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Diminished Visual Attention to Emotional Faces Is Associated with Poor Emotional Valence Perception in Frontotemporal Dementia

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Keywords

Visual attention · Emotion · Eye-tracking · Frontotemporal dementia

Abstract

Aim: The current study examined whether visual attention to emotional facial expressions is lower in individuals with frontotemporal dementia (FTD) compared to healthy controls, and whether visual attention to emotional facial expressions is associated with the ability to perceive others' emotional valence accurately. ***Methods:*** Participants with FTD (n = 17) and healthy controls (n = 23) passively viewed pairs of emotional and neutral faces while their visual attention was measured using eye-tracking. A subsample of participants (n = 28) also completed an emotional valence perception task. ***Results:*** Individuals with FTD spent less time looking at emotional faces than healthy controls. However, there was no difference in the amount of time individuals with FTD spent looking at neutral faces as compared to healthy controls. In the subsample, less time spent looking at emotional faces (but not neutral faces) was associated with a less accurate perception of others' emotional valence. ***Conclusion:*** Individuals with FTD displayed diminished visual attention to emotional facial expressions compared to healthy controls. Reduced attention towards emotional faces was associated with poorer emotional valence perception. Findings point toward diminished visual attention as potentially relevant for understanding oft-observed impairments in socioemotional functioning in FTD.

Introduction

Visual attention provides a valuable window into our emotional lives – the things we look at and look away from are major determinates of our feelings and behaviors [1, 2]. In neurotypical individuals, emotional facial expressions attract heightened visual attention and convey important information that helps us navigate the social world [3–5]. A smiling face may indicate an opportunity for social connection, whereas expressions of anger or fear can signal threats [6–8]. With this information in hand, sound decisions can be made about who to approach and who to avoid. Inattention to facial expressions may result in not having critical information about others' emotions, desires, and reactions, which may lead to poor behavioral choices, social errors, and damage to important social relationships.

Social and emotional deficits are common symptoms of frontotemporal dementia (FTD), a disease character-

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ized by progressive neurodegeneration in frontal and temporal lobe circuits [9, 10]. Neurodegeneration in these circuits leads to deficits in the ability to perceive others' emotions accurately [11–15]. However, few studies have examined whether individuals with FTD have diminished visual attention towards emotional facial expressions and whether these visual attention deficits relate to deficits in emotion perception.

Behavioral variant frontotemporal dementia (bvFTD) and semantic variant primary progressive aphasia (svPPA) are two of the major subtypes of FTD [16, 17]. Although both subtypes can lead to emotion perception deficits [18, 19], bvFTD is characterized by primary deficits in socioemotional functioning [20], whereas svPPA is characterized by primary deficits in language [17]. As svPPA progresses, expanding atrophy can result in socioemotional symptoms that are difficult to distinguish from those in bvFTD [21]. Neural regions that atrophy in these disorders, such as the amygdala [22] and ventromedial prefrontal cortex [23], are thought to play an important role in the automatic processing of emotional facial expressions and the detection of salient visual stimuli [24–28]. Thus, declines in visual attention towards emotional faces may result from damage to critical underlying circuitry in these diseases.

Existing research has not been definitive as to these issues. In one study examining visual attention to emotionally expressive faces in individuals with FTD, no significant differences were found between those with FTD and controls in the overall time spent looking at emotional faces [29]. However, participants in this study were shown one face at a time and were specifically instructed to look at each face. Thus, neither preference for emotional faces over non-emotional faces nor spontaneous attention to emotional faces was assessed. In the current study, we take a different approach by presenting participants with pairs of faces, one neutral and one emotional, and we do not instruct participants as to where to look. This allows us to capture visual preferences for emotional versus non-emotional faces and spontaneous attention in a more naturalistic manner. Past research on neurotypical individuals suggests that preferential attention for emotional faces versus neutral faces begins in early infancy [30–32]. Research is needed to examine whether individuals with FTD display diminished visual preferences for emotional faces and whether these are linked to deficits in perceiving emotion in others.

In the current study, we examined visual attention to emotional faces in individuals with the bvFTD and svPPA subtypes of FTD and a comparison group of healthy controls. We used a task in which participants viewed neutral and emotional face-pairs without specific attentional instructions while visual attention was monitored using eye-tracking technology. A subset of participants also completed an emotion perception task in which participants tracked the changing emotional valence of a character in a film using a rating dial.

We tested three hypotheses: (a) individuals with FTD would have less visual attention to emotional faces compared to healthy controls; (b) individuals with FTD would lack a visual preference for emotional faces over neutral faces; and (c) less visual attention to emotional faces (but not neutral faces) would be associated with less accurate perceptions of others' emotions. Finally, because there is evidence linking declines in visual attention to global cognitive impairments (e.g., orientation, visual processing, memory) in individuals with Alzheimer's disease [29, 33, 34], we included data from an assessment of global cognitive impairments in our participants. Because global cognitive impairments are less common in FTD than in Alzheimer's disease [35], we expected that less visual attention towards emotional faces in individuals with FTD would be associated with emotional perception impairments but not with global cognitive impairments.

Materials and Methods

Participants

There were forty participants in the study, including 17 individuals with FTD and 23 healthy controls. Of the 17 individuals with FTD, 10 met diagnostic criteria for bvFTD [20] and 7 met criteria for svPPA [17]. Participants with FTD were recruited through the Memory and Aging Center at the University of California, San Francisco (UCSF). At UCSF, participants received comprehensive diagnostic testing, including neuropsychological assessment, neurological examination, and structural magnetic resonance imaging. Testing was administered by a multidisciplinary team of neurologists, psychiatrists, psychologists, and nurses. Patient diagnoses were determined by a team of neurologists, after a thorough review of the above test measures. Disease severity was measured by the Clinical Dementia Rating Scale (CDR) and the CDR sum of boxes (CDR-Box) [36], and global cognitive impairment was measured by the Mini Mental State Exam (MMSE) [37]. Healthy control participants were recruited from the Bay Area community through advertisements and word of mouth. At UC Berkeley, all controls were screened by trained clinical psychology graduate students with the CDR and the MMSE. Healthy control participants were included and determined to be free of global cognitive and neurological impairments if they scored 0 on the CDR and 30 on the MMSE.

Procedure

All participants completed an eye-tracking face-pair task (see below) at the Berkeley Psychophysiology Laboratory at the University of California, Berkeley. Twenty-eight participants also

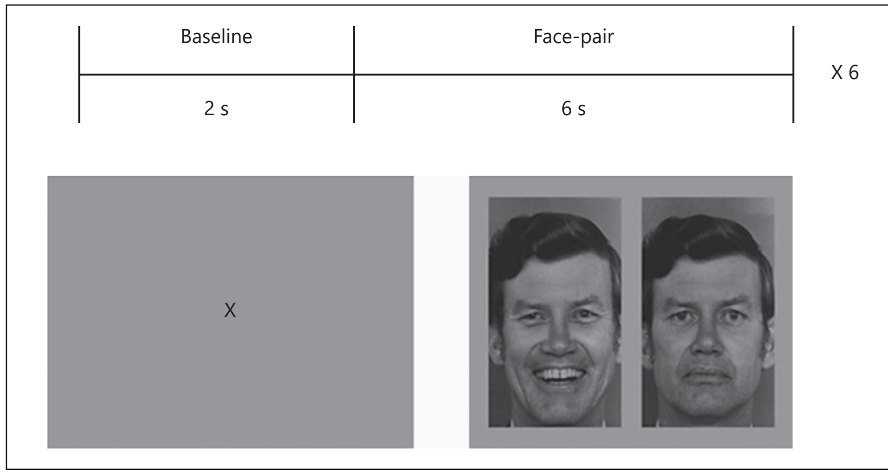

Fig. 1. Emotional face pair task. A total of six face-pairs were presented to the participants for 6 s each. Each emotional face (happy, sad, angry) was paired with a neutral face. The location of the emotional face alternated, such that one of each emotional face appeared on the left and one appeared on the right for each of the discrete emotions. In the sample shown, the happy face appears on the left and the neutral face on the right. Each face pair was preceded by a 2 s baseline, which depicted a black fixation point and a gray background. Participants were verbally instructed to, "watch the × please." Eye movements were tracked throughout the task.

completed an emotional valence perception task [38], including all participants with FTD (n = 17) and a subset of controls (n = 11). All procedures were approved by Berkeley's Committee for the Protection of Human subjects.

Eye-Tracking Face-Pair Task

Participants were seated 24 inches away from a 21-inch color television monitor. An Applied Sciences Laboratories head-mounted monocular eye tracking system (model number H6) was used to monitor eye movements. Following calibration procedures (using nine display points), participants passively viewed six face pairs (Fig. 1), while their eye movements were monitored. Each face pair consisted of an emotional face (happy, sad, or angry) paired with a neutral face. For each face pair, participants viewed a fixation screen (2 s) and then the face pair (6 s). There were 15 s between each face pair trial. All face images were selected from the Ekman and Friesen [39] Pictures of Facial Affect database, which consists of standardized black and white photographs of adults posing emotional expressions. The images measured 6.5 (w) × 10 (h) inches and were presented side by side on the computer monitor against a neutral gray background. Within each face pair, the person posing the emotional and neutral face was the same. Across face pairs, the persons differed, such that each face pair featured a different person. All the faces included in this task were those of males. Participants viewed two happy-neutral face pairs, two sad-neutral face pairs, and two angry-neutral face pairs. The position of the emotional and neutral faces alternated between pairs, such that each emotional face was presented on the left for one trial and on the right for one trial.

Emotional Valence Perception Task

Participants were seated in front of a color monitor with a rating dial located near their dominant hand. The rating dial consists of a small box with a rotating pointer that spans a 0–180° degree arc. The arc includes a nine-point scale and is labeled at three anchor points. The far left (0°) is labeled with the words "very bad" (depicted by a schematic frowning face), the middle (90°) is labeled "neutral" (90°), and the far right (180°) is labeled "very good" (depicted by a smiling face). Participants were instructed to adjust the rating dial as often as needed so that it consistently reflected the emotional valence of a target character in a film clip. The 80-s film clip is a Disney commercial and consists of a female target character expressing a wide range of positive and negative emotions after being given a gift by her male dinner companion. The dial generated a position-dependent voltage that was sampled by a computer every 3 milliseconds and averaged each second, resulting in a second-by-second time series of participant perceptions of the character's emotional valence.

Data Reduction

Time Spent Looking at Emotional and Neutral Faces

Using Gaze Tracker software (Version 06.04.26), regions of interest were drawn around each emotional and neutral face in the eye-tracking face-pair task. The software derives values that reflect the percent of time that participant's gaze fell within the regions of interest during the time tracked over the 6 s presentation period. For each face-pair, the gaze tracker software derived (1) the total percent of time spent looking at the emotional face and (2) the total percent of time spent looking at the neutral face. Given that each emotional face type (happy, sad, angry) paired with a neutral face was presented twice, the two values for each emotion type and its paired neutral face were averaged, resulting in 6 values (3 emotion face values and 3 neutral face values)[1] [40].

[1] Because each emotional face type (happy, angry, and sad) was repeated twice (with the emotional face on the right for the first repetition and on the left for the second repetition), we conducted a 2 × 2 × 3 repeated measures mixed model ANOVA with diagnosis as the between subjects factor (FTD vs. healthy controls), repetition (the emotional face presented on the right or on the left) and emotion as the within subject factor (sad, angry, happy) to determine if we could collapse across repetition. We found no significant repetition by diagnosis interaction ($F(1, 39) = 0.140$, $p = 0.711$ $\eta^2 = 0.004$). Therefore, we collapsed across repetition for future analyses. We did find a significant main effect of repetition ($F(1, 39) = F = 16.47$, $p < 0.001$ $\eta^2 = 0.315$), such that all individuals regardless of diagnosis spent more time looking at the first repetition, when the emotional face was on the left (52.3%, SE = 1.4) in contrast to the second repetition when the emotional face was on the right (44.4%, SE = 1.1). This left looking bias is common in eye-tracking studies [40].

Table 1. Participant demographic data by diagnostic group

Characteristics	HC	bvFTD	svPPA	Test statistics	Effect size (η^2)	*p* value
N	23	10	7			
Age	67.6 (5.0)	61.5 (5.0)*	64.7 (6.7)	$F(2, 39) = 5.5$	0.23	0.008
Sex (Male/Female)	9/14	9/2	5/2	$\chi^2 = (2, N = 40) = 6.31$		0.04
CDR-Box (0–12)	0 (0)	5.0 (2.2)**	4.3 (2.0)**	$F(2, 39) = 56.3$	0.78	<0.001
MMSE (0–30)	29.5 (0.57)	26.7 (3.4)*	24.7 (5.3)**	$F(2, 39) = 9.8$	0.35	<0.001
Emotional valence perception, %	85.9 (2.0)	48.7 (13.2)**	47.3 (5.6)**	$F(2, 26) = 8.68$	0.42	<0.001

bvFTD, behavioral variant frontotemporal dementia; HC, healthy controls; svPPA, semantic variant primary progressive aphasia; MMSE, Mini-Mental State Examination (0–30); CDR, clinical dementia rating (0–3 range, with 0 indicating no impairment); CDR-Box, Clinical Dementia Rating Scale (sum of boxes). For age, CDR-Box, MMSE, and Emotion Perception, the numbers indicate means (standard error). * Bonferroni adjusted means differed from controls at $p < 0.05$. ** Bonferroni adjusted means differed from controls at $p < 0.005$.

Emotional Valence Perception Accuracy

We determined each participant's accuracy in rating the valence of the target character in the film clip by comparing participants' dial ratings with those obtained from an expert panel of graduate students trained in behavioral coding [15, 41]. In line with previous research [42, 43], time-lagged cross-correlations were used to compute the association between each participant's ratings and expert ratings. To allow for processing and motor delays, the maximum correlation coefficient was selected for lags between −10 and +10 s (correlation coefficients ranged from −0.08 to 0.94). Higher values indicate more accurate emotional valence perception.

Global Cognitive Impairment

The Mini-Mental State Examination (MMSE) was used to measure global cognitive impairment. The MMSE is a 28-item measure which examines five domains of cognitive functioning, including memory, language, concentration/attention, abstraction/problem solving, and visuospatial information. The MMSE is well validated with older adults and individuals with dementia [37, 44].

Statistical Analysis

To increase power and limit type I error, we initially conducted our group-based analyses comparing all individuals with FTD to healthy controls. We then repeated these analyses, examining differences between three diagnostic groups (bvFTD vs. svPPA vs. healthy controls). Group differences in potential confounds including age, gender, and disease severity (as measured by CDR-Box) were assessed using independent sample *t*-tests. These analyses revealed group differences for age, gender, and CDR-Box in contrast to controls. Thus, we added these variables as covariates in subsequent between-group analyses.

To test our first hypothesis that individuals with FTD would have less attention to emotional faces, we examined diagnostic group differences in the percent of time spent looking at emotional faces using a 2 × 3 repeated measures mixed model ANOVA with diagnosis as the between subjects factor (FTD vs. healthy controls) and emotion as the within subjects factor (sad, angry, happy). Age, gender, and CDR-Box were also included in the model as covariates. Bonferroni corrections to control for type I error due to conducting multiple comparisons were used for all post hoc comparisons. To test our second hypothesis that individuals with FTD would lack a preference for emotional faces (relative to neutral faces), we conducted a 2 × 2 repeated measures mixed model ANOVA with diagnosis (FTD vs. healthy controls) as the between subjects factor and face type (emotional or neutral) as the within subjects factor.

Finally, to test our third hypothesis that less visual attention to emotional faces but not neutral faces would be associated with poorer emotional valence perception, we used correlations to examine associations between the percent time spent looking at emotional faces and neutral faces and performance on the emotional valence perception task. We also examined how visuals attention is related to cognitive impairment.

Results

Table 1 displays participant demographics. Preliminary analyses revealed group differences between participants with FTD and healthy controls in age, gender, and CDR-Box scores. The FTD group was significantly younger ($M_{diff} = 4.79$, SE = 1.59, $p = 0.005$); had a greater male to female ratio than the control group, $\chi^2(1, N = 39) = p < 0.027$; and had greater disease severity as compared to healthy controls ($M_{diff} = 4.71$, SE = 0.485, $p < 0.001$). Thus, in subsequent analyses we included age, gender, and CDR-box as covariates.

Hypothesis 1: Individuals with FTD Will Spend Less Time Looking at Emotional Faces Compared to Healthy Controls

The 2 (diagnosis) × 3 (emotional face) repeated measures ANOVA revealed a main effect for diagnosis ($F(1, 39) = 12.9$, $p < 0.001$, $\eta^2 = 0.27$), such that individuals with FTD spent less time (42.0%) looking at emotional faces compared to healthy controls (53.7%). The main effect of

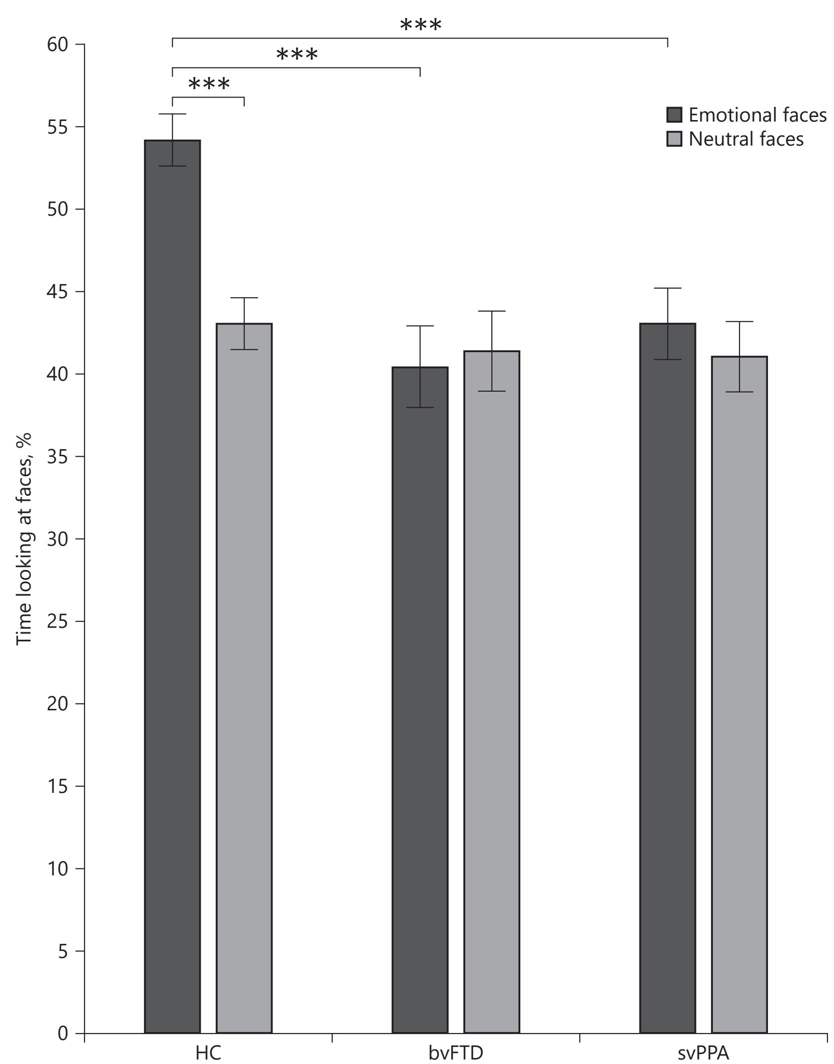

Fig. 2. Diagnostic group differences in mean time spent looking at emotional faces and neutral faces by diagnosis. ***$p < 0.001$. bvFTD = behavioral variant frontotemporal dementia, svPPA = semantic variant primary progressive aphasia, Group differences in percent time spent looking at emotional faces and neutral faces. A repeated measures mixed model ANOVA controlling for age, gender, and CDR-Box score revealed no interaction between percent time spent looking at specific emotional face type (emotional vs. neutral) and diagnosis (bvFTD, svPPA, NC), but did reveal a marginal face by diagnosis interaction ($F(2, 39) = 3.22$, $p = 0.052$, $\eta^2 = 0.15$) such that neither individuals with bvFTD ($M_{diff} = -0.961$, SE = 3.16, $p = 0.763$) or individuals with svPPA ($M_{diff} = 1.20$, SE = 2.753, $p = 0.473$) demonstrated no preference for emotional faces in contrast to neutral faces. Healthy controls demonstrated a visual preference for emotional faces as opposed to neutral faces ($M_{diff} = 11.14$, SE = 2.04, $p < 0.001$). We found diagnostic group differences in time spent looking at emotional faces such that individuals with bvFTD spent less time looking at emotional faces as compared to controls ($M_{diff} = -13.747$, SE = 3.78, $p < 0.001$). Similarly, individuals with svPPA spent less time looking at emotional faces as compared to controls ($M_{diff} = -11.12$, SE = 3.30, $p < 0.002$).

emotion and the diagnosis × emotion interaction were not significant. When we repeated these analyses comparing bvFTD, svPPA, and healthy controls, results were consistent, with a main effect of diagnosis on the time spent looking at emotional faces ($F(2, 39) = 7.34$, $p = 0.002$, $\eta^2 = 0.30$). No significant main effects of emotion or diagnosis × emotion interactions were observed in either model. Bonferroni corrected post hoc comparisons revealed that individuals with bvFTD and svPPA did not differ in time spent looking at emotional faces ($M_{diff} = 2.8$, SE = 2.3, $p = 0.695$) and both the bvFTD ($M_{diff} = 14.0$, SE = 3.7, $p = 0.002$) and the svPPA ($M_{diff} = 11.2$, SE = 3.3, $p = 0.005$) groups spent significantly less percent time looking at emotional faces compared to controls.

Hypothesis 2: Individuals with FTD Will Lack a Visual Preference for Emotional Faces in Contrast to Neutral Faces

Given that there were no significant differences by emotion type, we averaged across emotion types as an indication of the total time spent looking at emotional faces and the total time spent looking at neutral faces to test this hypothesis. Comparing individuals with FTD to healthy controls, we found a face type (emotion vs. neutral) by diagnosis (FTD vs. control) interaction ($F(1, 39) = 5.40$, $p = 0.026$, $\eta^2 = 0.13$). Bonferroni corrected post hoc comparisons revealed that healthy controls spent significantly more time looking at the emotional faces compared to the neutral faces ($M_{diff} = 6.76$, SE = 2.48, $p = 0.01$). How-

Table 2. Correlation table

	Average % time looking at emotional faces	Average % time looking at neutral faces	Emotional valence perception	MMSE
Average % time looking at emotional faces	–			
Average % time looking at neutral faces	0.063	–		
Emotional valence perception	0.450*	−0.137	–	
MMSE	0.103	0.004	0.512**	–

MMSE, Mini-Mental State Examination. * $p > 0.05$. ** $p < 0.01$.

ever, for individuals with FTD, time spent looking at emotional faces did not differ from time spent looking at neutral faces (M_{diff} = −0.944, SE = 2.55, p = 0.714). Although individuals with FTD looked significantly more at emotional faces compared to neutral faces (M_{diff} = 1.92, SE = 3.29, p = 0.001), FTDs and controls did not differ in the amount of time spent looking at neutral faces (M_{diff} = 11.61, SE = 3.18, p = 0.549). Similarly, when we examined the three groups separately (bvFTD, svPPA, controls), we found a marginal face by diagnosis interaction ($F(2, 39) = 3.22$, p = 0.052 η^2 = 0.16) with no preference for emotional faces in contrast to neutral faces observed for individuals with bvFTD (M_{diff} = −0.961, SE = 3.16, p = 0.763) or svPPA (M_{diff} = 1.20, SE = 2.753, p = 0.473). Controls demonstrated a visual preference for emotional faces as opposed to neutral faces (M_{diff} = 11.14, SE = 2.04, p < 0.001). Results are displayed in Figure 2.

Hypothesis 3: Less Visual Attention to Emotional Faces Will Be Associated with Less Accurate Emotional Valence Perception

We conducted correlations among variables of interest in the subset of participants who completed the emotional valence perception task (n = 16). Correlations are presented in Table 2. Across all participants (individuals with FTD and healthy controls), more time spent looking at emotional faces was associated with better emotional valence perception, r(27) = 0.450, p = 0.016.

To determine whether time spent looking at emotional faces was associated with global cognitive impairment, we examined the correlation between these measures and found them to be uncorrelated r(27) = 0.512, p = 0.520. Finally, percent time spent looking at neutral faces was associated with neither emotional valence perception nor global cognitive impairment.

Discussion

Given that diminished visual attention to emotional faces may have important links to the socioemotional deficits observed in neurodegenerative diseases, the current study explored visual attention to emotional faces in individuals with FTD as well as the relationship between visual attention to emotional faces and emotional valence perception. We examined whether: (a) individuals with FTD display less visual attention to emotional faces compared to healthy controls, (b) individuals with FTD lack a visual preference for emotional faces in contrast to neutral faces, and (c) less visual attention to emotional faces is associated with worse emotion perception. To address these questions, we used an eye-tracking face-pair task in which participants passively viewed emotional and neutral face pairs, as well as an emotional valence perception task in which participants rated the changing emotions of a character in a film. We found that, compared to healthy controls, participants with FTD displayed less visual attention to emotionally expressive faces. Further, individuals with FTD lacked a visual preference for emotional faces when shown both neutral and emotional faces (healthy controls showed a preference for emotional faces). Finally, in a subset of participants, we found that less visual attention to emotionally expressive faces was associated with worse performance on the emotional valence perception task.

To our knowledge, this is the first study to demonstrate that naturalistic visual attention to emotional faces is lower in individuals with FTD compared to healthy controls. Importantly, these differences in visual attention to emotional faces remained significant when controlling for age, gender, and disease severity. Differences were observed for individuals with two subtypes of FTD (bvFTD and svPPA). Thus, the frontal and temporal lobe neurodegeneration common across FTD subtypes likely plays an important role in diminished visual attention to emotional faces. This may include regions of the salience network and circuitry in visual attention network both of which include regions that are damaged in FTD [45, 46].

Past research demonstrates that emotionally expressive faces are naturally more salient and attention-commanding to healthy individuals than neutral faces [47] due to the important social information communicated by emotional facial expressions. In line with past research, healthy controls in the current study spent significantly more time gazing at emotional faces compared to neutral faces. Our finding that individuals with FTD lack this visual preference for emotional faces suggests that emotional information portrayed in faces has decreased salience for individuals with FTD. This would be consistent with the deficits in emotion perception often observed in individuals with FTD [18, 42].

Our results also point to an important link between diminished visual attention to emotional faces and worse emotional valence perception. Similar associations have been observed in neuropsychiatric disorders such as autism spectrum disorders (ASD) and schizophrenia. For example, less visual attention to emotional faces has been associated with a range of poor socioemotional functioning, including emotion perception in these individuals [48–51]. Importantly, we found no significant associations between emotional valence perception and the time spent looking at neutral faces or global cognitive impairments, suggesting that emotion perception deficits in FTD are tied specifically to attention towards emotional faces, rather than more global cognitive or attentional deficits.

Due to the correlational nature of our analysis, we cannot make causal inferences regarding the association between visual attention to emotional faces and emotional valence perception. It is possible that lower visual attention to emotional faces impacts the ability to recognize emotional experience and it is also possible that the inability to recognize emotion results in less visual attention to human faces. Furthermore, it may be that a third factor, such as lack of motivation to understand others, impacts both visual attention to emotional faces and emotion recognition. Nonetheless, prior research suggests that training individuals to look more at emotional faces can improve their ability to perceive emotion in others [52]. Future research should explore methods to increase attention toward emotional facial expressions in the early stages of FTD, and examine whether this leads to improved emotion perception and, if so, how long it is sustained. Although neurodegenerative diseases are progressive, intervening in the early stages of the disease may have benefits for the person with the disease as well as for caregivers who suffer from more depression and other health problems when the individual they care for has emotion perception deficits [15, 53, 54].

The current study was limited by a small sample size. Future studies should aim to replicate these findings in a larger sample and utilize neuroimaging methods to pinpoint the specific neural atrophy associated with diminished visual attention to emotional faces in FTD. Additionally, future research should examine if differences in visual preference for emotional faces in individuals with FTD are associated with diminished attention to specific facial features or atypical facial scanning patterns. This is important given that visual attention to facial features and patterns of facial scanning (e.g., the eyes-nose-mouth triangular pattern) seen in neurotypical adults [55] have been shown to be altered in individuals with neurological disorders [56]. Lastly, future studies should build upon these methods by also measuring visual attention during the emotional valence perception task. This would provide a direct measure of attentional deficits that occur during the processing of dynamic facial expressions.

Conclusion

Our study presents preliminary evidence that individuals with FTD, compared to healthy controls, display diminished visual attention to emotional facial expressions. This lack of attention towards emotional (but not neutral) facial expressions is associated with deficits in emotional valence perception. Given the aging population and the negative effects that emotion perception deficits can have on the health and well-being of individuals with neurodegenerative disease and their caregivers, future research should continue to examine naturalistic visual attention to emotional faces in FTD and work to develop and test interventions aimed at rectifying attentional deficits in the early stages of the disease.

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Statement of Ethics

This study protocol was reviewed and approved by the University of California Berkeley, Committee for Protection of Human Subjects (CPHS), and the Office for Protection of Human Subjects (OPHS) approval number 2010-02-861. Written informed consent was obtained from all study participants.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Ms. Suzanne M. Shdo was the primary contributor to the coauthored research. All the authors made substantial contributions to the conception and design of the work. Dr. Joyce Yuan was involved in a significant portion of the data acquisition. Ms. Suzanne M. Shdo conducted the data analysis with guidance from Drs. Casey L. Brown and Robert W. Levenson. All the authors participated in the interpretation of data for the work. Ms. Suzanne M. Shdo drafted the manuscript with assistance from Dr. Casey L. Brown. All the authors were involved in critical revisions and made important intellectual contributions to the manuscript. All the authors approved the final version of the manuscript for publication. All the authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Data Availability Statement

The data that support the findings of this study are not publicly available because they contain information that could compromise the privacy of the study participants; however, academic, not-for-profit investigators may request data for research studies from the corresponding author, R.W.L.

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