Neuropsychologia 75 (2015) 496–504

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Impaired recognition of body expressions in the behavioral variant of frontotemporal dementia

Jan Van den Stock [a,*,1], François-Laurent De Winter [a,1], Beatrice de Gelder [a,b], Janaki Raman Rangarajan [c], Gert Cypers [d], Frederik Maes [c], Stefan Sunaert [e], Karolien Goffin [f], Rik Vandenberghe [g], Mathieu Vandenbulcke [a]

[a] Laboratory for Translational Neuropsychiatry, Research Group Psychiatry, Department of Neurosciences, KU Leuven & Old Age Psychiatry, University Hospitals Leuven, Leuven, Belgium
[b] Cognitive Neuroscience, Faculty of Psychology and Neuroscience, Maastricht University, Maastricht, The Netherlands
[c] ESAT/PSI, Department of Electrical Engineering, KU Leuven & iMinds, Medical IT Department, University Hospitals Leuven, Leuven, Belgium
[d] Department of Neurology, Onze-Lieve-Vrouwziekenhuis Aalst-Asse-Ninove, Aalst, Belgium
[e] Department of Imaging and Pathology, KU Leuven & Department of Radiology, University Hospitals Leuven, Leuven, Belgium
[f] Department of Imaging and Pathology, KU Leuven & Division of Nuclear Medicine and Molecular Imaging, University Hospitals Leuven, Leuven, Belgium
[g] Laboratory for Cognitive Neurology, Department of Neurosciences, KU Leuven & Neurology, University Hospitals Leuven, Leuven, Belgium

ARTICLE INFO

Article history:
Received 24 March 2015
Received in revised form
28 May 2015
Accepted 27 June 2015
Available online 8 July 2015

Keywords:
Behavioral variant frontotemporal dementia
Emotion
Body
Inferior frontal gyrus
Supramodal emotion recognition

ABSTRACT

Progressive deterioration of social cognition and emotion processing are core symptoms of the behavioral variant of frontotemporal dementia (bvFTD). Here we investigate whether bvFTD is also associated with impaired recognition of static (Experiment 1) and dynamic (Experiment 2) bodily expressions. In addition, we compared body expression processing with processing of static (Experiment 3) and dynamic (Experiment 4) facial expressions, as well as with face identity processing (Experiment 5). The results reveal that bvFTD is associated with impaired recognition of static and dynamic bodily and facial expressions, while identity processing was intact. No differential impairments were observed regarding motion (static vs. dynamic) or category (body vs. face). Within the bvFTD group, we observed a significant partial correlation between body and face expression recognition, when controlling for performance on the identity task. Voxel-Based Morphometry (VBM) analysis revealed that body emotion recognition was positively associated with gray matter volume in a region of the inferior frontal gyrus (pars orbitalis/triangularis). The results are in line with a supramodal emotion recognition deficit in bvFTD.

1. Introduction

Fronto-temporal lobar degeneration (FTLD) is a neurodegenerative disorder that has a profound impact on personality and cognition. It is among the most frequent manifestations of early-onset dementia (Mercy et al., 2008). Clinical phenotypes of FTLD include language variants (Gorno-Tempini et al., 2011) and a behavioral variant (bvFTD). bvFTD is primarily characterized by deterioration of social behavior including loss of empathy and changes in personality (Piguet et al., 2011; Rascovsky et al., 2011). It is associated with early atrophy of medio-frontal cortex, anterior temporal cortex and striatum (Seeley et al., 2008; Whitwell et al., 2009). The loss of empathy has been related to impaired comprehension of emotional expressions displayed by others (Diehl-Schmid et al., 2007; Rankin et al., 2005). Studies investigating emotion recognition in bvFTD have primarily focused on perception of facial expressions. The results point to a deficit in recognizing facial expressions with a negative valence, while processing of positive facial expressions seems relatively preserved. Other between-emotion effects have been reported inconsistently (for a review, see Kumfor and Piguet (2012)).

Several studies have investigated the underlying pattern of atrophy by correlating regional gray matter volume with emotion recognition performance. The results indicate the involvement of a distributed network including the amygdala (Kumfor et al., 2013; Rosen et al., 2002), orbito-frontal cortex (Bertoux et al., 2012; Kumfor et al., 2013; Rosen et al., 2002, 2006), temporal pole (Kumfor et al., 2013; Rosen et al., 2006) and insula (Kumfor et al., 2013; Omar et al., 2011b).

Interestingly, these regions have also been associated with

* Corresponding author.
E-mail address: jan.vandenstock@med.kuleuven.be (J. Van den Stock).
[1] Equally contributing authors.

http://dx.doi.org/10.1016/j.neuropsychologia.2015.06.035
0028-3932/

perception of both static and dynamic whole body expressions of emotion in normal subjects (for reviews, see de Gelder (2006) and de Gelder et al. (2010)). It has been documented that whole body expressions convey reliable emotional cues, even when the face is not visible (Aviezer et al., 2012; de Gelder and Van den Stock, 2011; Kret et al., 2011b). To our knowledge, no study has addressed recognition of emotional body expressions in bvFTD. Our aim in the present study was to explore whether the deficits in emotion recognition that have been documented in the face modality extend to body expressions in bvFTD. Our second aim was to investigate the influence of motion by comparing static with dynamic body expressions and the influence of category by comparing bodily with facial expressions (Grezes et al., 2007; Kret et al., 2011b; Pichon et al., 2008; van de Riet et al., 2009). As perception of dynamic bodies is associated with more activation in fronto-temporal and subcortical areas compared to static bodies, we anticipate a larger impairment for recognizing dynamic stimuli. Similarly, perceiving bodies activates more subcortical and temporal areas than perceiving faces, with the important exception of the amygdala, which is more activated by faces than by bodies (Kret et al., 2011b; van de Riet et al., 2009). The third purpose of the study was to evaluate the hypothesis of a supra-modal emotion recognition deficit in bvFTD, which emerges from the overlap between the atrophic topography characteristic for early bvFTD (Seeley et al., 2008) and the functional neuro-anatomy of supra-modal emotion processing, specifically in medial prefrontal cortex (Peelen et al., 2010) and the temporal poles (Guo et al., 2013). In summary, the present study addresses categorical and motion effects of emotion recognition in bvFTD. The purpose is to investigate whether the visual emotion recognition deficit in bvFTD is category specific (and hence a 'conditional' visual emotion recognition deficit) in nature. Compared to facial expressions, body expressions convey more information regarding adaptive action (de Gelder, 2009), which may influence recognition performance. Similarly, dynamic stimuli are more naturalistic and contain temporal information that may provide recognition cues (de Gelder and Van den Stock, 2010). To evaluate the emotion specificity of the results, we included a control task consisting of identity recognition.

2. Material and methods

The study was conducted in accordance with the Declaration of Helsinki and included written informed consent from all participants. Ethical approval for the study was provided by the Ethical Committee of University Hospitals Leuven.

2.1. Participants

A total of 26 consecutive bvFTD patients were recruited. Six of these patients could not be included in the study since no experimental data could be acquired due to a lack of cooperation and/or agitation. The remaining 20 were recruited via the Memory Clinic ($N=6$) and Old Age Psychiatry Department of University Hospitals Leuven ($N=8$) and the Neurology Department of Onze-Lieve-Vrouwziekenhuis Aalst-Asse-Ninove ($N=6$). All patients were evaluated via clinical assessment, neuropsychological testing and structural MRI. In addition, $^{[18]}$Fluorodeoxyglucose Positron Emission Tomography (FDG-PET) was performed in all but two patients. Two patients fulfilled the revised diagnostic criteria for 'behavioral variant FTD with definite FTLD Pathology', based on a C9orf72 pathogenetic mutation, while the other 18 patients fulfilled the criteria for 'Probable bvFTD' (Rascovsky et al., 2011). In none of the patients, language difficulty was the most prominent clinical feature. Furthermore, in none of the patients, aphasia was the most prominent deficit at symptom onset and during the initial phase of the disease. These phenotypes are not in line with the current inclusion criteria for primary progressive aphasia (PPA) (Gorno-Tempini et al., 2011). Patients were included after clinical judgment deemed them able to successfully undergo an experimental scanning session.

Table 1
Demographic and neuropsychological test results.

		bvFTD ($N=20$)	Controls ($N=20$)		
				t (χ^2)	p
Age		65.7 (8.7)	66.6 (6.1)	0.385	.703
Sex (M/F)		12/8	12/8		(0.000)
1.000					
MMSE		26.7[$] (1.5)	29.2 (0.6)	6.773	.001
RAVLT	A1–A5	27.4[$] (9.1)	50.8 (7.3)	8.908	.001
	% recall	54.1[$] (31.5)	80.9 (17.4)	3.267	.003
	Recognition	6.0[$] (7.4)	14.0 (1.3)	4.622	.001
BNT		40.2[$] (13.0)	54.4 (2.9)	4.655	.001
AVF		15.1[$] (5.7)	22.1 (5.8)	3.862	.001
TMT	A (secs)	63.5[$] (42.7)	32.5 (9.4)	3.099	.006
	B (secs)	193.0[£] (141.2)	89.8 (42.3)	2.742	.015
BORB	Length	87.6[%] (7.3)	90.7 (4.5)	1.262	.218
	Size	85.5[%] (6.9)	88.9 (6.3)	1.577	.126
	Orientation	81.4[%] (9.1)	86.1 (6.0)	1.845	.074
RCPMT		16.4[$] (3.9)	20.8 (2.8)	3.999	.001
AAT	Comprehension	93.9[$] (12.3)	109.5 (5.3)	5.093	.001

MMSE = Mini-Mental-State Examination; RAVLT = Rey Auditory Verbal Learning Test; A1–A5 = the sum of scores on trials A1 to A5 of the RAVLT; Recognition = the recognition score constitutes the difference between the number of correct hits and false hits on the recognition trial; BNT = Boston Naming Test; AVF = Animal Verbal Fluency; TMT = Trail Making Test; BORB = Birmingham Object Recognition Battery; RCPMT = Raven Colored Progressive Matrices Test; AAT = Aachen Aphasia Test.

[$] $N=19$.
[£] $N=17$.
[%] $N=15$.

The control group was recruited through advertisements in local newspapers. Twenty control subjects participated in the behavioral and imaging experimental procedures, including neuropsychological examination. Exclusion criteria were present or past neurological or psychiatric disorders including substance abuse as well as significant systemic comorbidities or use of medication susceptible to affect the central nervous system. MRI scanning of all participants was performed on the same scanner. Demographic data and neuropsychological test results of all participants are presented in Table 1.

The individual demographic and neuropsychological data of the patients, including a detailed overview of the diagnostic criteria they fulfilled, are presented in Supplementary Table S1.

2.2. Experiment 1: static body emotion matching

The stimuli and procedure have been described in detail elsewhere (Van den Stock et al. (2007)). In short, the experiment consisted of a two-alternative forced choice simultaneous match to sample procedure. A stimulus consisted of a sample picture presented at the top and target and distracter underneath (see Fig. 1 for an example). One of the two bottom pictures (i.e. the target) expressed the same emotion as the picture on top (i.e. the sample). The Experiment consisted of 24 trials (4 emotions (anger, fear, happiness, and sadness) × 3 distracters/emotion × 2 genders). Stimulus presentation time was unlimited, but participants were instructed to respond as accurately and as fast as possible. Participants were instructed to indicate by a button press whether the left or right bottom picture displayed the same expression as the one on top.

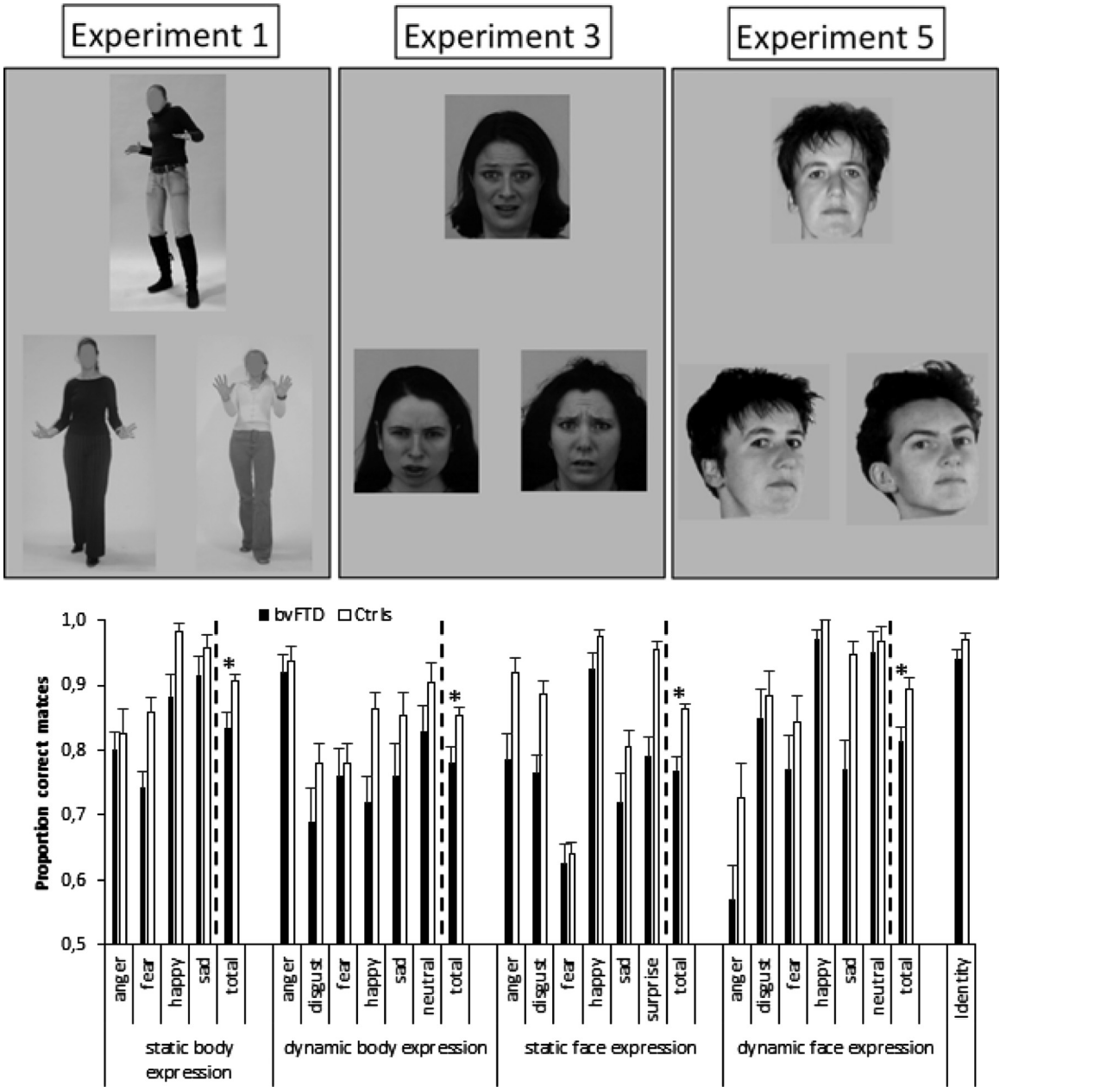

Fig. 1. Stimulus examples of Experiment 1 (left), Experiment 3 (middle) and Experiment 5 (right). In the examples of Experiment 1 and Experiment 3, the sample (top) shows a fearful expression with underneath an angry (left = distracter) and fearful (right = target) expression. Participants were instructed to match the bottom expression to the one on top. In Experiment 5, all pictures show a neutral expression. Participants were instructed to match the bottom identity to the one on top. The sample (top) shows a frontal view with underneath ¾ views of the same (left = target) and a different (right = distracter) identity. The bottom bar-chart displays the behavioral results as a function of group, Experiment and emotion (for illustrative purposes). Error bars represent 1 SEM. $^{*}p < .05$.

2.3. Experiment 2: dynamic body emotion matching

Stimuli were constructed from 90 validated 2 second video clips of emotional whole body expressions (15 anger, 15 disgust, 15 fear, 15 happy, 15 sad, 15 neutral), taken from our own database (for details on stimulus construction and validation, see Kret et al. (2011a, 2011b)). The procedure was analogous to Experiment 1, with the exception that the three clips in a stimulus looped until the participant responded (with a maximum of 10 repeats). The experiment consisted of 30 trials (6 emotions × 5 distracters per emotion).

2.4. Experiment 3: static face emotion matching

Frontal view pictures of emotional expressions (anger, happiness, disgust, fear, sadness and surprise) from the Karolinska Directed Emotional Faces set (Lundqvist et al., 1998) were validated on emotion recognition in a pilot study. One hundred and eighty pictures were similarly categorized by at least 15 of the 20 participants (75%) and were selected for the experiment. The procedure was analogous to Experiment 1. The experiment consisted of 60 trials (6 emotions × 5 distracters/emotion × 2 genders).

2.5. Experiment 4: dynamic face emotion matching

Stimuli were constructed from 90 validated video clips (2s) of emotional facial expressions (15 anger, 15 disgust, 15 fear, 15 happy, 15 sad, 15 neutral) of 6 professional male actors, taken from our own database (for details on stimulus construction and

validation, see De Winter et al. (2015) and Zhu et al. (2013)). The procedure was analogous to Experiment 2. The experiment consisted of 30 trials (6 emotions × 5 distracters/emotion).

2.6. Experiment 5 (control experiment): face identity matching

The stimuli and procedure have been described in detail elsewhere (Huis in 't Veld et al., 2012). In short, a stimulus consisted of a picture displaying a front view of a face presented on top, with 2 pictures displaying ¾ views of a face presented below. One of the bottom faces showed the same identity as the one on top. The Experiment consisted of 32 trials. The procedure was analogous to Experiment 1, with the exception that the task consisted of identity matching as opposed to emotion matching.

Trials in which the reaction time differed more than three standard deviations from the subject-specific mean reaction time were defined as outliers. These trials were excluded from further analysis. All subsequent analyses are performed on accuracy data. To test for normality of the data, Shapiro–Wilk tests were performed on the total score of every experiment and on the appropriate combined scores of experiments. This revealed that normality could not be assumed in any of the variables ($p < .021$). Box–Cox transformations did not sufficiently optimize the skewness of the data to a normal distribution. Therefore, we performed non-parametric Independent-Samples Mann–Whitney *U* tests on the variables of interest to investigate group differences. For every experiment, group differences were evaluated on the total score as well as on the performance for positive expressions to investigate whether any emotion recognition deficit was restricted to negative emotions. In addition, the average performance on the negative emotions was subtracted from the average performance of the positive emotion(s) and group differences were examined on this difference-score to investigate whether any emotion recognition deficit was disproportional regarding the valence of the emotions. Finally, group differences on the average performance on the negative emotions were investigated.

2.7. Magnetic Resonance Imaging and analysis

A high-resolution T1-weighted anatomical image (voxel size = $0.98 \times 0.98 \times 1.20\ mm^3$) was acquired on a 3T Philips Achieva system equipped with a 32 channel head coil using a 3D turbo field echo sequence (TR = 9.6 ms; TE = 4.6 ms; matrix size = 256×256; 182 slices). Analysis of local gray matter (GM) volume was performed with SPM8 (Wellcome Trust Centre for Neuroimaging, UCL, London, United Kingdom) within MatLab R2008a (Mathworks, Natick, MA). Preprocessing included image segmentation, spatial normalization, modulation and smoothing. Segmentation was performed using SPM8's unified segmentation routine in combination with in-house developed algorithms to address suboptimal segmentation results in the most atrophic regions, primarily the right temporal pole. Next, the images were spatially normalized by creating a customized group-specific template using SPM8's DARTEL routine and warping each of the individual GM segmentations onto this template. The warped GM segmentations were modulated to account for local shape differences and smoothed using a Gaussian kernel of 8 mm at FWHM. To investigate regional group differences in gray matter volume, we performed a two samples *t*-test on the gray matter voxels ($p < .001$, minimal cluster size = 100 voxels).

The GM maps were subsequently used in a regression analysis in which body expression recognition performance was entered as covariate in order to investigate correlations between performance and voxel-wise GM volume ($p < .001$, minimal cluster size = 100 voxels). As the primary focus of the present study was to gain insight into recognition of bodily expression in bvFTD and its associated structural neuro-anatomy, rather than into bodily expression recognition per se, we opted to confine the regression analysis to the patient group and hence not to combine it with the data from the control group. Although this does not benefit statistical power, it excludes contamination of the results by non-bvFTD data. While the alternative approach has proven valuable (Kumfor et al., 2013; Kumfor et al., 2014), the current method provides complementary evidence to it as well as to region of interest analyses (Bertoux et al., 2012; Couto et al., 2013).

3. Results

3.1. VBM group comparison

Two patient's T1 images were not included in the analysis due to excessive motion. The two samples *t*-test ($p < .001$, minimal cluster size = 100 voxels) revealed a large bilateral cluster covering the anterior half of the temporal lobes, insula, ventral striatum and orbitofrontal cortex, consistent with previous studies (Fig. 2).

3.2. Behavioral results

Behavioral results are displayed in Fig. 1.

3.2.1. Experiment 1: static body emotion matching

Nineteen outlier trials were detected (1.8%, maximum/subject: 2). There was a significant group difference on the total score ($p = .026$), on the score for matching happy expressions ($p = .046$) and on the average score for matching negative expressions ($p = .046$) but not on the difference between negative and positive expressions ($p = .289$).

3.2.2. Experiment 2: dynamic body emotion matching

One control subject did not take part in Experiment 2. Twelve outliers were detected (1.0%, maximum/subject: 1). There was a significant group difference on the total score ($p = .028$) and on the score for matching happy expressions ($p = .015$) but not on the difference between negative and positive expressions ($p = .101$) nor on the average score for matching negative expressions ($p = .120$).

3.2.3. Experiment 3: static face emotion matching

Forty-seven outliers were detected (1.9%, maximum/subject: 3). There was a significant group difference on the total score ($p < .001$), on the average score for matching happy and surprised static facial expressions ($p < .001$) and on the average score for matching negative expressions ($p = .004$), but not on the difference between negative and positive expressions ($p = .414$).

3.2.4. Experiment 4: dynamic face emotion matching

One control subject did not take part in Experiment 4. Fourteen outliers were detected (1.3%, maximum/subject: 1). There was a significant group difference on the total score ($p = .007$) but not on the score for matching happy dynamic facial expressions ($p = .428$). The difference between negative and positive expressions was significant ($p = .038$), as was the average score on the negative expressions ($p = .006$).

3.2.5. Experiment 5 (control experiment): face identity matching

One patient did not take part in Experiment 5. Twenty-three outliers were detected (1.8%, maximum/subject: 1). There was no significant group difference on the total score ($p = .184$).

3.2.6. Between and across experiments analysis

We investigated whether the deficit in matching body

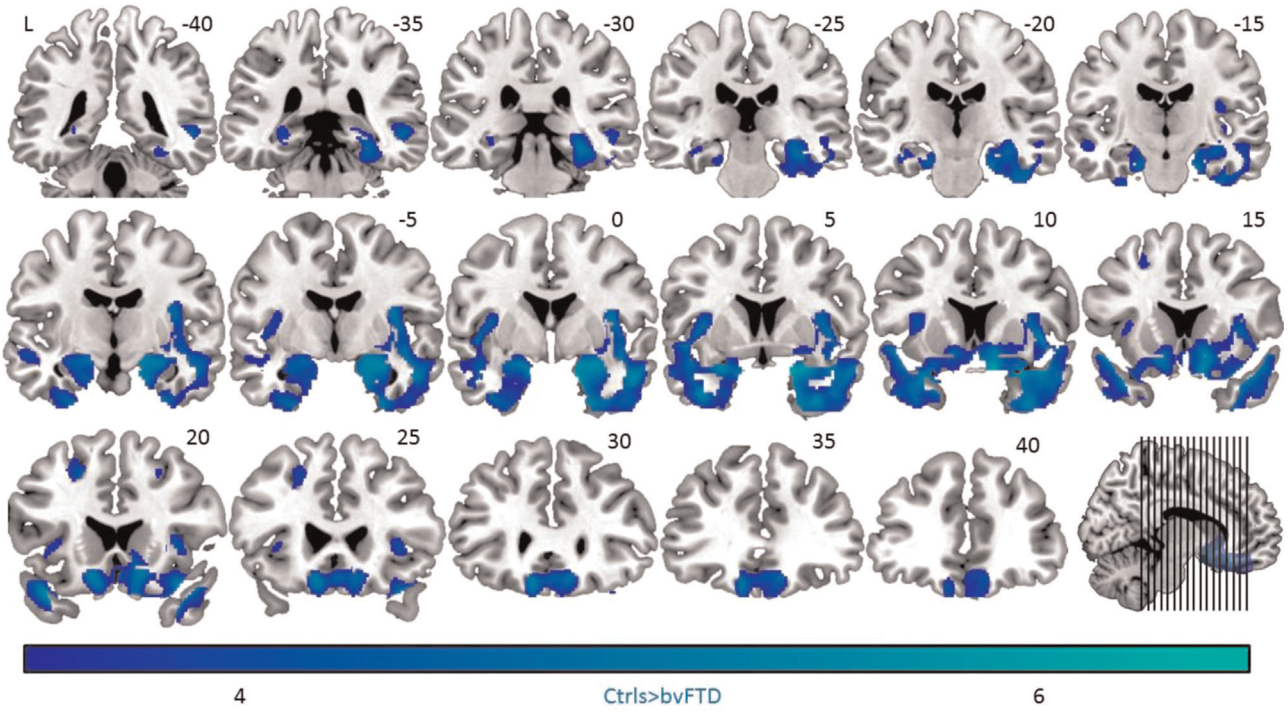

Fig. 2. Atrophic topography of patient group. Statistical map ($p < .001$) of group differences in gray matter volume, represented on coronal slices from posterior (top left) to anterior (bottom right) (Controls > bvFTD). Numbers refer to MNI *Y*-coordinates. Color coding refers to *t*-values. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

expressions was proportional to the deficit in matching facial expressions. For this purpose, the average performance on matching facial expressions (static and dynamic) was subtracted from the average performance on matching body expressions. The resulting difference did not show a significant group effect ($p=.620$). Similarly, to compare the deficit for matching static and dynamic expressions, the average performance on matching static expressions (faces and bodies) was subtracted from the average performance on dynamic expressions. Again, this variable showed no significant group difference ($p=.857$).

In addition, to investigate the association between categories (across motion conditions) in the bvFTD group, we computed the partial correlation coefficient between the score on the body and on the face (averaged over static and dynamic) emotion tasks factoring out the score on the identity task. This revealed a significant correlation ($r=.670$, $p=.002$, see Fig. 3).

Fig. 3. Scatterplot displaying the partial correlation between body and face emotion matching controlling for identity matching, i.e. the unstandardized residual following linear regression of body emotion matching to identity matching (*Y*-axis) as a function of the unstandardized residual following linear regression of face emotion matching to identity matching (*X*-axis).

3.3. Imaging results

To investigate the structural neuro-anatomy of body emotion recognition in bvFTD, the average score of Experiments 1 and 2 (static and dynamic body emotion matching) were entered as covariate in the regression model. Age did not correlate with the average score ($r=.106$; $p=.655$) and was hence not included as a nuisance variable. The score on the identity matching Experiment was included as a nuisance variable. Body expression matching performance correlated significantly with GM volume in the left inferior frontal gyrus (IFG) pars orbitalis/triangularis (285 voxels, MNI coordinates of peak voxel: −41; 26; 3; see Fig. 4). To investigate whether the normality assumption was fulfilled for this result, we performed a post-hoc Shapiro Wilk test on the unstandardized residuals of the linear regression. This revealed no significant outcome ($p=.744$), supporting the validity of the result. To investigate the specificity of these results, we computed the partial correlation between the GM volume in this region and face expression recognition performance (average of static and dynamic), controlling for identity recognition performance. This revealed a significant correlation ($r=.637$, $p < .008$).

As a supplementary analysis, we investigated the neural correlates of perceiving static and dynamic expressions as well as facial expressions (Supplementary materials).

4. Discussion

The main goal of the study was to investigate recognition of bodily expressions in bvFTD. Based on the clinical phenotype of bvFTD but also on the overlap between the atrophic topography and the functional neuro-anatomy of perceiving body expressions, we hypothesized a deficit in bvFTD. We recruited a sample with a minor global cognitive deterioration (as evidenced by an average

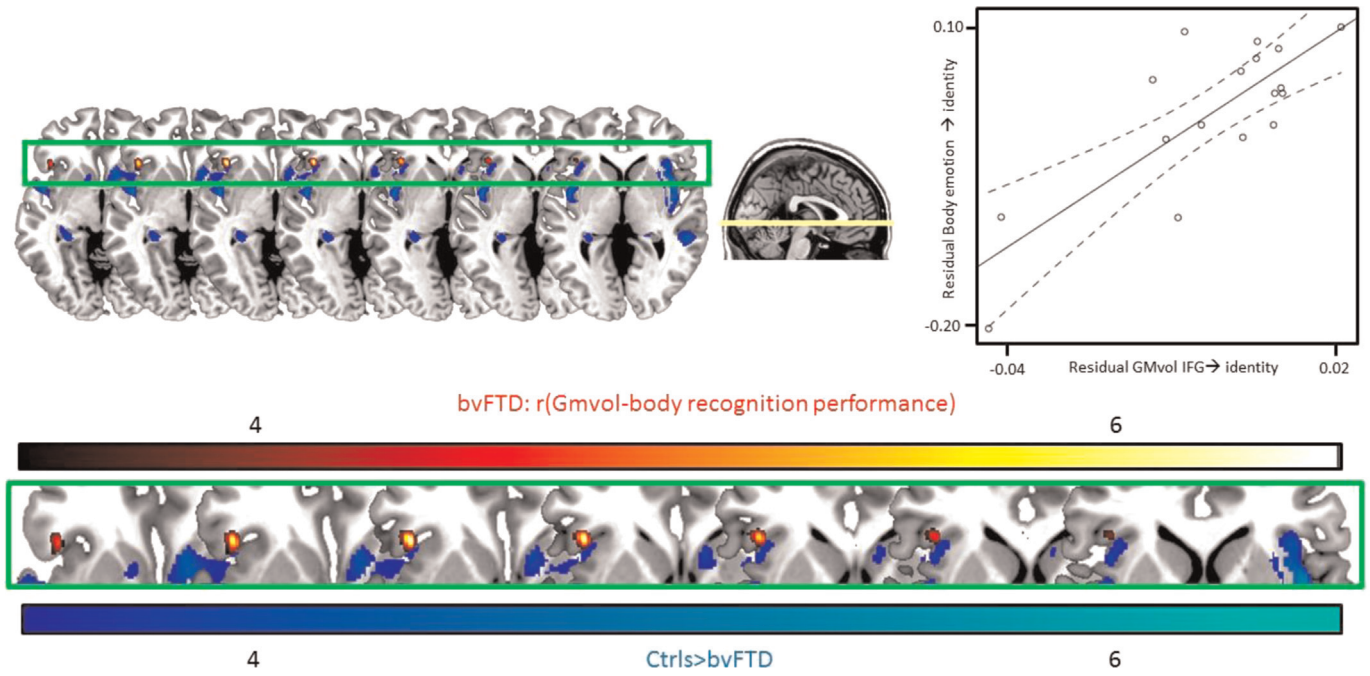

Fig. 4. Association between matching body expressions and regional gray matter volume. The top left panels display statistical maps (red to yellow) following regression of the body matching score to gray matter volume ($p < .001$, minimal cluster size = 100 voxels) with performance on the identity matching task as nuisance variable. For comparison purposes, the regional atrophy (blue to green) is also displayed ($p < .001$). The scatterplot at the top right displays the partial correlation between matching body expressions and the gray matter volume of the cluster in the inferior frontal gyrus (GMvol IFG), factoring out identity matching, i.e. the unstandardized residual following linear regression of body emotion matching to identity matching (*Y*-axis) as a function of the unstandardized residual following linear regression of IFG gray matter volume to identity matching (*X*-axis). The bottom panel displays a zoomed view of the green-delineated part of the top panel picture. Color bars indicate *t*-values. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

MMSE-score above 26) and displaying the expected anterior temporal and orbito-frontal atrophy.

4.1. Behavioral results

The behavioral experiments consisted of a forced choice procedure with only two alternatives to minimize decision options and executive task demands. Furthermore, a simultaneous match-to-sample task was administered, as this requires less semantic/word finding processing, which can also be impaired in bvFTD (Couto et al., 2013) as compared to for example a verbal categorization task (Hsieh et al., 2013; Miller et al., 2012; see also task 5 in Snowden et al. (2008)).

The results provide support for the hypothesis, as the bvFTD group displayed a body recognition impairment. This result extends previous reports of impaired recognition of emotion cues conveyed by faces (Lavenu et al., 1999), voices (Keane et al., 2002) and music (Omar et al., 2011a). On the other hand, the bvFTD group in the present study was not impaired on an identity matching task which matched the cognitive task demands of the emotion matching tasks, suggesting that the impairment was specific for emotions. The intact identity processing we observed here contrasts with recent evidence for impaired identity processing in bvFTD (Kumfor et al., 2015). This discrepancy might be explained by two factors. First, Kumfor et al. (2015) made use of an identity discrimination task with facial stimuli containing only the inner face, i.e. with identifying features like hair and ears removed. Secondly, the identity processing task in Kumfor et al. (2015) consisted of emotional mixed with neutral stimuli. Although the emotional information was task irrelevant, there is accumulating evidence that facial emotion and facial identity processing mutually influence each other (Chen et al., 2011; Gallegos and Tranel, 2005; Kaufmann and Schweinberger, 2004; Levy and Bentin, 2008; Van den Stock and de Gelder, 2012, 2014; Van den Stock et al., 2008). These methodological differences may account for the discrepancy with the present results showing intact matching of neutral whole face identities.

Secondly, to investigate the role of dynamic information conveyed by the body expressions, we investigated recognition of both static (Experiment 1) and dynamic (Experiment 2) body expressions. Similarly, to compare bodies with faces, we included static (Experiment 3) and dynamic (Experiment 4) facial expression recognition tasks. The results did not reveal a disproportionate deficit according to motion or category condition.

Furthermore, we tested the hypothesis that the emotion recognition deficit in bvFTD only applies to negative emotions, as has been reported in previous studies with facial expressions (Fernandez-Duque and Black, 2005; Lavenu et al., 1999; Lough et al., 2006; Rosen et al., 2002). While happy faces are typically among the easiest emotions to recognize, this is not the case for body expressions (de Gelder and Van den Stock, 2011). Happy faces are quite prototypical and are easily differentiated from other emotions, particularly in the lower half of the face (Calder et al., 2000; Smith et al., 2005), while (faceless) body expressions typically involve raising of the arms. This latter features is also typically for several negative body expressions like fear and anger. The present results do not support a valence based dissociation in emotion recognition impairment, as we did not observe a disproportionate deficit for negative emotions in three of the four emotion Experiments. The only support for a valence specific impairment was observed in the dynamic face Experiment (Experiment 4). However, all control subjects performed flawlessly in the happy condition, so this ceiling effect may conceal a latent group difference in this condition.

Interestingly, when controlled for cognitive task demands, there was a significant correlation between the performance on the body and face emotion tasks, independent of motion information. This indicates that the emotion recognition deficit in

bvFTD applies similarly for faces and bodies. This observation is in line with a previous study in which an association between facial and vocal emotion recognition was reported in the frontal variant of FTD (Keane et al., 2002).

However, as the behavioral results were not normally distributed, we made use of non-parametric tests. This does not allow controlling for neuropsychological variables, like MMSE score.

The study results have a clinical relevance, particularly related to the diagnosis. Deficits in social cognition are an important diagnostic domain in addition to standard clinical neuropsychological testing involving attention, memory, language and visuospatial functioning. There is currently little consensus regarding the optimal tool to assess social cognition in general and emotion recognition in particular. The present results suggest that recognition of bodily expressions may provide a valuable measure to evaluate social cognition abilities.

4.2. Imaging results

4.2.1. Controls vs. patients

Comparing GM volumes between the control and bvFTD group revealed reduced GM volume in the anterior temporal lobes, orbitofrontal cortex, insula, dorsolateral prefrontal cortex and striatum. This atrophic topography is largely in accordance with previous reports (Diehl-Schmid et al., 2014; Seeley et al., 2008; Whitwell et al., 2009).

4.3. Within-patient group result

We did not include the control group in the regression analysis nor did we use pre-defined regions of interest in order to provide complementary results to previous studies (Bertoux et al., 2012; Couto et al., 2013; Kumfor et al., 2013, 2014). The results from the regression analysis revealed an association between recognition of body expressions and gray matter volume in the IFG (pars orbitalis/triangularis). The IFG has also been associated with perceiving emotions from bodies in normal subjects (de Gelder et al., 2004), but also with emotion processing from faces and scenes (Sabatinelli et al., 2011). The cluster in the IFG we observe here was also associated with face expression recognition, in line with previous reports in FLTD (Kumfor and Piguet, 2012; Omar et al., 2011a). In addition, there is evidence that the IFG is involved in recognition of emotions from music in bvFTD (Omar et al., 2011a). These combined findings reveal an association between the structural integrity of the IFG and emotion recognition deficits in multiple stimulus categories in bvFTD. Furthermore, the involvement of the region in the IFG we observe here has been reported in other neurodegenerative disorders like Alzheimer's disease. A recent fMRI study reported reduced activation (compared to controls) in the IFG when viewing emotional vs. neutral faces (Lee et al., 2013).

There is evidence that the recognition of emotions shows both psychological and neuro-anatomical overlap with the experience of emotions (Bastiaansen et al., 2009). The IFG has been particularly associated with both experience and perception of emotions. Furthermore, activation in the IFG during emotion perception is positively associated with trait empathy (Jabbi et al., 2007; Lamm et al., 2011; Wicker et al., 2003). The present findings are in line with these notions, namely that recognition of emotion involves motor regions to understand the emotional state of others and that this is related to empathy, which is primarily affected in bvFTD.

However, it is remarkable that the cluster falls largely outside the atrophic region, similar to a previous study (Lee et al., 2013). This may suggest that symptom manifestation is not by default directly related to structural degeneration of an associated area, as revealed through MRI. In addition, there is evidence that the temporal poles constitute an amodal hub in storing semantic knowledge about emotions, operating through connectivity with primary and association cortices (Guo et al., 2013). Our results are therefore in line with the notion that it is primarily the degeneration of the combination of temporal poles with IFG that influences symptom severity.

Finally, some limitations of the study should be noted. As we did not include a clinical control group, there is no evidence that the present results obtain specifically for bvFTD. There is conflicting evidence regarding the degree of emotion recognition impairments between FTLD and other neurodegenerative disorders like Alzheimer's disease (AD). While some studies have reported a larger impairment in FTLD (Lavenu et al., 1999), other have reported equally large deficits (Miller et al., 2012). However, the latter study provided evidence that emotion recognition deficits are primarily associated with language impairments in SD as opposed to perceptual impairments in bvFTD and AD. Future studies can investigate whether emotion recognition deficits are observed already at the detection stage, or only emerge when the task is to discriminate emotions. In addition to the matching approach that we used here, it would be informative to investigate whether a similar impairment is present when the task is to select or categorize emotions (Bowers et al., 1999) and how performance differs from other neurodegenerative syndromes like AD. This may provide cues regarding the involvement of the specific emotion processing deficits in a recently proposed liability spectrum (Kret and Ploeger, 2015). Secondly, our clinical sample showed a primarily anterior temporal atrophic topography. It cannot be ruled out that the cooperative and motivational demands of the study resulted in an inclusion bias favoring temporal dominant variants (Whitwell et al., 2009). In fact, 6 patients were invited and agreed to participate in the study, but could not be included because of insufficient cooperation or agitation, similar to a previous study (Virani et al., 2013). In addition to comparisons with other neurodegenerative disorders, it would be informative to compare emotion recognition in bvFTD as a function of neuro-anatomic phenotype.

In conclusion, the present findings reveal that bvFTD is characterized by a deficit in recognizing both static and dynamic body expressions. Furthermore, the emotion recognition deficit was proportional regarding both category (faces compared to bodies) and motion (static compared to dynamic). We also observed a significant correlation between body and face emotion recognition, compatible with a supra-modal emotion recognition deficit.

Acknowledgments

We are particularly grateful to the patients for their cooperative participation in the study. In addition, we thank Dr. Marc Van Orshoven, Dr. Marleen Vieren and Dr. Miriam Bouckaert at the Neurology Department of OLV-Hospitals Aalst for their cooperation, Dr. Wim Van der Elst for statistical advice and Sherihane Bensemmane for technical support. The authors declare no competing financial interests. J.V.d.S. is a post-doctoral researcher supported by Fonds Wetenschappelijk Onderzoek - Vlaanderen (FWO) (1.5.072.13N) and Foundation for Alzheimer Research (SAO-FRA P#14013). M.V. is supported by Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO) (G074609). J.R.R is a post-doctoral researcher supported by IWT SBO project MIRIAD (Molecular Imaging Research Initiative for Application in Drug Development, SBO-130065). The funding sources had no role in the study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

Appendix A. Supplementary information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neuropsychologia.2015.06.035.

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