotherapeutic treatments (so called “talk therapies”), either a family oriented approach (i.e., family-based therapy; Le Grange et al., 1992), or a version Cognitive-Behavioral Therapy (CBT-E) that is specifically designed for adolescents and their caregivers (Fairburn et al., 2008). These interventions mainly target cognitions (using words) and are not designed to specifically target a distorted body representation (using the (enlarged) metric body representation). Although there is some evidence of the effectiveness of these specific psychotherapeutic treatments, relapse rate of AN remains very high (Herpertz-Dahlmann, 2017) and after recovery the body representation often remains (partly) disturbed (Engel & Keizer, 2017). Moreover, research has shown that a distortion in the perceptual domain of body representation predicts long-term outcome in adolescent AN patients (Boehm et al., 2016) and it hampers recovery (Castro et al., 2004; Sala et al., 2012). Developing add-on body-oriented interventions with a stronger focus on the (enlarged) metric body representation specifically for adolescents with AN may be a particularly important next step. Potentially, body-oriented treatments that include addressing the perceptual component may tap into a more sustainable method of improving a distorted body representation and may help to ultimately shorten duration of illness as well as preventing relapse in adolescent girls with AN.

The present research benefitted from several strengths such as a first systematic study into five different domains of body representation in a group of adolescent girls with AN, in comparison to a healthy control group. Specifically, the use of three different but related tasks to measure percept is a solid addition to the scarcity of adolescent studies on AN and body representation. Nevertheless, an important limitation of the present study needs to be addressed regarding the small sample size and the cross sectional study design. The small sample size may limit the generalizability to a larger population and results should be interpreted with caution. Future research may focus on investigating larger samples of adolescent girls with AN in order to test the replicability of the present results. Furthermore, longitudinal studies are required to carefully investigate the development of body representation over time in both clinical and non-clinical studies, especially within adolescence.

In sum, the current study adds to the scarcity in research of several domains of body representation in adolescent girls with AN and replicates previous work in adults with AN showing that they self-report more negative cognitions and attitudes toward their bodies, self-report engaging in more bodily behaviors (checking and avoidance), and overestimate their body size in experimental tasks that focus on these various perceptual domains of body representation when compared to adolescent girls without AN. Developing add-on body-oriented interventions that include a stronger focus on the perceptual domains of body representation, alongside existing treatment programs for adolescent girls with AN may be a fruitful and important next step. Moreover, this study provides a stepping-stone for the continuing disentanglement of body representation and may lead to a better understanding of a distorted body representation in adolescent girls with AN. Furthermore, we believe that examining anxiety related processes (e.g., IU) in relation to a distorted body representation may advance our understanding of the complex nature of body representation within puberty.

CRediT authorship contribution statement

Jojanneke M. Bijsterbosch: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lot C. Sternheim:** Writing – review & editing, Supervision. **Paul A. Boelen:** Writing – review & editing, Supervision. **Unna N. Danner:** Resources. **Caya H. van Eikenhorst:** Resources, Project administration. **H. Chris Dijkerman:** Writing – review & editing, Supervision, Conceptualization. **Anouk Keizer:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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