International Psychogeriatrics (2024), 36:6, 455–464
doi:10.1017/S1041610223000297

Error profiles of facial emotion recognition in frontotemporal dementia and Alzheimer's disease

Kimberly Gressie,[1,2] Fiona Kumfor,[2,3] Her Teng,[2,3] David Foxe,[2,3] Emma Devenney,[2,4] Rebekah M. Ahmed,[2,4] and Olivier Piguet[2,3]

[1]*Faculty of Medicine, The University of Amsterdam, Amsterdam, The Netherlands*
[2]*The University of Sydney, Brain and Mind Centre, Sydney, Australia*
[3]*The University of Sydney, School of Psychology, Sydney, Australia*
[4]*The University of Sydney, Central Clinical School, Sydney, Australia*

ABSTRACT

Objectives: To identify the patterns of errors in facial emotion recognition in frontotemporal dementia (FTD) subtypes compared with Alzheimer's disease (AD) and healthy controls.

Design: Retrospective analysis.

Setting: Participants were recruited from FRONTIER, the frontotemporal dementia research group at the University of Sydney, Australia.

Participants: A total of 356 participants (behavioral-variant FTD (bvFTD): 62, semantic dementia (SD)-left: 29, SD-right: 14, progressive non-fluent aphasia (PNFA): 21, AD: 76, controls: 90) were included.

Measurements: Facial emotion recognition was assessed using the Facial Affect Selection Task, a word-face matching task measuring recognition of the six basic emotions (anger, disgust, fear, happiness, sadness, and surprise), as well as neutral emotion, portrayed by black and white faces.

Results: Overall, all clinical groups performed significantly worse than controls with the exception of the PNFA subgroup ($p = .051$). The SD-right group scored worse than all other clinical groups (all p values $< .027$) and the bvFTD subgroup performed worse than the PNFA group ($p < .001$). The most frequent errors were in response to the facial emotions *disgust* (26.1%) and *fear* (22.9%). The primary error response to each target emotion was identified; patterns of errors were similar across all clinical groups.

Conclusions: Facial emotion recognition is impaired in FTD and AD compared to healthy controls. Within FTD, bvFTD and SD-right are particularly impaired. Dementia groups cannot be distinguished based on error responses alone. Implications for future clinical diagnosis and research are discussed.

Key words: emotion recognition, facial affect, social cognition, Alzheimer's disease, behavioral-variant frontotemporal dementia, semantic dementia, progressive non-fluent aphasia, primary progressive aphasia

Frontotemporal dementia (FTD) is an umbrella term used to describe a group of heterogeneous, progressive neurodegenerative brain disorders, characterized by degeneration of the frontal and/or temporal lobes (Piguet and Kumfor, 2020). It is the second most common cause of young-onset dementia (i.e. before the age of 65 years) after Alzheimer's disease (AD) with an estimated prevalence of 7–15/100,000 individuals (Coyle-Gilchrist *et al.*, 2016; Hogan *et al.*, 2016). FTD is clinically classified into three subtypes based on the most prominent clinical features at the time of presentation. The most common form is the behavioral variant of FTD (bvFTD), which is characterized by altered social behavior and personality (Rascovsky *et al.*, 2011) arising from atrophy primarily involving orbitofrontal, anterior cingulate and anterior temporal regions bilaterally, as well as the subcortical nuclei. The other two subtypes, semantic dementia (SD) and progressive non-fluent aphasia (PNFA) (also referred to as semantic variant and non-fluent variant of primary progressive aphasia), are characterized primarily by language disturbances (Gorno-Tempini *et al.*, 2011). Clinically, SD presents

Correspondence should be addressed to: Olivier Piguet, School of Psychology and Brain and Mind Centre, The University of Sydney, Camperdown, NSW 2006, Australia. Phone: +61 2 9114 4144. Email: olivier.piguet@sydney.edu.au
Received 20 Sep 2022; revision requested 10 Feb 2023; revised version received 20 Feb 2023; accepted 15 Mar 2023. First published online 11 April 2023.

with a progressive loss of word comprehension and conceptual (word) knowledge against a background of fluent speech output. SD is associated with marked asymmetric atrophy of the anterior temporal lobe, which is generally more pronounced in the left than in the right hemisphere. In ~30% of patients, the pattern of atrophy is reversed (i.e. right greater than left), hereon labeled SD-right. These patients tend to show additional behavioral changes, similar to those observed in bvFTD, as well as prosopagnosia (Kumfor *et al.*, 2016; Ulugut *et al.*, 2021). PNFA patients exhibit effortful and halted speech in the context of preserved comprehension. Speech output is markedly reduced and often distorted and can be accompanied by agrammatism. These deficits are associated with focal left hemispheric brain atrophy, involving primarily the left inferior frontal and insular regions.

Social cognition, of which a central aspect is the ability to recognize emotions in facial expressions, is essential to all social interactions (Frith, 2009). Deficits in facial emotion recognition have a profound impact on interpersonal social interactions, where failure to recognize, identify, and respond to emotional stimuli can lead to misinterpretation of social cues that guide normal behavior. Facial emotion recognition is supported by a large network of interconnected brain regions that includes anterior (orbitofrontal, temporal, insula, cingulate) posterior (parietal, fusiform), and subcortical (amygdala, thalamus) brain regions (Hutchings, *et al.*, 2017; Marshall *et al.*, 2019; Van den Stock *et al.*, 2014).

Disturbance of facial emotion processing is well established in bvFTD and SD (Kumfor and Piguet, 2012). These deficits have been consistently observed, regardless of the type of stimuli (e.g. static or dynamic; black and white, or color; with or without contextual information) and the complexity of the emotional information portrayed (i.e. basic vs. complex emotions) (Goodkind *et al.*, 2015). Unsurprisingly, emotion recognition failure is also associated with reduced quality of the relationship with carers and increased caregiver burden (Hsieh *et al.*, 2013; Spitzer, *et al.*, 2019).

On testing using basic emotions (*anger, disgust, fear, happiness, sadness, and surprise*), bvFTD and SD patients experience greatest difficulty recognizing and differentiating between the negative emotions (Kumfor *et al.*, 2011; Kumfor and Piguet, 2012; Savage *et al.*, 2014). This difficulty is observed when performance is compared against that of healthy controls or against patients diagnosed with AD (Bora *et al.*, 2016)—where emotion recognition deficits in this group tend to be milder, occur later in the disease process, and tend to be secondary to other cognitive deficits (e.g. attention, language, memory) (Bertoux *et al.*, 2015). Emotion processing is thought to be mostly preserved in PNFA, although the limited evidence is mixed, and when present is comparatively mild (Couto *et al.*, 2013; Piguet *et al.*, 2015).

To date, no research has examined the type of errors made during facial emotion recognition tasks in FTD and whether specific error patterns exist across the different subtypes. Analysis of error patterns will help determine if the errors committed reflect systematic errors between specific emotions, and whether errors involve subtle discrimination (e.g. *fear* vs. *surprise*), or gross recognition failures (e.g. *happiness* vs. *sadness*). In addition to improving understanding of the clinical phenomenology of FTD subtypes and potentially aid with diagnosis, knowledge of emotion processing error profiles may assist with the management of the disease, reduce carer burden, and help improve the social interactions between patient and carer.

To gain insight into error patterns in facial emotion recognition across FTD subtypes, we analyzed the errors made during a task of emotional face identification involving the six basic emotions and neutral faces: the Facial Affect Selection Task (FAST) (Kumfor *et al.*, 2014; Miller *et al.*, 2012). Performance of FTD patients was compared against healthy controls and patients diagnosed with AD, to identify whether patterns of errors reflect a global effect of dementia (i.e. that would be similar across groups) or whether errors are group specific.

The overall aim of the study was to (1) identify the patterns of deficits on a task of basic emotion recognition in FTD subtypes compared with typical AD and (2) determine whether the types of errors (i.e. which emotions are mostly likely to be wrongly identified) and error patterns (i.e. which incorrect responses are most likely to be selected) differ across groups. Based on previous research, we hypothesize that: (i) all patient groups—but particularly bvFTD and SD—will experience disturbance in facial emotion recognition compared with healthy controls, most pronounced for negative emotions; (ii) the profiles of errors will differ across the dementia groups due to their different patterns of brain atrophy; and (iii) within groups, the incorrectly selected emotions (i.e. errors) will be perceptually similar to the target emotion.

Methods

Participants

Two-hundred-and-two individuals diagnosed with dementia (bvFTD: 62, SD-left: 29, SD-right: 14, PNFA: 21, AD: 76) were recruited from FRONTIER, the frontotemporal dementia clinical research group at the University of Sydney, Australia. All dementia patients underwent a comprehensive clinical

https://doi.org/10.1017/S1041610223000297

and cognitive examination, a structural brain magnetic resonance imaging (MRI), supplemented by a carer-based interview. All patients met relevant current diagnostic criteria at the time of testing (Gorno-Tempini *et al.*, 2011; McKhann *et al.*, 2011; Rascovsky *et al.*, 2011). Clinical diagnosis was established by a multidisciplinary team including a behavioral neurologist, neuropsychologist, and occupational therapist. As part of the cognitive evaluation, participants completed the Addenbrooke's Cognitive Examination (ACE), either the Revised or third version (Mioshi *et al.*, 2006, 2010; Hsieh *et al.*, 2013; So *et al.*, 2018). The ACE is a cognitive screening instrument that includes measures of attention, memory, fluency, language, and visuospatial function. Where necessary in the current study, ACE-R Total, Attention, Language and Visuospatial subdomain scores were converted to equivalent ACE-III scores as previously described (So *et al.*, 2018). Disease severity was measured using the Frontotemporal Lobar Degeneration Modified Clinical Dementia Rating Scale Sums of Boxes (CDR-FTLD; Knopman *et al.*, 2008), where higher CDR-FTLD scores denote greater disease severity.

Ninety age- and education-matched healthy controls were also included in the study. Controls were recruited from our panel of volunteers or from the community and scored >88/100 on the ACE. Exclusion criteria for all participants included the following: concurrent psychiatric diagnosis, presence of other dementia or neurological disorders affecting the central nervous system, traumatic brain injury with loss of consciousness >5 minutes, and history of alcohol or substance abuse.

All participants or their person responsible provided written informed consent in accordance with the Declaration of Helsinki. The South Eastern Sydney Local Health District and the University of New South Wales ethics committees approved the study.

Facial emotion recognition assessment

Facial emotion recognition was assessed using the FAST (Kumfor *et al.*, 2014; Miller *et al.*, 2012). In this task, participants are shown arrays of seven faces from the same person, expressing the six basic emotions (*happy, angry, sad, surprise, fear, and disgust*) and a neutral expression and asked to point to a verbally cued target (e.g. "point to the *angry* face"). Stimuli for this task were from the NimStim database (http://www.macbrain.org) and were unfamiliar identities to the participant. All faces were cropped to remove extraneous features such as hair, converted to grayscale and presented using Microsoft PowerPoint. The task comprised 42 trials and performance was untimed. No feedback was given during the task. One point was given for each correct answer and zero for an incorrect answer. Accuracy was converted to a percentage correct score for statistical analysis. In addition to the overall score, responses for each individual item were recorded to enable error analysis.

Statistical analyses

Data were analyzed using SPSS version 24.0 (IBM). Shapiro–Wilk tests were conducted to check assumptions of normality. All variables were normally distributed. Chi-squared test was used to assess dichotomous variables (i.e. sex). ANOVAs were used to assess group differences on demographic measures and overall performance on the FAST, followed by Bonferroni post hoc tests where appropriate. Performance on individual emotions was first analyzed using a repeated-measures ANOVA. Given the presence of a significant emotion by group interaction, group performance on each emotion was examined individually with univariate ANOVAs followed by Bonferroni post hoc tests where appropriate. Finally, the patterns of errors for each emotion were investigated with multivariate ANOVAs followed by Bonferroni post hoc tests where relevant. For all analyses, statistical significance was set at $p < .05$.

Results

Demographic and cognitive performance

No significant group differences were found for age ($F(5, 286) = 1.756$, $p = .122$), sex distribution ($\chi^2(5) = 4.552$, $p = .473$), or years of education ($F(5, 286) = 2.129$, $p = .062$) (Table 1). Disease duration was similar across patient groups ($F(4,197) = 1.891$, $p = .113$). Overall, group differences in general cognition were present as demonstrated by the ACE total score ($F(5, 286) = 68.607$, $p < .001$), with all clinical groups performing significantly worse than controls (all p values $< .001$). Among the clinical groups, bvFTD and PNFA performed better than AD and SD-left on the ACE, with PNFA also outperforming SD-right (all p values $< .007$) (Table 1). Disease severity, as indexed by the CDR-FTLD, was significantly different across groups ($F(5, 214) = 32.925$, $p < .001$), with all the clinical groups scoring significantly higher than controls, with the exception of PNFA (Table 1). In addition, the PNFA group scored lower than the AD, bvFTD, and SD-right groups, and the SD-left group scored lower than the SD-right group.

Facial emotion processing

The total FAST score and performance on the individual emotions are presented in Figure 1 and Table 2. A significant group difference was present

https://doi.org/10.1017/S1041610223000297

Table 1. Demographic characteristics and cognitive performance for the clinical groups (AD, bvFTD, SD-left, SD-right, and PNFA) and healthy controls

	CONTROLS ($N = 90$)	AD ($N = 76$)	BVFTD ($N = 62$)	SD-L ($N = 29$)	SD-R ($N = 14$)	PNFA ($N = 21$)	F-VALUE	POST HOC TESTS[A]
Sex (F:M)	44:46	30:46	23:39	11:18	6:8	12:9	4.552[#]	–
Age (years)	65 ± 5.4	65 ± 8.4	62 ± 5.7	63 ± 6.0	63 ± 7.2	65 ± 10.1	1.756	–
Education (years)	13.5 ± 2.7	12.1 ± 3.4	12.3 ± 3.2	12.8 ± 3.0	12.8 ± 3.7	13.4 ± 3.1	2.129	–
Disease duration (m)	–	43 ± 24	47 ± 27	55 ± 26	56 ± 20	43 ± 29	1.891	–
ACE Total (/100)	96 ± 3.4	68.6 ± 13.8	76.9 ± 13.8	62.2 ± 14.0	67.6 ± 15.5	81.6 ± 9.0	68.607[*]	bvFTD, PNFA > AD, SD-L; PNFA > SD-R
CDR-FTLD	0.2 ± 0.3	4.6 ± 2.4	5.7 ± 2.6	3.3 ± 1.8	4.8 ± 3.3	1.8 ± 3.0	32.925[*]	SD-L > bvFTD; PNFA > AD, SD-R, bvFTD

Note. Values are mean ± standard deviation. [*]$p < .001$; [#]Chi-square value; highlighted cells denote significant differences with Controls. [A]Significant post hoc tests across clinical groups. ACE = Addenbrooke's Cognitive Examination; AD = Alzheimer's disease; bvFTD = behavioral-variant frontotemporal dementia; CDR-FTLD = Frontotemporal Lobar Degeneration Modified Clinical Dementia Rating Scale Sums of Boxes; F:M = female : male; m = months; PNFA = progressive non-fluent aphasia; SD-L = semantic dementia, left-sided; SD-R = semantic dementia, right-sided; y = years.

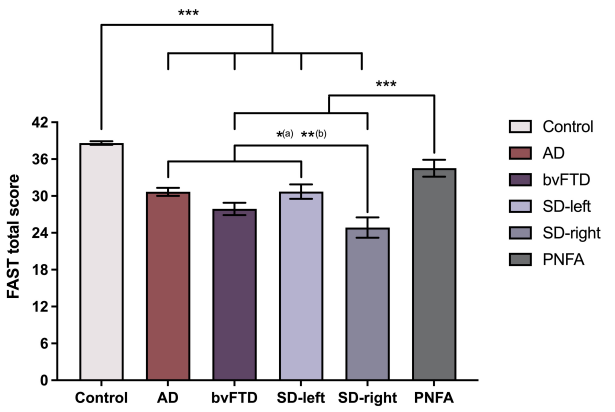

Figure 1. Facial Affect Selection Task (FAST) total score across groups. Error bars represent the standard error of the mean. *$p < .05$, **$p < .01$, ***$p < .001$; significant difference between SD-Right and AD (a) and SD-Left (b). AD = Alzheimer's disease. bvFTD = behavioral-variant frontotemporal dementia. PNFA = progressive non-fluent aphasia. SD = semantic dementia.

on total FAST performance ($F(5, 286) = 36.24$, $p < .001$) (Figure 1). Post hoc tests revealed that all clinical groups were impaired compared with controls (all p values $< .001$), with the exception of PNFA ($p = .051$). Among the clinical groups, the SD-right group performed significantly lower than all the other groups (all p values $< .027$), and the bvFTD group also scored lower than the PNFA group ($p < .001$). No other statistical differences were present across the clinical groups.

Analyses of the individual emotions using a repeated-measures ANOVA revealed an emotion by group interaction ($F(30, 1425) = 5.360$, $p < .001$). This interaction was investigated for each emotion with separate ANOVAs, which uncovered, in each instance, a significant group difference. Post hoc tests showed that, compared with controls, all clinical groups were impaired for the detection of *disgust* (all p values $< .001$). Furthermore, with the exception of PNFA, all groups were impaired for all the other negative emotions (*anger, fear, sadness*) as well as for *surprise* compared with controls (all p values $< .002$). The AD and bvFTD groups were also impaired for the detection of *happiness* and *neutral* (both p values $< .001$), and the SD-right group was also impaired for the detection of *neutral* emotions ($p = .029$).

Error pattern analyses

We investigated the frequency and profiles of errors made for each emotion. Overall (i.e. regardless of group membership), the most frequent errors were in response to the target emotions *disgust* and *fear*; together, these incorrect responses accounted for almost half of all errors made on this task (26.1% and 22.9%, respectively). The next most frequent

https://doi.org/10.1017/S1041610223000297

Table 2. Total and accuracy (%) scores on the Facial Affect Selection Task (FAST) across clinical groups and healthy controls

	CONTROLS	AD	BVFTD	SD-L	SD-R	PNFA	*F*-VALUE	POST HOC TESTS[A]
FAST Total (/42)	38.6 ± 2.7	30.7 ± 5.7	27.9 ± 7.9	30.7 ± 6.4	24.9 ± 6.2	34.5 ± 6.3	36.240**	PNFA, bvFTD, SD-L > SD-R; PNFA > bvFTD
Happy	99 ± 1.8	91 ± 14.2	91 ± 16.4	97 ± 7.8	94 ± 14.0	97 ± 6.7	7.236**	
Sad	88 ± 14.3	74 ± 23.0	65 ± 28.2	68 ± 25.2	46 ± 21.9	83 ± 19.3	15.115**	SD-R < AD, SD-L, PNFA; bvFTD < PNFA
Angry	96 ± 8.4	83 ± 18.7	69 ± 26.0	79 ± 20.2	58 ± 20.4	87 ± 22.7	20.754**	SD-right, bvFTD < AD, PNFA; SD-R < SD-L
Disgust	87 ± 16.1	55 ± 27.9	49 ± 29.6	58 ± 31.1	36 ± 29.9	70 ± 23.9	19.264**	
Fear	79 ± 22.8	52 ± 26.7	51 ± 20.9	41 ± 26.2	39 ± 19.2	60 ± 32.7	25.154**	bvFTD, SD-R < PNFA
Neutral	99 ± 4.5	79 ± 24.1	72 ± 31.6	93 ± 19.2	80 ± 21.9	92 ± 14.5	14.712**	AD, bvFTD < SD-L; bvFTD < PNFA
Surprise	95 ± 11.0	78 ± 23.3	68 ± 29.5	76 ± 30.4	61 ± 33.7	88 ± 21.2	13.515**	bvFTD, SD-R < PNFA

Note. Scores are shown as means ± standard deviations. Highlighted cells denote significant differences with Controls. [A]Significant post hoc tests across clinical groups. AD = Alzheimer's disease. bvFTD = behavioral-variant frontotemporal dementia. SD-L = semantic dementia left SD-R = semantic dementia right. PNFA = progressive non-fluent aphasia. **$p < .001$.

incorrect response was to the target emotion *sadness* (15.6% of all errors made).

The patterns of errors are displayed in the heat maps in Figure 2. Errors mostly arose in response to negative target emotions and were generally within the same valence dimension (i.e. negative emotions were mistaken for another negative emotion). For each target emotion, we identified the primary error response (PER); that is, the emotion most commonly mistaken for the target emotion in each group (represented by black circles in each heat map, Figure 2).

Group differences in PER were investigated using multivariate analyses of variance. These analyses revealed two distinct patterns: PER for *happy*, *disgust*, *anger*, *surprise*, and *neutral* were the same for all groups (Figure 3A), except for *surprise* and *neutral* in the SD-right group (Figure 3B). In contrast, multiple PERs were observed across groups for *fear* and *sadness* (Figure 3C).

The PER for *happy* targets was *surprise* in all groups. Post hoc tests showed that AD and bvFTD tended to endorse *surprise* more frequently than controls (both p values < .001).

For *disgust* targets, the PER was *anger* in all groups. The AD, bvFTD, and SD groups were more likely to select this PER compared to controls (all p values < .001), and SD-left also endorsed *anger* significantly more frequently than PNFA ($p = .001$).

Response to *anger* targets revealed the opposite pattern with *disgust* being the PER for all groups. Post hoc tests showed that all groups, with the exception of PNFA, endorsed *disgust* more frequently than controls (all p values < .008). Among the clinical groups, SD-right selected the PER more frequently than AD, SD-left and PNFA, while bvFTD chose this PER more often than AD and PNFA (all p values < .002).

For *surprise* targets, the PER was *fear* for all groups, except for SD-right where it was *happy*. Post hoc tests showed that AD and bvFTD endorsed *fear* more frequently than controls (both p values < .007), while SD-right, AD, and bvFTD endorsed *happy* more often than controls (all p values < .015).

The PER in response to *neutral* targets was *happy* in all groups except for SD-right, where it was *fear*. Post hoc analyses showed that AD and bvFTD groups selected *happy* more frequently than the other groups (all p values < .001). The SD-right group selected *fear* significantly more frequently compared to all the other groups (all p values < .001).

The last two target emotions, *fear* and *sadness*, were associated with multiple PERs across groups (Figure 3). For the target emotion *fear*, four PERs emerged: *surprise* in controls and SD-left, *sadness* in SD-left and PNFA, *disgust* in bvFTD and SD-right,

https://doi.org/10.1017/S1041610223000297

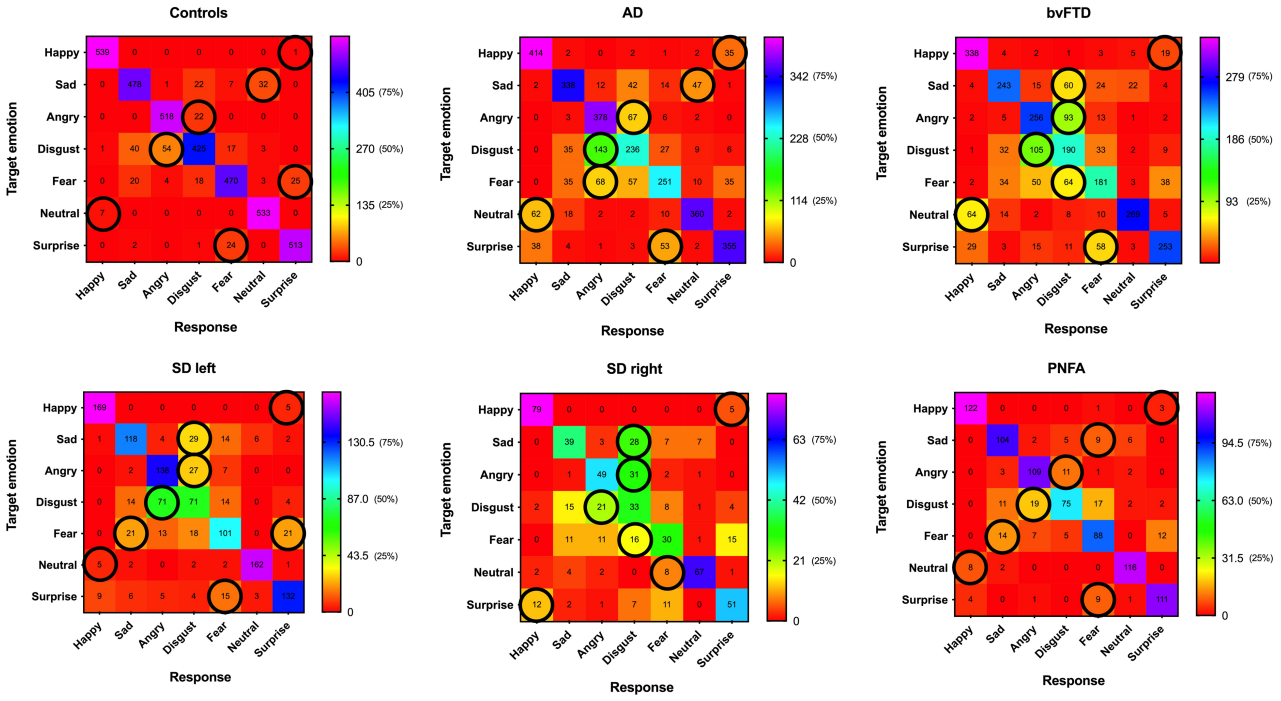

Figure 2. Heat maps of error matrix by group. Numbers show total number of responses to the target emotion. Circles show the primary error responses (PERs). AD = Alzheimer's disease. bvFTD = behavioral-variant frontotemporal dementia. SD = semantic dementia. PNFA = progressive non-fluent aphasia.

and *anger* in AD. Post hoc tests showed that SD-right endorsed *surprise* more often than controls ($p < .008$), while SD-left endorsed *sadness* more frequently than controls ($p < .018$), AD, SD-left and SD-right selected *disgust* more often than controls (all p values $< .003$), while SD-right chose *disgust* more frequently than PNFA ($p < .032$). Finally, AD and bvFTD endorsed *anger* more frequently than controls (both p values $< .001$).

For the target emotion *sadness*, three PERs emerged: *disgust* in bvFTD, SD-left and SD-right, *fear* in PNFA, and *neutral* in controls and AD. Post hoc tests revealed that *disgust* was endorsed more frequently by SD-right than by any other groups (all p values $< .003$) and more frequently by bvFTD and SD-left compared with controls (both p values $< .001$). All clinical groups selected *fear* more often than controls, with the exception of AD (all p values $< .039$). No significant group differences were observed with regard to the selection of *neutral* as an incorrect response.

Discussion

To our knowledge, this is the first study to systematically investigate patterns of error responses in FTD subtypes and AD in a task of basic facial emotion recognition. Although errors were committed by participants in all clinical groups, error patterns differ across groups. Not surprisingly, errors were predominantly observed in response to negative emotions. These incorrect responses tended to be primarily between emotions within the same valence dimension (e.g. *fear* vs. *anger*) and appeared to involve subtle discrimination errors, rather than across valence dimensions (e.g. *happiness* vs. *sadness*). Findings for each basic emotion are discussed below, as well as their implication for our understanding of facial emotion processing disturbance in these younger-onset dementia syndromes and their diagnosis.

Overall, a significant deficit in facial emotion recognition was observed in all dementia groups when compared with the healthy controls, supporting our first hypothesis, a finding consistent with previous research (Bora, *et al.*, 2016; Hutchings *et al.*, 2017; Kumfor and Piguet, 2012). The severity of the deficit, however, varied across groups with bvFTD and SD-right showing the lowest accuracy rate overall. In contrast, the PNFA group was only mildly impaired, with the difference in performance with the control group approaching statistical significance. When examining each basic emotion separately, difficulties recognizing the facial emotions were most pronounced for the negative emotions (anger, disgust, fear, sadness), in line with previous studies (Kumfor *et al.*, 2011; Kumfor and Piguet, 2012; Park *et al.*, 2017; Savage *et al.*, 2014), and for surprise. Most commonly, the negative target

https://doi.org/10.1017/S1041610223000297

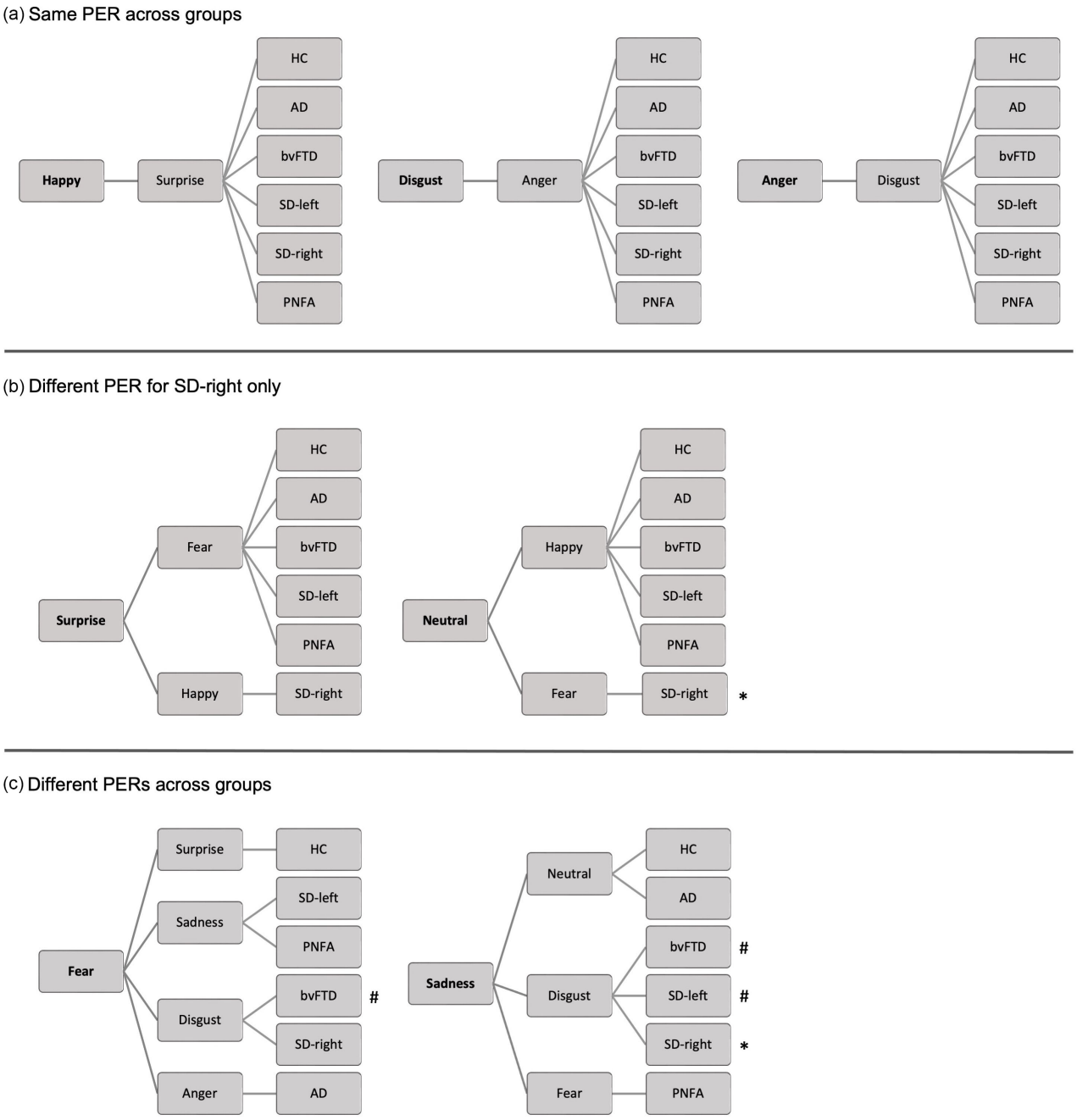

Figure 3. Primary error responses (PERs) across study groups. The first column represents the target emotion, the second column the PER, followed, in the third column, by the group. * = significantly more PERs in SD-right than in all the other groups ($p < .05$). # = significantly more PERs in bvFTD and SD-left than in PNFA ($p < .05$). AD = Alzheimer's disease. BvFTD = behavioral-variant frontotemporal dementia. HC = healthy controls. SD = semantic dementia. PNFA = progressive non-fluent aphasia.

emotions were primarily mistaken for other negative emotions. The notable exception, however, was, for the emotions *surprise* (positive) and *fear* (negative), emotions which have different valences but are perceptually similar and share more muscle movements than they possess distinctive ones (Roy-Charland *et al.*, 2014). In addition, difficulties with neutral detection were also identified in SD-right, bvFTD and AD, as well as with happiness in bvFTD and AD. In contrast to the well-established reports of a facial emotion recognition disturbance in bvFTD, findings in SD-right have been mixed (Kamminga *et al.*, 2015; Mendez *et al.*, 2015). The present study demonstrates that SD-right patients are indeed severely impaired on facial emotion recognition, and this deficit extends across all emotion types.

Turning our attention to the error profiles, we demonstrated that the types of errors made to the

https://doi.org/10.1017/S1041610223000297

target emotions were similar across the clinical groups, providing limited support for our second hypothesis. The same PER was observed across the groups for three out of the seven displayed emotions (*happy, disgust, anger*). For another two emotions, *surprise* and *neutral*, all groups had the same PER, with the exception of SD-right, which tended to confuse *surprise* for *happy* (rather than for *fear* in the other groups) and *neutral* for *fear* (rather than *happy* in the other groups). For the remaining two emotions (*sadness, fear*), PERs across groups were more variable. Nevertheless, a common pattern emerged for *sadness* where three subtypes of FTD, SD-left, SD-right, and bvFTD, mistook this facial emotion for *disgust* significantly more frequently.

Further, although syndrome-specific error patterns were not identified, the PERs in bvFTD and SD-right were more commonly *disgust*. This emotion was never endorsed as the PER by the other groups, with the exception of *anger* where it was the PER for all groups including controls. Whether this default error response in bvFTD and SD-right reflects, a shared cognitive or biological mechanism will require further investigations but would align with the overlapping clinical features between these two clinical populations previously documented (e.g. changes in eating habits, increased behavioral rigidity) (Sato *et al.*, 2021; Younes *et al.*, 2022).

Notably, profiles of errors were not random, providing support for our third hypothesis. Indeed, errors tended to occur with emotions that were perceptually similar and followed a predicted model of errors based on confusability (Young *et al.*, 2002). Nevertheless, reciprocal error patterns were found for only two emotions: *disgust* and *anger* in all groups, including controls. This shared disturbance would suggest the presence of a common breakdown in high-level cognitive emotion categorization for these two emotions. The absence of reciprocity and increasing variable patterns of error responses for the other emotions would indicate the combination of low- (perceptual, configural) and high- (classification) cognitive mechanisms. This is best illustrated with *fear* and *sadness,* emotions which had different PERs across groups and also greater within-group variability in errors, as shown by the heat maps in Figure 2. For these two emotions, errors were spread across most other negative emotions.

Although the dementia groups could not be distinguished based on PERs alone, our findings have important clinical implications during the clinical workup for dementia. Our results indicate that the recording of error responses during a facial emotion recognition task has relevance, but only if the differential diagnosis under consideration includes bvFTD or one of the SD subtypes. For the other groups, these data do not help differentiate across groups. It would then be sufficient to only record accuracy (i.e. correct or incorrect response). Moreover, for the sake of clinical efficiency, it appears that testing negative facial emotion recognition during screening cognitive assessment is sufficient, as recognition of positive emotions seems to be generally preserved across dementia groups.

Arguably, one limitation of this study relates to the method of testing and the use of static, black and white, two-dimensional faces, which bear little resemblance to real-life situations. In recent years, a growing body of research has used dynamic stimuli or images that have contained contextual information (Goodkind *et al.*, 2015; Kumfor *et al.*, 2018). Regardless of the testing method used, however, facial emotion processing disturbance has been found in bvFTD. Whether the pattern of errors would differ across FTD subtypes using these novel approaches remain to be investigated. The cross-sectional design of the study may also be another potential limitation. Indeed, it is possible that the profiles of errors may change with disease progression, which may help distinguish across these dementia syndromes.

In sum, this study was the first to examine systematically patterns of error response in facial emotion recognition across all subtypes of FTD. Research involving the SD-right subtype has been limited to date, and this study demonstrates that this group differs from the more common SD-left group and the other FTD groups. Nevertheless, this study also demonstrates that FTD subtypes cannot be distinguished based on error response alone. These findings add to previous research showing impaired facial emotion recognition in FTD subtypes, with bvFTD and SD-right having the poorest performance. It remains a challenge to clinically differentiate different subtypes of FTD, and more research should be done to gain insight into facial emotion recognition in FTD. Understanding the emotion recognition deficits specific to each FTD subtype may assist the management of the disease, as well as help to improve carer burden.

Conflict of interest

None.

Description of authors' roles

K Gressie planned the study, analyzed the data, and wrote the initial version of the manuscript. F Kumfor was involved in the analysis of the data and manuscript revision. H Teng was involved in data

https://doi.org/10.1017/S1041610223000297

collection and manuscript preparation. D Foxe provided statistical advice and was involved in manuscript revision and figure preparation. E Devenney was involved in data collection and manuscript revision. R Ahmed was involved in data collection and manuscript revision. O Piguet was responsible for the study design, supervision of data collection and analysis, and overall manuscript preparation.

Acknowledgements

This work was supported in part by funding to ForeFront, a collaborative research group dedicated to the study of frontotemporal dementia and motor neuron disease, from the National Health and Medical Research Council (NHMRC) (GNT1037746). In addition, this study was supported by NHMRC Project Grant (GNT1121791). FK is supported by an NHMRC Career Development Fellowship (GNT1158762). OP is supported in part by a NHMRC Leadership Fellowship (GNT2008020).

References

Bertoux, M., de Souza, L. C., Sarazin, M., Funkiewiez, A., Dubois, B. and Hornberger, M. (2015). How preserved is emotion recognition in Alzheimer disease compared with behavioral variant frontotemporal dementia? *Alzheimer Disease & Associated Disorders*, 29, 154–157. https://doi.org/10.1097/WAD.0000000000000023.

Bora, E., Velakoulis, D. and Walterfang, M. (2016). Meta-analysis of facial emotion recognition in behavioral variant frontotemporal dementia: comparison with Alzheimer disease and healthy controls. *Journal of Geriatric Psychiatry and Neurology*, 29, 205–211. https://doi.org/10.1177/0891988716640375.

Couto, B. *et al.* (2013). Structural neuroimaging of social cognition in progressive non-fluent aphasia and behavioral variant of frontotemporal dementia. *Frontiers in Human Neuroscience*, 7, 467. https://doi.org/10.3389/fnhum.2013.00467.

Coyle-Gilchrist, I. T. S. *et al.* (2016). Prevalence, characteristics, and survival of frontotemporal lobar degeneration syndromes. *Neurology*, 86, 1736–1743. https://doi.org/10.1212/WNL.0000000000002638.

Frith, C. (2009). Role of facial expressions in social interactions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364, 3453–3458. https://doi.org/10.1098/rstb.2009.0142.

Goodkind, M. S. *et al.* (2015). Emotion recognition in frontotemporal dementia and Alzheimer's disease: a new film-based assessment. *Emotion*, 15, 416–427. https://doi.org/10.1037/a0039261.

Gorno-Tempini, M. L. *et al.* (2011). Classification of primary progressive aphasia and its variants. *Neurology*, 76, 1006–1014. https://doi.org/10.1212/WNL.0b013e31821103e6.

Hogan, D. B. *et al.* (2016). The prevalence and incidence of frontotemporal dementia: a systematic review. *Canadian Journal of Neurological Sciences*, 43, S96–S109. https://doi.org/10.1017/cjn.2016.25.

Hsieh, S., Irish, M., Daveson, N., Hodges, J. R. and Piguet, O. (2013). When one loses empathy: its effect on carers of patients with dementia. *Journal of Geriatric Psychiatry and Neurology*, 26, 174–184. https://doi.org/10.1177/0891988713495448.

Hutchings, R., Palermo, R., Piguet, O. and Kumfor, F. (2017). Disrupted face processing in frontotemporal dementia: a review of the clinical and neuroanatomical evidence. *Neuropsychology Review*, 27, 18–30. https://doi.org/10.1007/s11065-016-9340-2.

Kamminga, J., Kumfor, F., Burrell, J. R., Piguet, O., Hodges, J. R. and Irish, M. (2015). Differentiating between right-lateralised semantic dementia and behavioural-variant frontotemporal dementia: an examination of clinical characteristics and emotion processing. *Journal of Neurology, Neurosurgery, and Psychiatry*, 86, 1082–1088. https://doi.org/10.1136/jnnp-2014-309120.

Knopman, D. S. *et al.* (2008). Development of methodology for conducting clinical trials in frontotemporal lobar degeneration. *Brain*, 131, 2957–2968. https://doi.org/10.1093/brain/awn234.

Kumfor, F. *et al.* (2011). Are you really angry? The effect of intensity on facial emotion recognition in frontotemporal dementia. *Social Neuroscience*, 6, 502–514. https://doi.org/10.1080/17470919.2011.620779.

Kumfor, F. *et al.* (2016). On the right side? A longitudinal study of left- versus right-lateralized semantic dementia. *Brain*, 139, 986–998. https://doi.org/10.1093/brain/awv387.

Kumfor, F., Ibanez, A., Hutchings, R., Hazelton, J. L., Hodges, J. R. and Piguet, O. (2018). Beyond the face: how context modulates emotion processing in frontotemporal dementia subtypes. *Brain*, 141, 1172–1185. https://doi.org/10.1093/brain/awy002.

Kumfor, F. and Piguet, O. (2012). Disturbance of emotion processing in frontotemporal dementia: a synthesis of cognitive and neuroimaging findings. *Neuropsychology Review*, 22, 280–297. https://doi.org/10.1007/s11065-012-9201-6.

Kumfor, F., Sapey-Triomphe, L. A., Leyton, C. E., Burrell, J. R., Hodges, J. R. and Piguet, O. (2014). Degradation of emotion processing ability in corticobasal syndrome and Alzheimer's disease. *Brain*, 137, 3061–3072.

Marshall, C. R. *et al.* (2019). The functional neuroanatomy of emotion processing in frontotemporal dementias. *Brain*, 142, 2873–2887. https://doi.org/10.1093/brain/awz204.

McKhann, K., *et al.* (2011). The diagnosis of dementia due to Alzheimer's disease: recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia*, 7, 263–269.

Mendez, M. F., Ringman, J. M. and Shapira, J. S. (2015). Impairments in the face-processing network in developmental prosopagnosia and semantic dementia. *Cognitive and Behavioral Neurology: Official Journal of the Society for Behavioral and Cognitive Neurology*, 28, 188–197. https://doi.org/10.1097/WNN.0000000000000077.

Miller, L. A., Hsieh, S., Lah, S., Savage, S., Hodges, J. R. and Piguet, O. (2012). One size does not fit all: face emotion processing impairments in semantic dementia, behavioural-variant frontotemporal dementia and alzheimer's disease are mediated by distinct cognitive deficits. *Behavioural Neurology*, 25, 53–60.

Mioshi, E., Dawson, K., Mitchell, J., Arnold, R. and Hodges, J. R. (2006). The Addenbrooke's Cognitive Examination Revised (ACE-R): a brief cognitive test battery for dementia screening. *International Journal of Geriatric Psychiatry: A journal of the psychiatry of late life and allied sciences*, 21, 1078–1085.

Mioshi, E., Hsieh, S., Savage, S., Hornberger, M. and Hodges, J. R. (2010). Clinical staging and disease progression in frontotemporal dementia. *Neurology*, 74, 1591–1597. https://doi.org/10.1212/WNL.0b013e3181e04070.

Park, S. *et al.* (2017). Behavioral and neuroimaging evidence for facial emotion recognition in elderly Korean adults with mild cognitive impairment, Alzheimer's disease, and frontotemporal dementia. *Frontiers in Aging Neuroscience*, 9, 389. https://doi.org/10.3389/fnagi.2017.00389.

Piguet, O. and Kumfor, F. (2020). Frontotemporal dementias: main syndromes and underlying brain changes. *Current Opinions in Neurology*, 33, 215–221.

Piguet, O., Leyton, C. E., Gleeson, L. D., Hoon, C. and Hodges, J. R. (2015). Memory and emotion processing performance contributes to the diagnosis of non-semantic primary progressive aphasia syndromes. *Journal of Alzheimer's Disease*, 44, 541–547. https://doi.org/10.3233/JAD-141854.

Rascovsky, K. *et al.* (2011). Sensitivity of revised diagnostic criteria for the behavioural variant of frontotemporal dementia. *Brain*, 134, 2456–2477. https://doi.org/10.1093/brain/awr179.

Roy-Charland, A., Perron, M., Beaudry, O. and Eady, K. (2014). Confusion of fear and surprise: a test of the perceptual-attentional limitation hypothesis with eye movement monitoring. *Cognition & Emotion*, 28, 1214–1222. https://doi.org/10.1080/02699931.2013.878687.

Sato, S. *et al.* (2021). Characteristics of behavioral symptoms in right-sided predominant semantic dementia and their impact on caregiver burden: a cross-sectional study. *Alzheimer's Research & Therapy*, 13, 166. https://doi.org/10.1186/s13195-021-00908-2.

Savage, S. A., Lillo, P., Kumfor, F., Kiernan, M. C., Piguet, O. and Hodges, J. R. (2014). Emotion processing deficits distinguish pure amyotrophic lateral sclerosis from frontotemporal dementia. *Amyotrophic Lateral Sclerosis and Frontotemporal Degeneration*, 15, 39–46. https://doi.org/10.3109/21678421.2013.809763.

So, M. *et al.* (2018). Addenbrooke's Cognitive Examination III: Psychometric Characteristics and Relations to Functional Ability in Dementia. *Journal of the International Neuropsychological Society*, 24, 854–863. https://doi.org/10.1017/S1355617718000541.

Spitzer, N., Shafir, T., Lerman, Y. and Werner, P. (2019). The relationship between caregiver burden and emotion recognition deficits in persons with MCI and early AD: the mediating role of caregivers' subjective evaluations. *Alzheimer Disease & Associated Disorders*, 33, 266–271. https://doi.org/10.1097/WAD.0000000000000323.

Ulugut, H. *et al.* (2021). Right temporal variant frontotemporal dementia is pathologically heterogeneous: a case-series and a systematic review. *Acta Neuropathologica Communications*, 9, 131. https://doi.org/10.1186/s40478-021-01229-z.

Van den Stock, J., Vandenbulcke, M., Sinke, C. B., Goebel, R. and de Gelder, B. (2014). How affective information from faces and scenes interacts in the brain. *Social Cognitive and Affective Neuroscience*, 9, 1481–1488. https://doi.org/10.1093/scan/nst138.

Younes, K. *et al.* (2022). Right temporal degeneration and socioemotional semantics: semantic behavioural variant frontotemporal dementia. *Brain*, 145, 4080–4096. https://doi.org/10.1093/brain/awac217.

Young, A., Perrett, D., Calder, A., Sprengelmeyer, R. and Ekman, P. (2002). *Facial Expressions of Emotion: Stimuli and Tests (FEEST)*. Bury St. Edmunds: Thames Valley Test Company.