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ORIGINAL ARTICLE

Evidence for a perceptual mechanism relating body size misperception and eating disorder symptoms

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Abstract

Purpose There are known and serious health risks associated with extreme body weights, including the development of eating disorders. Body size misperceptions are particularly evident in individuals with eating disorders, compared to healthy controls. The present research investigated whether serial dependence, a recently discovered bias in body size judgement, is associated with eating disorder symptomatology. We additionally examined whether this bias operates on holistic body representations or whether it works by distorting specific visual features.

Methods A correlational analysis was used to examine the association between serial dependence and eating disorder symptomatology. We used a within-subjects experimental design to investigate the holistic nature of this misperception. Participants were 63 young women, who judged the size of upright and inverted female body images using a visual analogue scale and then completed the Eating Disorder Examination-Questionnaire (EDE-Q) to assess eating disorder symptoms.

Results Our findings provide the first evidence of an association between serial dependence and eating disorder symptoms, with significant and positive correlations between body size misperception owing to serial dependence and EDE-Q scores, when controlling for Body Mass Index. Furthermore, we reveal that serial dependence is consistent with distortion of local visual features.

Conclusions Findings are discussed in relation to the broader theories of central coherence, cognitive inflexibility, and multisensory integration difficulties, and as providing a candidate mechanism for body size misperception in an eating disorder population.

Level of evidence Level 1, experimental study.

Keywords Eating disorder symptoms · Serial dependence · Body inversion effect · Cognitive inflexibility

Introduction

Excess body fat is associated with a higher risk of developing coronary artery disease [1], type 2 diabetes [2], and stroke [3]. Conversely, impaired bone health [4], pubertal delay [5], and risk to fertility [6] are among the adverse consequences of very low body weight, a core feature of anorexia nervosa [7]. Despite the significance of weight as a potential marker of health, perception of body size is not always veridical. Research has shown that individuals often misperceive their own and others' physical body shape and weight [8–10]. This can make it difficult for individuals to effectively recognise weight gain or loss in themselves and others, which may in turn contribute to delayed action or help seeking to modify weight-related health behaviours.

Behavioural, cognitive, affective, and perceptual processes are commonly implicated in body image disturbance [11]. Behavioural research highlights the impact of bodily avoidance, among other behaviours, which contribute to body image disturbance [12]. Cognitive components (e.g., distorted thought patterns) are hypothesised to play a causal role in these behavioural manifestations [12]. Additionally, some research suggest that differences in affective processes (such as attitudinal factors regarding one's body weight

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[13]), contribute to body image disturbance, while others emphasise the influence of perceptual biases. Our research focuses on the visual–perceptual causes of body size misperceptions. However, it is important to note that perceptual impairments in body perception may also be non-visual (e.g., tactile and proprioceptive) and complex, encompassing multisensory processes [11].

With regard to perceptual biases, prolonged exposure to visual stimuli can distort the appearance of subsequently viewed, visually related stimuli. This is known as an adaptation aftereffect and adaptation-induced biases in perceived body size have been repeatedly demonstrated [9, 14–16]. A second form of bias in body size judgment can arise due to regression to the mean, whereby judgements of magnitude are biased toward the mean of a set [17]. Cornelissen et al. [8] have demonstrated regression to the mean in body size estimation.

Recently, a third type of bias known as serial dependence was reported in body size estimation [10]. Serial dependence is said to occur when errors in perceptual judgements are consistent with the assimilation of features of a previously viewed stimulus with the current stimulus [10, 18]. That is, judgements are biased toward prior experience. In the context of body size, serial dependencies cause a body to be perceived as smaller when preceded by a smaller body and larger when preceded by a larger body [10]. This assimilation is thought to facilitate the temporal continuity of perception [18]. Serial dependence differs from adaptation in that it occurs in rapid moment-to-moment judgments and the direction of perceptual bias, towards the prior stimulus, is the opposite of adaptation. Serial dependence occurs for a large number of visual processes, including those subserving judgments of visual number [19, 20], line orientation [18], face gender [21], identity [22] and attractiveness [23] and also body size [10].

While these perceptual sources of bias have been shown to influence the body size estimations of healthy individuals, individuals with eating and weight disorders have been found to display larger misperceptions [24]. Preliminary evidence has shown these individuals to exhibit altered patterns of body adaptation [24]. However, the question of whether serial dependence biases are associated with eating and weight disorders has not been explored. A novel bodyline task was recently developed by Alexi et al. [10]. The bodyline task can be used to measure both regression to the mean and serial dependencies, in body size estimation [10]. Using this task, the primary goal of the current study was to investigate whether serial dependence is associated with eating disorder symptoms.

In addition to assessing the relevance of serial dependence to eating disorder symptoms, we investigated whether body size biases due to serial dependence can be trivially explained as distortions of a simple visual cue such as horizontal body width, or alternatively, are distortions of holistic body representations. Here, the term 'holistic' infers that the bodies have been integrated and processed as a whole, as opposed to being processed as a series of individual features. Recent research demonstrates that holistic processes contribute to body size adaptation effects [25] but the contribution of holistic body-selective processes in serial dependence is yet to be examined.

Past neurobiological methods have revealed that the fusiform body area (FBA) and the extrastriate body area (EBA) are the two main areas of the brain which are involved in holistically processing human bodies [26]. However, one behavioural method that can be used to examine whether biases in body size estimation involve such high-level holistic processes is to test for an inversion effect (i.e., a change in bias magnitude due to inverting a stimulus). Inversion effects have been presented as strong evidence for holistic coding of faces, including facial identity [27] and expression [28]. Pertinent to our study, inversion effects have been observed for body posture judgments, implying a holistic representation of body posture [29]. Finding a difference in body size misperception for an inverted versus upright body would be strong evidence that the bias occurs higher in the visual hierarchy, at the level of holistic processing. Conversely, finding no inversion effect would imply the bias is underpinned by distortion of discrete features processed in early, low-level perceptual areas. This represents the second goal of the current study. If body size misperceptions due to serial dependence involve holistic body-selective areas of the brain, then we would expect to find inversion effects for bias magnitude.

To summarise, the current study tested for an association between eating disorder symptomatology and bias in body size estimation due to serial dependence. Given previous findings that individuals with eating disorders experience greater body size misperception, we would expect a positive association between the magnitude of serial dependence bias and eating-disorder symptomatology. In addition, we investigated whether an inversion effect occurs for serial dependence in body size judgements. If the magnitude of serial dependence differs for upright and inverted stimuli it would be strong evidence that this bias involves high-level holistic body-selective visual processes.

Methods

Participants

A young adult female sample was chosen as eating disorder prevalence is most common in this demographic [30]. Sixty-three young women took part in the current research. One participant's data were removed as they did not follow the instructions of the bodyline task. This left 62 participants aged between 17 and 25 years (*M* 20.55, SD 1.94). Participant Body Mass Index (BMI kg/m^2) ranged from 16.95 to 30.32 (*M* 22.16, SD 3.20). Eating Disorder Examination-Questionnaire (EDE-Q) scores ranged from 0 to 4.44 (*M* 1.68, SD 1.12).

Participants received course credit for participating or recruiting volunteers. All participants gave written informed consent. The study was approved by the University of Western Australia's Human Research Ethics Committee and performed in accordance with their guidelines, rules, and regulations.

Materials

The experiment was completed on an Asus PC running Matlab [31] and the Psychophysics-Toolbox [32]. The experiment was presented on a Viewpixx display, resolution of 1920 × 1080 and an average luminance of 50.4 cd/m^2. Viewing distance from the computer display was 870 mm. Data were analysed using SPSS and GraphPad Prism. Stimuli were 35 real female body images (6.5° × 6.5°), representing seven discrete categories that ranged from extremely thin to extremely large. The stimuli used in the current study were drawn directly from previous research [10] and a full description can be found in that article. Each of the body images were presented at 20% of their full contrast. A visual noise mask (measuring 11° x 11°), comprised of various pixels from each of the female body images was also implemented. The visual noise mask was presented to diminish visual persistence of the image.

Eating Disorder Examination-Questionnaire

The EDE-Q 6.0 is a well-validated self-report questionnaire version of the widely used Eating Disorder Examination, which is an interview-based assessment for eating disorder symptoms [33]. The EDE-Q consists of 28 items in total; 22 of the items examine the attitudinal components of eating disorder symptomatology [34]. These 22 items form the subscales of dietary restraint (5 items), eating concern (5 items), weight concern (5 items), and shape concern (8 items). These items all focus on the preceding 28 days and participants respond to these items using a seven-point, forced-choice, Likert rating scale (0 = complete absence of feature to 6 = acute presentation of feature) [34]. The remaining six items measure the frequency of engagement in eating disorder behaviours and were not included in the present study. The Cronbach's alphas for the EDE-Q in the present sample were 0.70 (dietary restraint), 0.80 (eating concern), 0.83 (weight concern), 0.89 (shape concern), and 0.94 (total EDE-Q).

Procedure

Each participant completed the experimental task in a quiet room, and were seated facing a computer screen, keyboard, and mouse. All participants completed two experimental conditions of the bodyline task: one of which required participants to judge a set of upright female bodies, and the second of which required participants to judge the same set of body images presented to them in an inverted format (Fig. 1).

Participants were instructed to judge the perceived size of the body images by left-clicking the mouse along an

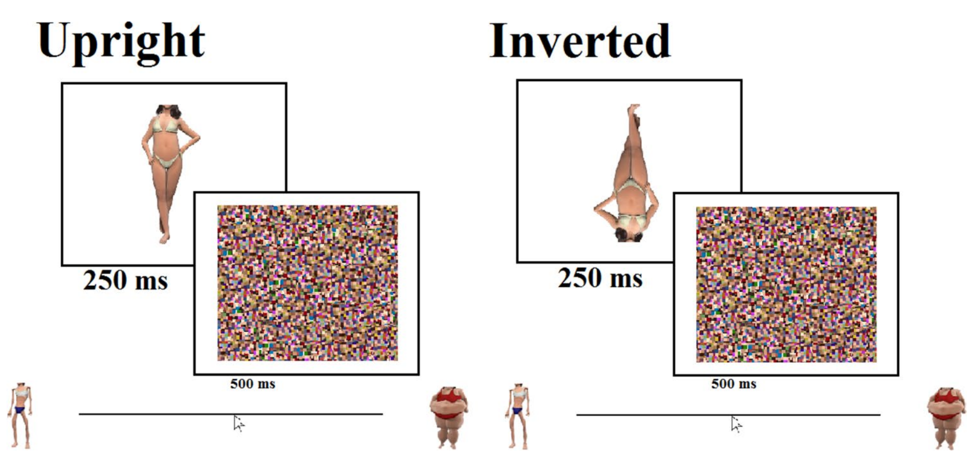

Fig. 1 An example of the bodyline task, whereby images of female bodies were presented for 250 ms, subsequently followed by a visual noise mask for 500 ms. Participants were instructed to indicate the perceived size of the body image by left-clicking along the bodyline which depicted extreme female bodies as anchors at each end, beyond the scale. The anchors were more extreme in size than any of the body images presented throughout the task. The bodyline was continuously displayed throughout the experiment. For illustration purposes this figure was created using synthetic body images created in Poser® [35]

unmarked visual analogue scale (scored as 1.0–7.0), known as the bodyline [10]. On each trial, a female body image was presented for 250 ms and was followed immediately by a visual noise mask for 500 ms.

The starting condition was randomised and counterbalanced. Half of the participants completed the upright experimental condition followed by the inverted experimental condition, and vice versa for the remaining half. In both conditions, participants completed 14 practice trials, where they were presented with the full spectrum of images (categories 1–7) twice. Participants were then also informed that the anchors (displaced from each end of the VAS) were smaller and larger than any of the images they would see during the experiment. Following the practice trials, participants completed 3 blocks of 50 trials. Presentation order was fixed across all participants to ensure that within each block of 50 trials, each body size category both preceded and followed each other's category, including its own. Following completion of both upright and inverted conditions, participants completed the EDE-Q. Lastly, participants' height and weight were measured to calculate BMI.

Results

The results below are separated into three main components. We firstly report on the data screening and outlier removal process. Next, we present the data showing serial dependence (Fig. 2) for the upright and inverted conditions. In doing so, we also present the data relating to our secondary aim, whether an inversion effect occurs for body size judgements in serial dependence. We then examine our primary question, are the magnitudes of this bias associated with eating disorder symptoms, as measured using the EDE-Q?

Data cleaning

Data were assessed for outliers, using the criterion of skew < |2.00| and kurtosis < |7.00| [36]. Additionally, variables were examined according to the outlier criterion of three standard deviations above and below the mean [37]. BMI consisted of two outliers using the latter criterion that were subsequently winsorised [38]. All other variables were within normal limits.

Serial dependence biases in body size judgements

We report the magnitudes of serial dependence in body size estimation for the upright and inverted conditions separately (see Fig. 2). Serial dependence was calculated as per the methodologies outlined by Alexi et al. [10]. To summarise, in Fig. 2, biases in size judgment (vertical axis) are plotted as a function of the relative size of the previously viewed body (horizontal axis). Location zero (i.e., zero on both axes) acts as the comparison condition since here the previous body was the same size as the current body, and thus no bias was predicted. Data falling along the horizontal dotted line would be consistent with veridical or unbiased perception. Instead, the data from both the upright and inverted conditions were consistent with serial dependence, whereby participants were biased by previously viewed body images. The direction of the bias was toward previously seen bodies. Specifically, the lower left quadrant of Fig. 2 reveals that participants were biased to see body images as smaller when preceded by a smaller body and vice versa in the top right quadrant. This bias was strongest when the size change from trial to trial was small-to-moderate (± 2 or 3), and the bias is all but abolished for larger trial-to-trial body size differences. The data were well fitted by a Kalman-filter model as per previous findings [10], $R^2 = 0.61$ and 0.68, respectively, for upright and inverted. This model allowed us to estimate and compare the bias magnitude in each condition. While there was a trend for a larger magnitude of serial dependence in the inverted condition, this difference was not significant [$F(2, 5824) = 2.00$, $p = 0.14$]. Thus, there was no strong evidence of an inversion effect in serial dependence and consequently, no real indication that serial dependence in body size estimation involves holistic body-selective processes.

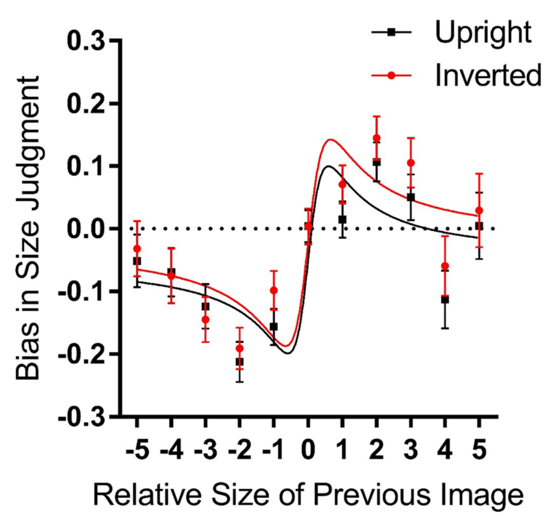

Fig. 2 Serial dependence in body size judgements, plotted for upright and inverted conditions. Data display the average biases in the perceived size (comprised of the difference between perceived and actual size), as a function of the size difference of the body on the preceding trial. Error bars show ± 1 SEM. The curved solid black and red lines represent the prediction of the Kalman-filter model for the upright and inverted conditions. The Kalman-filter model used here has been outlined in a previous study [10]. The horizontal black dotted line shows veridical or unbiased perception

Are serial dependencies related to eating disorder symptoms?

Having demonstrated the presence of serial dependence in our data, we now turn to our primary question, is there is an association between eating disorder symptomatology, measured using global EDE-Q scores and the magnitude of body size misperception, due to serial dependence? To estimate individual serial dependence magnitudes, we simply took the slope of a linear regression fitted to each participant's data, in each condition. To control for the effects of BMI on eating disorder symptomatology, partial correlations are reported.

Results revealed small-to-moderately sized significant positive correlations between EDE-Q scores, and the magnitude of serial dependence in the upright [$r(59) = 0.28$, $p < 0.05$] and inverted [$r(59) = 0.36$, $p < 0.01$] conditions (see Fig. 3). These results, the first evaluation of serial dependencies in perception in any clinically relevant context, reveal that participants with higher eating disorder symptomatology experience greater body size misperceptions relating to serial dependence.

Discussion

There were two main goals of the current research. Our primary aim was to examine the association between eating disorder symptomatology and body size misperceptions due to serial dependence. Our secondary aim was to test whether an inversion effect occurs in serial dependence in body size judgements. We discuss the findings of our research in the order of our analyses.

Our data were consistent with previous reports of serial dependence in body size judgements [10], allowing us to

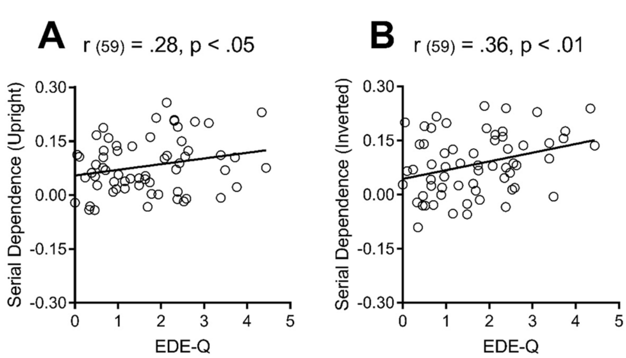

Fig. 3 Scatterplots depicting the correlations between EDE-Q scores and serial dependence. **a, b** Depict the correlation between EDE-Q scores and upright and inverted serial-dependence variables, respectively. As can be seen, significant small-to-moderate correlations were found between EDE-Q scores and serial dependence in both conditions

address our research questions. With regard to the involvement of holistic processing in serial dependence, we did not find an inversion effect for serial dependence bias in body size estimation, suggesting that serial dependencies may be a low-level form of perceptual bias occurring prior to holistic integration. This conclusion is supported by recent fMRI findings [39] which suggested serial dependence occurs within the primary visual cortex. Overall then, we conclude that the distortion of specific visual features, such as hip width, can explain serial dependence in body size estimation.

Our main goal, however, was to examine the association between eating disorder symptomatology and body size misperceptions due to serial dependence. Our data revealed that eating disorder symptoms were significantly and positively associated with serial dependence. These results demonstrate that participants with higher levels of eating disorder symptomatology experienced greater body size misperceptions. These findings extend previous research showing that perceptual adaptation differs in those with a diagnosed eating disorder [24] by demonstrating a second perceptual process that contributes to clinically relevant biases in body size perception. Finally, it is worth noting that our bias correctly predicts the overestimations of body size seen in those with an eating disorder [40]. Since those with anorexia would predominantly see other individuals who have a heavier body size, a serial dependence bias may cause them to misperceive their own body size as appearing larger than it physically is, as the literature shows.

One speculative explanation for finding a correlation with a low- rather than a high-level perceptual bias is that those at risk of developing an eating disorder tend toward processing bodies in a 'piecemeal' manner, in line with the weak central coherence theory of superior local than global processing [41]. There is emerging research supporting this view [42]. Urgesi et al. [42] examined individuals with anorexia nervosa and found them to have deficient holistic processing for bodies. They proposed that this was related to their perceptual style, which is known to involve obsessive attention to detail of body parts and body size [42]. Furthermore, a meta-analysis [41] which examined weak central coherence in individuals with anorexia nervosa concluded that they displayed a superior processing of local information and inefficient processing of global information, compared to healthy controls. Our reports of a correlation between a perceptual bias driven by discrete visual features and eating disorder symptomatology, accords with that view.

Another way of considering our findings is in relation to a cognitive framework. Serial dependence occurs due to the incorporation of past information into our current percept. Individuals with larger serial dependence biases can be thought of as overusing past information, to the detriment of perceptual accuracy. This is loosely consistent with the framework of cognitive inflexibility [43]. Cognitive inflexibility is a well-studied neuropsychological construct that is defined by a deficit in the ability to switch between tasks or concepts and a difficulty in adapting when unexpected changes arise [43]. Larger serial dependence magnitude in individuals with higher eating disorder symptomatology may be reflective of a perceptual inflexibility to update body size information and minimise past experience. Previous research has revealed that poor central coherence and cognitive inflexibility are prevalent thinking styles in anorexia nervosa [43, 44]. Our findings appear to be consistent with this body of literature and lead us to suggest that the neuropsychological deficit of cognitive inflexibility may also be present in the mechanisms of perception.

Alternatively, our results could be interpreted within the context of multisensory body integration. Multisensory body integration has been defined as a process involving the synthesis of sensory processes (e.g., vision and touch) with internal modalities (e.g., interoception), which are then influenced by conceptual (e.g., meaning ascribed to one's body), perceptual (e.g., size of one's body), and episodic (e.g., autobiographical events associated with the experience of one's body) memories [45]. Multisensory integrative processes lead to the emergence of 'bodily self-consciousness' and bodily awareness [45]. Within this view, it has been hypothesised that an impairment in multisensory body integration may lead to deficits in the ability to update bodily information [46] (for a review, see: [45]). While our study involved only one sensory modality, it seems plausible that our results could reflect multisensory integration difficulties in individuals with elevated eating disorder symptoms. Accordingly, future research would benefit from examining the nature of the relationship between cognitive inflexibility, multisensory integration, and serial dependence biases in body size estimation. In turn, this may help to elucidate which of the two processes, cognitive inflexibility or deficient multisensory integration, better aligns with our reported findings.

It should be noted that our study entailed a community sample. Investigating body size misperception due to serial dependence in those with diagnosed eating disorders is therefore warranted. Another potential shortcoming of our study is that it involved the use of two-dimensional images of female bodies. It is of course pertinent to extend our findings to more ecologically valid stimuli, be they avatar-based or involving real world settings.

In summary, the present findings provide the first evidence of a relationship between a perceptual mechanism of body size misperception, serial dependence, and eating disorder symptomatology. This association appears to reflect both, a detail-oriented perceptual style and difficulty in updating, by those with higher eating disorder symptomatology. As outlined above, our findings may prove useful in helping to understand the causes of body size misperception in eating disorder populations. Finally, our findings lead to testable predictions about a possible relationship between cognitive inflexibility, weak central coherence and serial dependence in individuals at risk of developing an eating disorder.

Acknowledgements JA and JB designed the study. Testing and data collection were performed by JA. JA and JB analysed the data and drafted the manuscript. JA, JB, RP, and ER provided critical revisions and approved the final manuscript for submission.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest. Furthermore, there are no competing financial interests.

Ethical approval This research was approved by the University of Western Australia's Human Research Ethics Committee and performed in accordance with their guidelines, rules, and regulations.

Informed consent Informed written consent was obtained from all individual participants included in the study.

Data availability The datasets created and analysed during the current research are available from the corresponding author on reasonable request.

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