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Spatial orientation constancy is impaired in anorexia nervosa ☆

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ABSTRACT

In anorexia nervosa (AN), body distortions have been associated with parietal cortex (PC) dysfunction. The PC is also the anatomical substrate of a supramodal reference framework involved in spatial orientation constancy. Given the impaired spatial orientation constancy found in hemineglect, we sought to determine whether similar disturbances could be observed in anorexic patients. We investigated the effect of passive lateral body inclination on the tactile subjective vertical (SV). Fifty participants (25 AN patients and 25 healthy controls) were asked to manually set a rod into the vertical position under three postural conditions. For tilted conditions, we observed a significant deviation of the tactile SV towards the body. This effect was abnormally accentuated in AN patients and might be caused by higher weighting with respect to the egocentric frame of reference. Our findings reinforce the role of the PC in AN and suggest that this dysfunction affects spatial orientation constancy as well as body boundaries.

1. Introduction

Patients with anorexia nervosa (AN) very frequently report that they feel larger and fatter than they really are. This alteration in body representation is thus a major, troublesome, clinical symptom of AN (APA, 1994) and can counteract the benefits of therapy by increasing the obsessive will to lose weight and thus maintaining restrictive eating behaviors (Heilbrun and Friedberg, 1990). However, the notion of body representation is not unique and at least two types have been proposed: the body schema and the body image (De Vignemont, 2010). Even though most research to date has tended to emphasize the aesthetical/emotional components of body representation (i.e. the body image), some researchers (Grunwald et al., 2002; Guardia et al., 2010; Nico et al., 2010) have also suggested that the sensorimotor representation of the body which initiates and guides actions (i.e. the body schema) could be disturbed in AN. It has been suggested that the body schema distortion in AN is related to dysfunction of the parietal cortex (PC), since this cortical lobe has a role in the establishment of a coherent body schema (Daprati et al., 2010).

For instance, the AN patients in Grunwald et al.'s (2002) experiment had to manually adjust a bar (without visual feedback) into a parallel position relative to a reference bar sensed by the other hand. The difference between the results for the right and left hands was interpreted by the authors as evidencing dysfunction of the right parietal cortex. In the experiment by Nico et al. (2010), anorexics underestimated their left body-boundary in the same way as hemineglect patients with right parietal lobe lesions did. The task involved anticipating when an approaching light beam would hit the body.

Even though the PC is viewed as the locus of the body schema, it is also considered to be the anatomical substrate of a supramodal frame of reference involved in spatial orientation constancy (Kerkhoff, 1999; Funk et al., 2010). Spatial orientation constancy is defined as the central nervous system's capability to maintain the sense of gravitational, vertical orientation (i.e. the sense of verticality) despite inclination of the body and/or the visual context (Howard, 1982). Funk et al. (2010) recently tested spatial orientation constancy in hemineglect patients suffering from right parietal lesions. Participants had to adjust a bar into the vertical or horizontal position with visual or tactile modalities and with the head vertical, left roll-tilted or right roll-tilted. It is well known that in darkness, head and/or body tilts cause the subjective vertical (SV) to deviate in healthy controls (Howard, 1982; Luyat et al., 2001; Luyat and Gentaz, 2002). Whereas A-effects (deviations of the SV towards the axis of the head) are observed in vision and large tilts, E-effects (deviations of the SV away from the axis of the head) are usually found with tactile adjustments (Bauermeister et al., 1964; Luyat et al., 2001; Bortolami et al., 2006; Gentaz et al., 2008). In Funk et al.'s (2010) experiment, the hemineglect patients showed strong A-effects after left roll-tilting of the head. The A-effect was also more pronounced under tactile modality and was interpreted by the authors as an abnormal weighting towards an egocentric frame of reference (such as the

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idiotropic vector; Mittelstaedt, 1983), due to impaired processing of gravitational information in AN.

Given the PC's involvement in spatial orientation constancy, the objective of the present research was to determine whether spatial orientation constancy could be also affected in AN. We expected to find similar disturbances in AN to those observed in Funk et al.'s experiment with hemineglect patients. Such a finding would emphasize the role of the PC in AN and suggest that PC dysfunction affects not only body boundary representation but also the importance given to the body as a frame of reference.

2. Method

2.1. Participants

Twenty-five women with AN participated in the study (mean ± S.D. age: 24.3 ± 6.4). The diagnosis was made after at least 1 year of AN and in accordance with the DSM IV criteria (APA, 1994). Patients with the following comorbidities were excluded from the study: bulimia, anxiety and mood disorder, psychotic disorder and substance abuse. The mean time since onset of AN was 5.3 ± 4.8 years. The mean body mass index (BMI) was 15.14 ± 1.5. Fifty-six percent ($n = 14$) of the patients had restrictive-type AN and 44% ($n = 11$) had mixed-type AN.

The control group consisted of 25 women (mean age: 23.04 ± 5.98) and did not differ significantly from the AN group in terms of age and educational level. The mean BMI was 21 ± 1.99. The presence of a DSM IV Axis 1 disorder led to exclusion of the study. Clinical examination and interview performed by medical staff did not reveal any attentional or intellectual impairments. Participants with a history of neurological or vestibular problems or those taking psychotropic medication at the time of the study were excluded. Each participant received a study information sheet and signed an informed consent form. Parental consent was required for juvenile subjects. The study was approved by a regional independent ethics committee.

2.2. Procedure

The Body Shape Questionnaire (BSQ; Cooper et al., 1987) and the Eating Disorder Inventory-2 (EDI-2; Garner, 1991) were used to evaluate psychological and behavioral features related to eating disorders. For the SV task, the material consisted of a rod pivoting around an axis on a circular metal plate. The rod was connected to a potentiometer which measured the angle (in degrees) from the gravitational vertical with a sensitivity of ± 1%. The task required the participant to manually adjust the rod to the gravitational vertical (0°) with either the right or the left hand but in the absence of visual feedback. Three postural conditions were tested: sitting upright (0°), body roll-tilted to the left (−90°) and body roll-tilted to the right (+90°). In body roll-tilted conditions, the participant is lying on her side. Six trials were performed in each condition. The rod's initial position was +45° and −45° from the vertical alternatively. Likewise, the six experimental conditions were presented to the participants in pseudorandom order. For each trial, the absolute deviation from the gravitational vertical was noted. By convention, deviations to the participant's left (rod turned counter-clockwise from 0°) were counted as negative and deviations to the right (clockwise rotations) were counted as positive. In order to determine the value of the tactile SV in each postural condition, the mean errors (in degrees) over the six trials were computed for each postural condition. In order to compare the precision of the adjustment in the two groups, the individual standard deviation was also computed over the six trials and in each experimental condition.

2.3. Statistical analysis

All analyses were performed with Statistica 7.1 software (Statsoft Inc., 2007). Demographical and clinical data were studied with non-parametric Mann–Whitney and Spearman tests, given that both non-normal distributions and non-homogenous intergroup variances were observed. The respective influences of group, posture and hand used were studied in an analysis of variance (ANOVA). The validity of the tests' conditions of application was also determined. The variance–covariance matrices were not spherical ($P<0.1$ in a Mauchly test) and so a Greenhouse–Geisser correction was applied.

3. Results

Demographical and clinical data are reported in Table 1. As expected, there was no significant difference between the two groups in terms of age ($U = 278$; $Z = 0.669$; $P = 0.503$) or educational level ($U = 296.5$; $Z = 0.31$; $P = 0.756$). The BMI was significantly lower in the AN group ($U = 0.5$; $Z = -6.054$; $P<0.001$). The overall EDI-2 scores were significantly higher in the patient group ($\text{median}_{AN} = 109$, $\text{median}_C = 22$; $U = 5.5$; $Z = 5.957$; $P<0.001$). The BSQ scores were also significantly higher in the patient group ($\text{median}_{AN} = 136$, $\text{median}_C = 67$; $U = 40.5$; $Z = 5.277$; $P<0.001$).

Table 1
Demographical and clinical data from the anorexia nervosa and control groups.

	Anorexia nervosa ($n = 25$) Mean (S.D.)	Control ($n = 25$) Mean (S.D.)	$P^{(*)}$
Age	24.3 (6.4)	23.04 (5.98)	0.503
Educational level	3 (2.2)	2.56 (2.55)	0.756
Height (cm)	166.7 (5.9)	166.7 (4.82)	0.919
Weight (kg)	42.2 (5.7)	58.56 (7.67)	<0.001
BMI (kg/m^2)	15.14 (1.52)	21 (1.99)	<0.001
BSQ	135.12 (34.8)	71.4 (16.281)	<0.001
EDI-2 total	110.76 (38.68)	25 (14.393)	<0.001

Educational level: number of years in full-time education, after the high school leaving examination; BMI: Body Mass Index; BSQ: Body Shape Questionnaire; EDI-2: Eating Disorder Inventory second version; (*) according to a Mann–Whitney U test.

The results of the SV task are summarized in Table 2. An ANOVA on the mean absolute errors was performed, with repeated measures on both *body orientation* and *hand* and with *group* as a categorical predictor. This analysis revealed a significant effect of body position [$F(2,96) = 25.637$; $P_{G\text{-}G}<0.001$]. Compared with the upright posture ($M_{0°} \pm \text{S.D.} = 0.87° \pm 0.32$), the SV in tilted positions deviated towards the body axis ($M_{-90°} = -4.80° \pm 1.38$ and $M_{+90°} = 6.38° \pm 1.05$). The interaction between *group* and *body orientation* was also significant: $F(2.96) = 5.208$; $P_{G\text{-}G} = 0.018$ (see Fig. 1). In the upright posture, the difference between the two groups' performances was not significant [$F(1,48) = 0.618$; $P = 0.435$]. In contrast, the deviations of the SV towards the body axis (in both left- and right-tilted positions) were significantly more pronounced in AN patients [$F_{-90°}(1,48) = 4.559$; $P = 0.038$ and $F_{+90°}(1,48) = 3.657$; $P = 0.061$, respectively]. The analysis did not reveal any other significant factors or interactions. Moreover, a similar ANOVA performed on the intra-individual precision of the adjustments (individual standard deviations) revealed neither a significant effect of *group* factor nor an interaction between *group* and the other factors (all $P>0.25$). In AN group, a Spearman correlational analysis showed a significant negative correlation between the EDI-2 subscale “interoceptive awareness” and performance in tilted position ($r = -0.493$; $t_{25} = -2.717$; $P = 0.012$). Analysis did not reveal significant correlation between behavioral data and others EDI-2 subscales, BSQ or anthropometric data such as BMI (all $P>0.1$, n.s.).

4. Discussion

We determined whether spatial orientation constancy was disturbed in AN patients (compared with healthy control participants) in a task involving the manual adjustment of a rod to the vertical when the body was upright and when it was tilted. In both groups, the tactile

Table 2
Deviation of the subjective vertical (mean constant error (M) and standard deviation in degrees) under each experimental condition.

	Anorexia nervosa ($n = 25$)		Control ($n = 25$)	
	M	S.D.	*M*	S.D.
Body upright 0°				
• Right hand	0.62	3.15	−0.96	2.92
• Left hand	1.62	3.29	2.19	2.73
Body tilted +90°				
• Right hand	7.89	8.59	4.10	8.49
• Left hand	8.89	10.56	4.63	8.57
Body tilted −90°				
• Right hand	−7.80	10.42	−1.35	10.74
• Left hand	−7.70	9.17	−2.33	12.59

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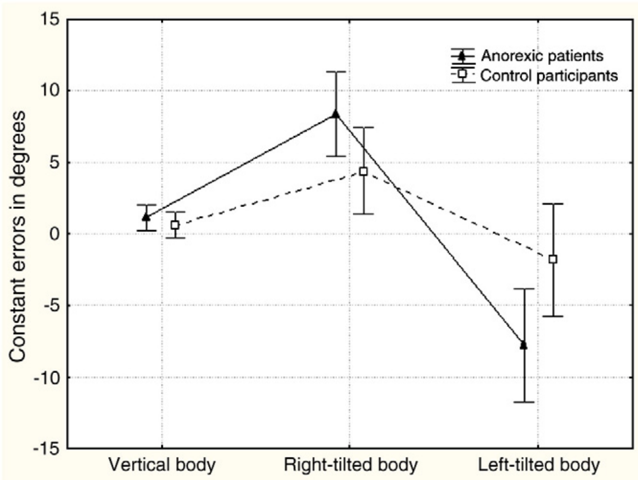

Fig. 1. Deviation of the subjective vertical (mean constant errors in degrees) as a function of the participant group (anorexic patients versus healthy controls) and body orientation.

SV measured in the upright position was very close to the gravitational vertical. However, tilting the body led to significant deviations of the tactile SV. In contrast to the E-effect found in previous studies when the SV was estimated with tactile adjustments only (Bauermeister et al., 1964; Luyat et al., 2001; Bortolami et al., 2006; Gentaz et al., 2008), we observed a slight but significant A-effect in the control group. This could be due to methodological factors. It is noteworthy that only young women participated in our experiment — in contrast to previous studies in which male participants were usually tested. Hence, a gender effect cannot be ruled out. Other methodological factors (such as the length of the bar or a use of tilted chair versus the body lying on a tilted surface) may also be involved.

Our findings indicated that the A-effect yielded by a body tilt was abnormally high in the AN patients, whereas no difference between the two groups was observed in an upright condition. Our hypothesis is supported by the fact that the disturbances in spatial orientation constancy evidenced here in AN patients were very similar to those observed in Funk et al.'s (2010) experiment on hemineglect patients. Moreover, the AN patients' impairment was not related to less precise adjustments, since there was no significant inter-group difference in individual standard deviations (i.e. the intra-individual variability of adjustment). It is well-known that the A-effect is also subjected to large interindividual differences (Kaptein and Van Gisbergen, 2004) as evidenced here by the obtained standard deviations (S.D.) (see Table 2). However, ANOVA did not reveal difference in this inter-variability between the two groups. Thus, the results rather traduce a shift of the distribution of the AN population's A-effect (a specific bias) and cannot be solely considered as belonging to the "normal" interindividual variability inherently linked to A-effect. Our data reveal that spatial orientation constancy is impaired in AN and reinforce the hypothesis in which the PC has a key role in this pathology.

Impaired orientation constancy can be interpreted in the context of today's best accepted model of the SV. This model considers the SV to be the sum of various weighted vectors representing visual, gravitational and body cues (Mittelstaedt, 1983; Dyde et al., 2006). Thus, an A-effect is interpreted as a more pronounced weighting given to body cues or (in Mittelstaedt's model) the result of an attraction of the SV towards the idiotropic vector. *Body-tilt without visual cues* paradigm uncouples the gravitational and the egocentric frames of reference. We had previously suggested that the A-effect could show that the tilted individual can only access a subjective gravitational frame of reference (biased towards the direction of the body's orientation in space), rather than an objective frame of reference (Luyat et al., 2001). Thus, the abnormally increased A-effect in anorexics could be interpreted as a higher dependency towards the egocentric reference, resulting from a parietal dysfunction to integrate gravitational cues such as vestibular ones in the PC. However, in contrast to Grunwald et al.'s (2002) data, we did not observe asymmetrical performance when comparing the SV adjustments made by the left and right hands. This prevents us from suggesting a specific, right-side parietal dysfunction in AN.

Given that bodily cues seem to play a role in the emergence of the A-effect (Mittelstaedt, 1996; Trousselard et al., 2004;) and that the patients and control differ with respect to body weight, a Spearman correlational analysis was performed between anthropometric data (weight, BMI), psychological and behavioral features related to eating disorders (BSQ, EDI) and the amplitude of the A-effect. The lack of correlation between weight and the A-effect reduces the accountability of gravitational cues in favor of the idiotropic vector (Mittelstaedt, 1983). However, we find a negative relationship between interoceptive awareness and A-effect. Indeed, patients with anorexia suffer from a lack of interoceptive awareness (Pollatos et al., 2008). This lack of interoceptive awareness could also contribute to this increase of A-effect. Thus, this drop in performance (perception of orientation) could be related to poor recognition of interoceptive signals, as mentioned in your references (Trousselard et al., 2004). Further experiments (including visual adjustment of the SV and measure of interoceptive cues) will be needed to see whether the impaired orientation constancy is restricted to tactile tasks or reflects a supramodal deficit.

A limitation of our study is that it does not give direct measure demonstrating the association between parietal dysfunction and anorexia nervosa. We rather transferred techniques and conceptual framework that have been used successfully in neuroscientific research with patients suffering from parietal lesions (see Funk et al., 2010). Further experiments are needed as for instance, the comparison with other spatial tasks and in different population groups (healthy participants, patients with anorexia, hemineglect subjects and also psychiatric patients without AN).

In conclusion, our findings suggest that orientation constancy (with tactile adjustment of the vertical) is impaired in AN. This impairment can be explained by a stronger attraction of the SV towards an egocentric reference framework due (perhaps) to impaired processing of gravitational information (e.g. vestibular cues) in the PC. Thus, we can legitimately suppose that PC dysfunction disturbs the integration of the body-orientation representation (needed to achieve spatial orientation constancy) as well as the body boundary representation.

Contributors

Authors DG, PT, OC and ML designed the study and wrote the protocol. Authors DG and ML managed the literature searches and analyses. Authors DG, VD and OC managed inclusion of the participants. Authors DG and ML undertook the statistical analysis, and wrote the manuscript. All authors contributed to and have approved the final manuscript.

Conflict of interest

There is no conflict of interest, financial or otherwise, related directly or indirectly to the submitted work for all authors.

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