

## Preliminary findings on the relation between the personality trait of stress reaction and the central neural control of human vocalization

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### Abstract

The objectives of this study were to examine whether the personality trait of stress reaction (SR), as assessed with the *Multidimensional Personality Questionnaire-Brief Form (MPQ-BF)*, (1) influences prefrontal and limbic area activity during overt sentence reading and if (2) SR and associated individual differences in prefrontal and limbic activations correlate with sensorimotor cortical activity during overt sentence reading. Ten vocally healthy adults (22–57 years) participated in a functional MRI study using an event-related sparse sampling design to acquire brain activation data during sentence production tasks (covert, whispered, overt). The outcome measure was the blood oxygenation level-dependent signal change in prefrontal, limbic, and primary somatosensory (S1) and motor cortices (M1). Significant positive correlations were found between SR scores and S1, dorsolateral prefrontal cortex (both  $r = .73$ ,  $p < .05$ ), and periaqueductal gray ( $r = .88$ ,  $p < .01$ ) activity. M1 activity was positively correlated with SR ( $r = .64$ ,  $p < .05$ ) and negatively with social potency ( $r = -.70$ ,  $p < .05$ ). Our findings suggest that motor cortical control subserving voice and speech production varies with expression of selected personality traits. Future studies should investigate the functional significance of personality differences in the central neural control of vocalization.

**Keywords:** *Functional magnetic resonance imaging, voice, limbic system, stress reaction, personality.*

### Introduction

A biopsychosocial perspective of voice disorders has been advocated to achieve a more holistic understanding of a person's voice disorder and to guide diagnosis and treatment (Aronson, 1990; de Jong, Cornelis, Wuyts, Kooijman, Schutte, Oudes, et al., 2003; Nichol, Morrison, & Rammage, 1993). For instance, psychological stress (henceforth simply called "stress") is frequently observed in a variety of persons with voice disorders (Dietrich, Verdolini Abbott, Gartner-Schmidt, & Rosen, 2008; Seifert & Kollbrunner, 2005). It is generally presumed that stress can exacerbate or maintain voice problems and that stress can be the result of living with a voice disorder (Butcher, Elias, Raven, Yeatman, & Littlejohns, 1987; Roy, 2003; Smith, Verdolini, Gray, Nichols, Lemke, Barkmeier, et al., 1996). However, a far greater burden of evidence lies on the proposition that certain personality traits, such as being "introverted" or "neurotic", may predispose individuals to certain forms of voice disorders as suggested in the *Trait Theory of Voice Disorders* (Roy &

Bless, 2000). To complicate matters, neuroticism is a broad construct that reflects a predisposition for a wide range of negative emotionality including anxiety, stress reaction, hostility, and aggression (Costa & McCrae, 1992; Patrick, Curtin, & Tellegen, 2002; Suls & Martin, 2005). Differentiated research is needed on the relation of personality traits and its possible effects on the control of voice. To stimulate biopsychosocial research in voice science, we present the following overview of the literature and our preliminary study that focused on the relations among the personality trait of stress reaction, limbic activity, and select cortical regions subserving human vocalization.

Personality is the consistent manner in which a person processes perceptual, cognitive, and emotional information and how these processes modulate behaviour. Personality further refers to individual differences in neurophysiological structures and functioning in the brain that fundamentally underlie these tendencies (Patrick et al., 2002; Roberts, Wood, & Caspi, 2008). The *Trait Theory of Voice Disorders*

(henceforth called trait theory) is a model that proposes interactions between personality traits, dispositional behaviour, and vulnerabilities for voice disorders (Roy & Bless, 2000). The trait theory was developed with biological theories of personality in mind to predict individual differences in vocally-related laryngeal behaviour (Eysenck & Eysenck, 1985; Gray, 1982). One proposal derived from the trait theory is that a predisposition to react with anxiety to novel or threatening situations will activate a *behavioural inhibition system (BIS)* (Gray, 1982), which may influence motor cortical activity. This reaction pattern was characteristic of individuals psychometrically identified as introverts based on Eysenck's personality theory (Eysenck & Eysenck, 1985). According to Gray's (1982) theory on the neuropsychology of anxiety, the septo-hippocampal system plays a central role in mediating anxiety and behavioural inhibition. Updates to Gray's theory ascribe an equally important role to the amygdala (McNaughton & Corr, 2004) with other research suggesting that the anterior cingulate cortex may also be a key neural correlate of the *BIS* (Amodio, Master, Yee, & Taylor, 2008).

Psychobiological research to test the trait theory has drawn on affective science and health psychology to study individual differences in extralaryngeal behaviour (surface electromyography) under conditions of (1) emotion induction in participants with primary muscle tension dysphonia (van Mersbergen, Patrick, & Glaze, 2008) and (2) induced social-evaluative stress in vocally healthy participants assigned to an introversion group (Dietrich & Verdolini Abbott, 2012). Both studies found evidence suggestive of behavioural inhibition and findings that further encourage neurobiological research to study the underlying processes in the brain. A pathway for the effect of emotion on vocal control, the limbic vocal control pathway, has already been described in the voice science literature and will serve as a starting point into this brief review.

#### *The central neural control of emotional vocalization*

In primates, vocalization is considered an innate and stereotypic behaviour whose central regulation is dominated by subcortical and brainstem regions. This so-called limbic (cingulo-periaqueductal) vocal control pathway has been described in detail by Jürgens (2002, 2009). The principal components of this pathway include the anterior cingulate cortex (ACC), the midbrain periaqueductal gray (PAG), the nucleus retroambiguus (pre-motoneuronal site), nucleus tractus solitarius (second-order somatosensory neurons), and the nucleus ambiguus proper, the origin of laryngeal system lower motor neurons. Primates generally lack direct monosynaptic motor cortical projections to the nucleus ambiguus (Kuypers, 1958b). Emotion-, arousal-, and behaviour-regulating

regions such as the amygdala (AG), hypothalamus (HY), midline thalamus, and the ACC all provide modulatory input to the PAG (Beitz, 1982; Jürgens & Pratt, 1979; Marchand & Hagino, 1983; Meller & Dennis, 1986). The ACC acts to voluntarily initiate as well as suppress vocalization patterns in primates (Jürgens, 2002; Jürgens & von Cramon, 1982; Sutton, Larson, & Lindeman, 1974). The PAG encodes the incoming input, relays it to the brainstem's reticular formation, and facilitates voluntary as well as unconditioned species-specific vocal reactions (e.g., hissing) (Jürgens, 2002; Jürgens & Zwirner, 1996).

In contrast to primates, humans rely on a volitional and motor cortical vocal control pathway. The primary somatosensory and motor cortices play a major role in volitional laryngeal control during propositional speech (Barlow, Farley, & Andreatta, 1999; Ludlow, 2005). Projections from motor cortical areas to the nucleus ambiguus are mostly monosynaptic (Kuypers, 1958a), suggesting that humans have the anatomical substrate to cortically and intentionally mediate laryngeal lower motor neuron activity. Interestingly, innate and non-propositional vocalizations in humans with cortical lesions are spared (e.g., laughter, crying), suggesting that humans may possess two pathways for vocalization output, one that is cortically mediated and used for learned vocal behaviours and a second capable of generating emotionally-laden non-voluntary vocal patterns (Ludlow, 2005; Ludlow, Loucks, Simonyan, & Lowell, 2008).

Activation of components of the limbic vocal control pathway has been inconsistent in neuroimaging studies of voice during speech (fMRI, PET). Studies investigating propositional speech have reported activations of the ACC, neighbouring regions of the medial prefrontal cortex (mPFC; BA9,10) (Blank, Scott, Murphy, Warburton, & Wise, 2002; Schulz, Varga, Jeffries, Ludlow, & Braun, 2005), and PAG (Schulz et al., 2005). Other studies that used vowel, syllable, or humming vocalization tasks reported ACC activity, but did not find PAG activity specifically (Haslinger, Erhard, Dresel, Castrop, Roettinger, & Ceballos-Baumann, 2005; Loucks, Poletto, Simonyan, Reynolds, & Ludlow, 2007; Olthoff, Baudewig, Kruse, & Dechent, 2008). In yet a third set of studies, neither ACC nor PAG activity during sound, vowel, and speech production (words/phrases/reading) was noted (Brown, Laird, Pfordresher, Thelen, Turkeltaub, & Liotti, 2009; Brown, Ngan, & Liotti, 2008; Özdemir, Norton, & Schlaug, 2006).

Further, Simonyan and colleagues (Simonyan & Horwitz, 2011; Simonyan, Ostuni, Ludlow, & Horwitz, 2009) used structural and fMRI-based functional connectivity analysis to investigate laryngeal motor cortical (LMC) networks. Sensorimotor and motor planning structural connections were found for the premotor cortex, primary motor cortex (M1), somatosensory cortex (S1), inferior frontal

gyrus (IFG), and supplementary motor area (SMA) (Simonyan & Horwitz, 2011). Reciprocal structural connections with regions controlling motivation, emotion, cognition, and behaviour were found for the dorsolateral PFC (dlPFC), cingulate cortex, and thalamus. A unilateral connection from the LMC to the orbitofrontal cortex (OFC) was also noted. While functional connectivity was found between the LMC and the midbrain during overt syllable repetitions, activity in the PAG was not found specifically. Furthermore, ACC activity was found to be suppressed during overt syllable repetitions (Simonyan et al., 2009). The common explanation across these studies for any lack of ACC or PAG activation during voice production was that the experimental tasks did not elicit an emotional experience (Loucks et al., 2007; Ludlow et al., 2008; Simonyan et al., 2009).

Together, these reports indicate that neuroimaging studies to date have not been well suited to illuminate the role of the limbic vocal control pathway in human vocalization. Research has yet to identify the extent to which emotion-controlling cortical and subcortical regions are integrated with voice production loci and their potential modulatory consequences on vocal sensorimotor performance (Ludlow et al., 2008). To rectify this situation, knowledge about the limbic regulation of emotion, stress, and motor behaviour in humans should be incorporated with voice science to guide future research.

#### *The neural correlates of emotion in humans*

A recent meta-analysis of 162 neuroimaging studies in healthy adults using emotion induction or emotion experience (regardless of valence) investigated functional grouping (consistent patterns of co-activation) and cortical–subcortical interactions (Kober, Barrett, Joseph, Bliss-Moreau, Lindquist, & Wager, 2008), to determine if regions critical for emotion processing in animals (e.g., HY, PAG) are relevant in humans. Five functional groups were identified: (1) the occipital/visual association group and medial posterior group; (2) mPFC (dorsomedial PFC [dmPFC], ACC); (3) lateral paralimbic (OFC, ventral striatum [vSTr]); (4) core limbic (PAG, HY, vStr, thalamus, AG); and (5) a cognitive/motor network (lateral PFC – pre-SMA, IFG, frontal operculum [frOP]) (Kober et al., 2008). A noteworthy finding was that the dmPFC (BA9/32) was the only frontal region that co-activated with the HY and the PAG. Across studies, the dmPFC was found to act as an interface between cognitive context and core affect. Kober et al. suggested that activations of HY and PAG were likely related to emotional-cognitive appraisals with strong physiological consequences (e.g., autonomic arousal). In addition, the AG was co-activated with the dmPFC, ACC, and frOP.

Activity in insular and core limbic regions may influence more general motivational states, which in turn could influence attention and selection of action

in the cognitive/motor group (Kober et al., 2008). Thus, emotional processing networks ranged from prefrontal, limbic, to subcortical regions with implications for motor control. These data may serve to inform the selection of regions of interest and aid with the interpretation of data derived from the study of relations between limbic activity and human vocalizations.

#### *The neural correlates of stress*

When a person perceives the environment as stressful, a variety of psychological, physiological, metabolic, and behavioural effects occur within the brain (Dedovic, D'Aguiar, & Pruessner, 2009a). Recent studies have begun to outline a framework of prefrontal and limbic regions involved in the perception and regulation of stress (Dedovic et al., 2009a; Dedovic, Duchesne, Andrews, Engert, & Pruessner, 2009b; Gianaros & Sheu, 2009). The PFC, AG, and hippocampus (HC) play important roles in processing stress and regulating the hypothalamic-pituitary-adrenal (HPA) axis, which releases the stress marker cortisol (Dedovic et al., 2009a, b; Pruessner, Dedovic, Pruessner, Lord, Buss, Collins, et al., 2010). A major difference between emotional processing and stress processing is that cortisol is only released in response to stress perception (Dedovic et al., 2009a). Another characteristic difference between emotion and stress appears to be the pattern of stressor-induced limbic deactivations (mPFC, OFC, ACC, HC, HY) that enables the cortisol response in the first place (cortisol increase was primarily correlated with HC activity) (Pruessner, Dedovic, Khalili-Mahani, Engert, Pruessner, Buss, et al., 2008; Pruessner et al., 2010). In the future, determining the unique neural characteristics of perceived stress as confirmed by cortisol reactivity will aid in the discovery of neural biomarkers that may be linked to disordered human functions such as those involving voice production.

Limbic deactivation is an interesting occurrence because of its sensitivity to individual differences in stress reactivity. Stress responders (demonstrated by increases in cortisol) compared to non-responders (no change or decrease in cortisol) have shown elevated baseline states (rest, non-stressful situation) in the mPFC, OFC, ACC, HC, and HY (Pruessner et al., 2008). These elevated baseline states appeared to reflect heightened vigilance and appraisal (similar to anticipatory stress), to scan the environment for signs of conflict, threat, and novelty (Dedovic et al., 2009b; Pruessner et al., 2010). Elevated baseline states in stress responders relate well with notions that persons who tend to experience negative affect selectively process it, and appraise more situations as threatening, over-react emotionally, ruminate, and/or have an increased susceptibility to experiencing stress (Suls & Martin, 2005). In summary, research on the neural correlates of stress has shown that individual

differences in stress reactivity do exist in the brain and that stress sensitivity is influenced by limbic structure activations (Dedovic et al., 2009a, b).

Finally, it should be noted that activity in the mPFC, ACC, insula, AG, and the PAG also mediate autonomic cardiovascular activity that may be directly related to stressor responses (Dedovic et al., 2009b; Gianaros & Sheu, 2009; Gianaros, Sheu, Matthews, Jennings, Manuck, & Hariri, 2008; Wager, van Ast, Hughes, Davidson, Lindquist, & Ochsner, 2009). The autonomic and metabolic effects of stress and their potential implications for vocal fold physiology are intriguing, but not of immediate interest in this study (cf. Hisa & Sato, 1991). However, differentiating between negative emotions and stress will help to characterize activation differences in the brain and will guide hypothesis-driven mechanistic research in the future.

### The limbic-motor interface

Much of the current research on stress has focused on how autonomic responses are mediated by the limbic system and their potentially detrimental effects on health (e.g., cardiovascular disease) (Gianaros & Sheu, 2009). In comparison, far less research has investigated how limbic activity may modulate motor activity in humans. Research on motor conversion disorders (e.g., limb paralysis, aphonia) is a powerful example in this regard. For example, the ACC and its functional sub-divisions is one of the key regions that integrates emotional, cognitive, and visceral processes, with output influence over motor control (Gianaros & Sheu, 2009; Paus, 2001; Paus, Petrides, Evans, & Meyer, 1993). In conversion disorders, it has been suggested that overactivity of the OFC could have an inhibitory influence on the motor cortex through connectivity with the ACC (Chastan, Parain, Verin, Weber, Faure, & Marie, 2009; Feinstein, 2009; Marshall, Halligan, Fink, Wade, & Frackowiak, 1997; van Beilen, Vogt, & Leenders, 2010). Further, related research on motor conversion disorders with positive motor symptoms (psychogenic movement disorder, e.g., tremor or dystonia) found greater functional connectivity between the AG and SMA during fearful and happy affective stimuli in individuals with motor symptoms compared to controls (Voon, Brezing, Gallea, Ameli, Roelofs, LaFrance, et al., 2010). Individual differences in emotion processing and arousal appear to modulate motor planning processes, but the precise mechanisms that elicit the positive motor symptoms have yet to be determined (e.g., excessive facilitation or impaired inhibition) (Voon et al., 2010). Findings by Wassermann, Greenberg, Nguyen, and Murphy (2001) using transcranial magnetic stimulation and concurrent electromyography in the hand are consistent with these previous reports, confirming that the personality trait neuroticism (NEO-PI-R; Costa & McCrae, 1992) is correlated with increased

cortical excitability. Further research in this direction will be crucial to better understand a variety of motor disorders.

### Research questions and hypotheses

Recent research has advanced our understanding of how the brain controls voice with an emphasis on identifying laryngeal motor networks (Simonyan & Horwitz, 2011) and sensory control mechanisms (Behroozmand, Liu, & Larson, 2011; Narayana, Jacks, Robin, Poizner, Zhang, Franklin, et al., 2009; Simonyan & Ludlow, 2010). However, significant gaps still exist in the literature with regard to the role of the limbic system in the central neural control of human vocalization. Within that broad context, a specific gap concerns the influence of negative emotionality such as stress on sensorimotor cortical activity underlying voice production. From the preceding brief overview of the literature, it should be evident that the limbic vocal control pathway overlaps with neural networks that process emotion and stress in humans and thus may modulate input to motor cortical networks, as summarized in Figure 1. Information on the activity of the limbic system during voice for speech will complement our basic understanding of normal voice control mechanisms.

The objectives of this preliminary study were to examine (1) whether the personality trait of stress reaction influences prefrontal and limbic area activity during overt sentence reading and (2) whether stress reaction and associated individual differences in prefrontal and limbic activations also correlate with sensorimotor cortical activity during overt sentence reading. We directionally hypothesized that individuals scoring higher on the trait of stress reaction as assessed with the *Multidimensional Personality Questionnaire-Brief Form* (Patrick et al., 2002) would exhibit heightened prefrontal and limbic activations

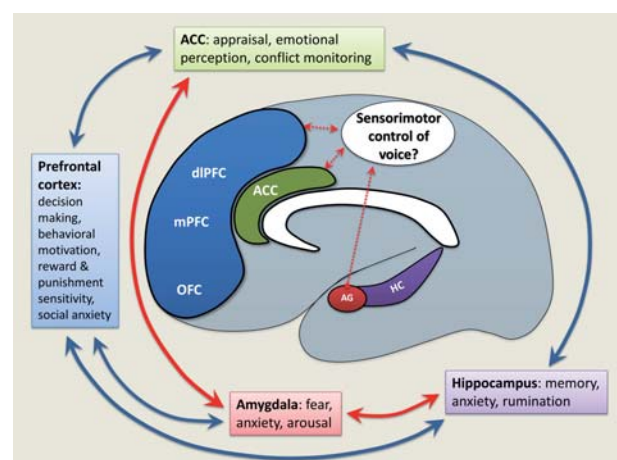


Figure 1. Overview of prefrontal and limbic regions involved in processing of emotion and stress and their potential influence on the sensorimotor cortical control of voice (the periaqueductal gray is not pictured). The dashed arrows do not imply direct functional connectivity.

with concomitant heightened somatosensory and motor cortical activity, compared with individuals scoring lower on stress reaction assessment.

**Method**

*Participants*

Ten vocally healthy adults between 22–57 years of age ( $M_{age} = 34.7$  years,  $SD = 14.8$ ; eight female, two male) participated in our protocol. Inclusion criteria were: native speakers of English, right handed, in good general health, vocally healthy, and no metal in the body. Vocal health status was determined by two certified speech-language pathologists (A.J., & J.C.S.) based on auditory-perceptual ratings using the *Consensus Auditory Perceptual Evaluation of Voice (CAPE-V)* (Kempster, Gerratt, Verdolini Abbott, Barkmeier-Kraemer, & Hillman, 2009) and visual-perceptual evaluations of the structure and function of the participants’ vocal folds using laryngeal videostroboscopy.

The data derived for this study originally came from a comprehensive data set collected previously in our laboratory. A separate portion of these comprehensive data, specifically on temporo-parietal cortical activation during human phonatory behaviours, has been previously reported (Andreatta, Stemple, Joshi, & Jiang, 2010). The analysis and questions addressed in this current paper are distinct and include the addition of personality characteristics that were not part of the original comprehensive data set. Participants were contacted post-hoc to complete the *Multidimensional Personality Questionnaire – Brief Form (MPQ-BF)* (Patrick et al., 2002). Participant scores on stress reaction (SR) were used to divide participants into a high and a low SR group. Based on a median split (median T-score 48), five participants were assigned to the low SR group ( $M = 38.0$ ,  $SD = 7.4$ , range 31–47) and five were assigned to the high SR group ( $M = 57.4$ ,  $SD = 8.3$ , range 49–71). Median splits have been used in personality research to study individual differences in performance (e.g., Cavanagh, Frank, & Allen, 2011). In the current study, the SR study groups were used at a descriptive level to illustrate the differences between total group-average analyses and individual differences analyses. The participants’ personality characteristics are provided in Table I. All participants provided written consent in accordance with the regulations of the Institutional Review Board at the University of Kentucky.

*Personality assessment*

Various personality instruments have been used in voice research. The *Eysenck Personality Questionnaire (EPQ)* (Eysenck & Eysenck, 1994) and the *Multidimensional Personality Questionnaire (MPQ/MPQ-BF)* (Patrick, et al., 2002; Tellegen, 1982) have been used

Table I. Distribution of personality traits (T-scores) based on the Multidimensional Personality Questionnaire–Brief Form (MPQ-BF).

MPQ-BF scale	Total sample ( <i>n</i> = 10) M (SD)	Stress reaction groups	
		Low ( <i>n</i> = 5) M (SD)	High ( <i>n</i> = 5) M (SD)
Positive emotionality	62.2 (8.1)	63.0 (10.1)	61.4 (6.6)
Wellbeing	55.9 (6.6)	56.8 (5.3)	55.0 (8.2)
Social potency	56.4 (6.4)	58.6 (4.8)	54.2 (7.5)
Achievement	56.2 (8.5)	55.0 (10.3)	57.4 (7.1)
Social closeness	60.0 (5.0)	57.6 (5.5)	62.4 (3.3)
Negative emotionality	46.1 (9.7)	39.0 (6.2)	53.2 (6.8)
Stress reaction	47.7 (12.6)	38.0 (7.4)	57.4 (8.3)
Alienation	49.0 (6.6)	47.4 (6.2)	50.6 (7.4)
Aggression	44.2 (6.8)	41.2 (4.4)	47.2 (8.0)
Constraint	51.1 (7.0)	54.8 (6.6)	47.4 (5.8)
Control	54.5 (6.6)	56.6 (6.2)	52.4 (7.1)
Harm avoidance	48.9 (8.7)	53.0 (7.3)	44.8 (8.5)
Traditionalism	49.2 (7.0)	50.2 (6.5)	48.2 (8.2)
Absorption	62.8 (7.3)	58.8 (8.2)	66.8 (3.7)

Note: The two males in the total sample were assigned to the low stress reaction group.

to test the trait theory (Dietrich & Verdolini Abbott, 2012; Roy, Bless, & Heisey, 2000a, b; van Mersbergen, et al., 2008). Both instruments represent models of the biological bases of personality, with Eysenck’s model partially used to develop the trait theory (Roy & Bless, 2000). The *EPQ-Revised (EPQ-R)* (Eysenck & Eysenck, 1994) is a 90-item self-report questionnaire that identifies three major dimensions: extraversion (extraversion–introversion), neuroticism (emotionality or stability–instability), and psychoticism (tough-mindedness). Prototypically, extraversion refers to a person who is sociable, needs to have people to talk to, always has a ready answer, craves excitement, and tends to be aggressive and impulsive. Neuroticism in the *EPQ* refers to a person who is generally characterized as a worrier. This person is typically anxious, moody, frequently depressed, and overreacts to emotional stimuli and has difficulty recovering from them. Psychoticism refers to a person who is solitary, does not care for people, lacks feeling and empathy, is hostile, and generally insensitive (Eysenck & Eysenck, 1994).

In comparison to the *EPQ*, the *MPQ* provides a more detailed personality description by assessing traits underlying each broad dimension. The *MPQ-BF* is a 155-item self-report questionnaire composed of the three broad dimensions: positive emotionality (PEM), negative emotionality (NEM), and constraint (CON). The *MPQ* differs from the *EPQ* regarding the conceptualization of the traits. The *MPQ* places the emphasis on emotion and temperament constructs that have been conceptualized in psychobiological terms and also incorporates behavioural motivations (Patrick et al., 2002). Conceptually, PEM has been related to extraversion and appetitive-approach motivation, NEM to neuroticism and defensive-withdrawal motivation, and CON

to behavioural constraint, the opposite of impulsivity (Church, 1994; Patrick et al., 2002). The *MPQ-BF* provides precision at the trait level with 10 scales across three factors: (a) PEM: wellbeing, social potency, achievement, social closeness; (b) NEM: stress reaction, alienation, aggression; (c) CON: control, harm avoidance, traditionalism. Of these scales, the core affective facets of PEM and NEM are wellbeing (happy disposition, optimistic) and SR (easily upset, has unaccountable mood changes, nervous, tense, prone to feel guilty, sensitive, vulnerable, worry-prone, anxious), respectively (Patrick et al., 2002). The *MPQ-BF* possesses good validity and reliability similar to the full version *MPQ* (Patrick et al., 2002). Cronbach's alpha coefficients to assess internal consistency and reliability of the primary trait scales ranged from .74 (control) to .84 (SR) (Patrick et al., 2002).

In summary, the *MPQ-BF* covers domains of temperament, interpersonal style, and behavioural regulation. Its conceptualization as a research-screening tool to investigate the neurobiological, psychological, and behavioural substrates of personality and their linkages (Patrick et al., 2002) makes it a suitable instrument for the present study. The aim was to isolate the SR trait from the larger construct of neuroticism as stress reaction is theoretically and clinically of interest in voice science, is mediated by regions of the limbic system, and can help to identify individual differences in the central control of voice. Based on the definition of SR in the *MPQ-BF* (e.g., nervous, tense, worry-prone, anxious) we choose to study stress reaction associated with perceiving increased arousal in negative emotions that appears to be a function of a biological predisposition.

#### *Functional MRI experimental paradigm*

Participants produced multiple trials of the six sentences from the *Consensus Auditory Perceptual Evaluation of Voice (CAPE-V)*; one trial = one sentence) (Kempster et al., 2009) at a habitual pace and with modal pitch and loudness. Participants completed 30 trials each of overt, whispered, and covert sentence reading as well as 60 trials of rest (visual fixation cross) distributed over three fMRI runs. These performance conditions were pseudo-randomized within each run. The performance condition "voice" (overt) completely engaged the larynx and integrated articulatory activity; the "whisper" condition required articulatory activity but with minimal movement of the vocal folds; and the "covert" condition required the least engagement of the laryngeal or articulatory structures (participants were instructed to read the sentences silently "in their heads"). As the same sentences were produced across performance conditions, they shared commonalities in terms of language. As a result, task-related cortical activity could be examined in relation to the varying

demands on the laryngeal system. The participants were familiarized with the production tasks prior to entering the scanner.

E-Prime software (Psychology Software Tools Inc., Pittsburgh, PA) and an MRI compatible projection system (SilentVision SV-6011 LCD, Avotec Inc., Stuart, FL) were used to project the task instructions and stimuli onto a small screen attached to the head coil of the MRI scanner. An event-related sparse sampling design was used to acquire blood oxygenation level dependent (BOLD) fMRI data resulting from speech production (Siemens Magnetom TRIO 3 Tesla MRI scanner). Each task production slide provided a time window of 4 seconds to perform the task (scanner off, jittered 3.5–4.5 s) and each instruction slide for the target stimulus lasted for 3 seconds (scanner on, one whole brain volumetric scan). As the hemodynamic response to speech production occurs with a delay, an event-related sparse sampling design was used to allow for speech production in the absence of gradient noise and to efficiently capture task-related cortical responses (Birn, Cox, & Bandettini, 2002).

The functional data consisted of T-2\* weighted echo-planar images. A single echo-planar imaging volume was acquired with a TR of 7 seconds using the following parameters: TR = 2.5 s; TP = 156; TE = 30 ms; flip angle = 81°; 39 axial slices; 224 mm × 224 mm FOV (field of view); slice thickness = 3.5 mm; 64 × 64 matrix (yielding 3.5 mm × 3.5 mm × 3.5 mm voxel size); and bandwidth = 2056 Hz/Px. A high-resolution, 3D anatomic image was acquired using a sagittal T-1 weighted (MPRAGE) sequence (TR = 2100 ms, TE = 2.93 ms, TI = 1100 ms, flip angle = 12°, FOV = 192 mm × 224 mm × 256 mm, with 1 mm isotropic voxels).

#### *Data analysis*

Image processing and analyses were conducted using Analysis of Functional NeuroImages (AFNI) software (Cox, 1996). After pre-processing, the structural 3D data were transformed into Talairach and Tournoux (1988) space. The first and last three functional volumes were eliminated due to T1 saturation effects and differences in timing between slices due to acquisition order and sync interpolation. The fMRI data were corrected for motion artifacts by registering data to the image obtained nearest in time to the structural image and smoothed (4 mm FWHM). The general linear model on event-related fMRI was used to estimate the evoked haemodynamic delay for each performance condition with no assumptions about the shape of the BOLD responses.

The selection of regions of interest (ROI) for the fMRI BOLD analyses was hypothesis-driven and based on regions that have been previously implicated in processing emotion, stress, behaviour, and voice production. The following regions were selected: primary somatosensory cortex (S1, post-central

gyrus), premotor cortex (BA6), primary motor cortex (M1, BA4), dlPFC (BA46/9), rostral PFC (BA10), OFC (BA11), ACC, AG, HC, HY, and PAG. The Talairach Daemon database (Lancaster, Woldorff, Parsons, Liotti, Freitas, Rainey, et al., 2000) was used to create areal masks for these regions (except for PAG), separately for the left and right hemispheres. To measure activity in the PAG, a bilateral ROI mask was manually drawn using AFNI. The stereotaxic Talairach space co-ordinates for the PAG mask were x-axis - 8 to + 8; y-axis - 26 to - 33; and z-axis - 4 to - 16 and these dimensions were informed anatomically and by a literature review (Gianaros, Derbyshire, May, Siegle, Gamalo, & Jennings, 2005; Jürgens, 2002; Schulz et al., 2005; Wager et al., 2009).

We calculated the averaged fMRI activations in the brain for the overt and covert performance conditions. For the purpose of our preliminary investigation, the brain regions showing significant signal enhancement or reduction were defined as voxels with  $p < .05$  for the overall experimental effect. All of the voxels were averaged within the ROI for each time point creating a single, spatially averaged time course for each performance condition. The percentage BOLD signal change for each performance condition was calculated in the ROIs and functioned as the dependent variable. BOLD activation data were summarized with descriptive statistics. The data were screened for outliers ( $\geq 3$  SD from group mean). Pearson product-moment correlation coefficients and bivariate regressions were calculated to measure relations between the BOLD signal changes in each ROI during the overt condition and personality data in the total sample as well as correlations among activities in the ROIs. SPSS statistics version 19 (SPSS Inc., Chicago, IL) was used for all statistical analyses.

**Results**

Mean BOLD percentage signal changes in each ROI for the overt condition are presented in Table II, first for the total sample and then for the low and high SR groups. Differences in activations between the left and right hemispheres were tested with paired t-tests in the total sample. Activity in the ACC was significantly greater in the right hemisphere than the left hemisphere,  $t(9) = -2.54$ ,  $p = .032$ . No other hemispheric differences were noted.

The descriptive data from the low and high SR groups revealed a differentiated picture of BOLD activity that contrasted with the averaged data from the total sample. Brain responses in prefrontal and limbic as well as sensorimotor cortical regions were descriptively greater in the high SR group than in the low SR group during overt sentence reading. Considering the variance in the data, distinct group differences during the overt performance condition were demonstrated for most ROIs except for the

Table II. Brain responses (mean percentage BOLD signal change) in regions of interest (ROI) during overt sentence reading in the total sample and in the low and high SR groups.

ROI	Side	Total sample (n = 10) M (SD)	Stress reaction groups	
			Low (n = 5) M (SD)	High (n = 5) M (SD)
S1	L	.67 (.24)	.52 (.21)	.82 (.16)
	R	.69 (.32)	.52 (.19)	.87 (.33)
BA6	L	.69 (.31)	.60 (.37)	.78 (.24)
	R	.76 (.39)	.62 (.38)	.89 (.40)
BA4	L	.67 (.25)	.52 (.23)	.81 (.19)
	R	.71 (.29)	.59 (.26)	.83 (.29)
BA46	L	.58 (.29)	.41 (.29)	.74 (.19)
	R	.61 (.38)	.35 (.18)	.88 (.35)
BA9	L	.85 (.47)	.59 (.38)	1.11 (.43)
	R	.96 (.62)	.61 (.42)	1.31 (.62)
BA10	L	.46 (.22)	.33 (.24)	.58 (.12)
	R	.48 (.25)	.34 (.21)	.61 (.21)
BA11	L	.11 (.09)	.07 (.05)	.14 (.12)
	R	.12 (.11)	.07 (.06)	.17 (.13)
ACC	L	.71 (.36)	.55 (.41)	.86 (.26)
	R	.76 (.34)	.59 (.38)	.92 (.21)
AG	L	.83 (.36)	.60 (.22)	1.07 (.31)
	R	.73 (.28)	.60 (.30)	.86 (.22)
HC	L	.87 (.48)	.78 (.43)	.96 (.55)
	R	.79 (.42)	.62 (.24)	.95 (.51)
HY	L	.34 (.69)	.08 (.08)	.61 (.95)
	R	.35 (.50)	.15 (.15)	.55 (.67)
PAG	B	.85 (.44)	.61 (.21)	1.08 (.51)

Note: ROI, region of interest, based on Talairach Daemon database; L, left; R, right; B, bilateral; S1, primary somatosensory cortex; ACC, anterior cingulate cortex; AG, amygdala; HC, hippocampus; HY, hypothalamus; PAG, periaqueductal gray.

premotor cortex (BA6) and HC (Figure 2). Further, the differences in BOLD activations between SR groups were not specific to the overt condition. The descriptive data for the high SR group also showed greater activations for the covert and whispered conditions compared to the low SR group. Specifically, the relation was such that activity in ROIs increased in the high SR group from the covert to the overt condition (except for BA9, HY), whereas activations for the covert and overt conditions in the low SR group varied minimally in comparison (Figure 2).

To investigate the relations between personality traits and BOLD activity in ROIs during overt sentence reading, we calculated Pearson product-moment correlations for the total study sample (n = 10). Several statistically significant relations emerged. Table III shows the correlations for activations in the left hemisphere. We found strong correlations between SR scores and S1 (left  $r = .73$ ,  $p < .05$ , right  $r = .81$ ,  $p < .01$ ), dlPFC (left BA46  $r = .73$ ,  $p < .05$ , right BA46  $r = .80$ ,  $p < .01$ , right BA9  $r = .67$ ,  $p < .05$ ), and PAG activity ( $r = .88$ ,  $p < .01$ ). To determine how much of the variance in these BOLD changes could be explained by personality traits, bivariate regression analyses were used. Results of regression analyses using SR scores showed that SR accounted for 66% of the variance in right hemispheric S1 activity, 64% in right BA46 activity, and

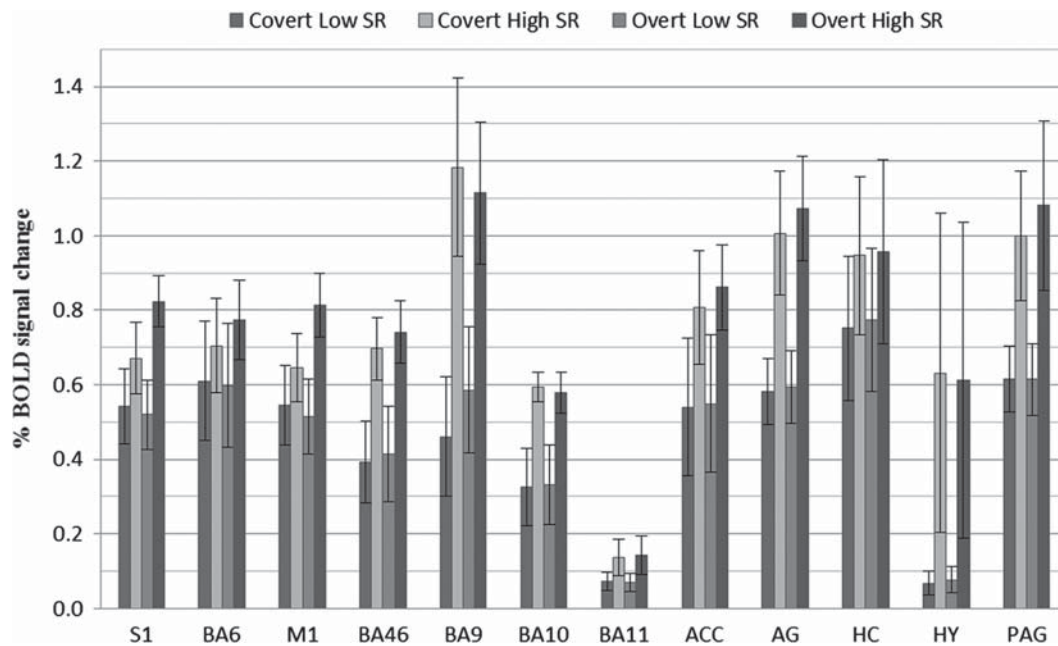


Figure 2. Brain responses (mean percentage BOLD signal change) in the regions of interest (left hemisphere, except PAG bilateral) by performance condition (covert vs overt sentence reading) and group (low stress reaction [SR] group vs high SR group). S1, primary somatosensory cortex; BA6, premotor cortex; M1, primary motor cortex; BA46/9, dorsolateral prefrontal cortex; BA10, rostral prefrontal cortex; BA11, orbitofrontal cortex; ACC, anterior cingulate cortex; AG, amygdala; HC, hippocampus; HY, hypothalamus; PAG, periaqueductal gray.

77% in PAG activity (Figure 3(b)). SR scores were also moderately correlated with M1 activity (left  $r = .64$ ,  $p < .05$ , right  $r = .57$ , ns) (Figure 3(b)). In addition, a strong negative correlation was also found between scores on the personality trait of social potency (enjoys visibility; dominance; likes to be in charge; persuasive; strong; a leader) (Patrick et al., 2002) and M1 activity (left  $r = -.70$ , right  $r = -.72$ , both  $p < .05$ ). Scores on both traits explained a comparable amount of the variance in the left M1 activity, that is 41% for SR and 49% for social potency.

Furthermore, significant correlations with BOLD activity were found for a third personality trait. Moderate-to-strong negative correlations were found

between scores on the trait harm avoidance (avoids risk of injury; dislikes dangerous emergencies; dislikes disaster areas; dislikes risky adventures) (Patrick et al., 2002) and activity in the left hemisphere (Table III): S1 (left  $r = -.67$ ,  $p < .05$ ; right ns), BA6 (left  $r = -.79$ ,  $p < .01$ ; right  $r = -.82$ ,  $p < .01$ ), dlPFC (left BA46  $r = -.82$ , BA9  $r = -.96$ ,  $p < .01$ ; right BA46 ns, BA9  $r = -.83$ ,  $p < .01$ ), and ACC activity (left  $r = -.67$ ,  $p < .05$ ; right  $r = -.66$ ,  $p < .05$ ). The harm avoidance scores (lower scores are associated with sensation seeking) (Patrick et al., 2002) were significantly correlated with regions that process behaviour and action, and pre-motor cortical activity, but not with M1 activity.

Table III. Correlations between scores on scales of the Multidimensional Personality Questionnaire–Brief Form (MPQ-BF) in the total sample ( $n = 10$ ) and mean BOLD percentage signal change in regions of interest (left hemisphere, PAG bilateral) during overt sentence reading.

MPQ-BF	BA3,1,2	BA6	BA4	BA46	BA9	BA10	BA11	ACC	AG	HC	HY	PAG
Positive emotionality	-.22	-.28	-.45	-.32	-.27	-.25	-.22	-.46	-.23	.15	.00	.16
Wellbeing	-.27	-.18	-.57	-.08	-.02	-.35	-.45	-.26	-.41	.07	-.23	.06
Social potency	-.49	-.40	-.70*	-.28	-.32	-.40	-.35	-.33	-.46	-.13	-.18	-.03
Achievement	.06	-.09	-.04	-.40	-.28	.02	.26	-.48	.14	.40	.45	.18
Social closeness	.40	.14	.32	.02	.18	.29	.33	.07	.63	.09	.44	.08
Negative emotionality	.54	.09	.51	.57	.40	.42	.04	.17	.33	.27	.06	.89**
Stress reaction	.73*	.33	.64*	.73*	.57	.63	.15	.33	.39	.43	.15	.88**
Alienation	.20	-.01	.43	.26	.15	.02	-.22	.03	.08	.03	-.40	.55
Aggression	.09	-.30	-.09	.25	.01	.13	-.15	-.21	-.15	.19	.10	.74*
Constraint	-.57	-.65*	-.61	-.76*	-.83**	-.45	-.24	-.81**	-.44	-.08	-.01	-.03
Control	-.13	-.24	-.02	-.40	-.55	.10	.23	-.28	-.08	.02	.13	.01
Harm avoidance	-.67*	-.79**	-.58	-.82**	-.96**	-.41	.08	-.67*	-.20	-.37	.24	-.12
Traditionalism	-.16	-.10	-.45	-.08	.06	-.45	-.77**	-.46	-.56	.25	-.44	.12
Absorption	.18	-.06	.18	.15	.24	-.08	-.07	-.06	.36	.05	.04	.51

ACC, anterior cingulate cortex; AG, amygdala; HC, hippocampus; HY, hypothalamus; PAG, periaqueductal gray. \* $p < .05$ , two-tailed. \*\* $p < .01$ , two-tailed.



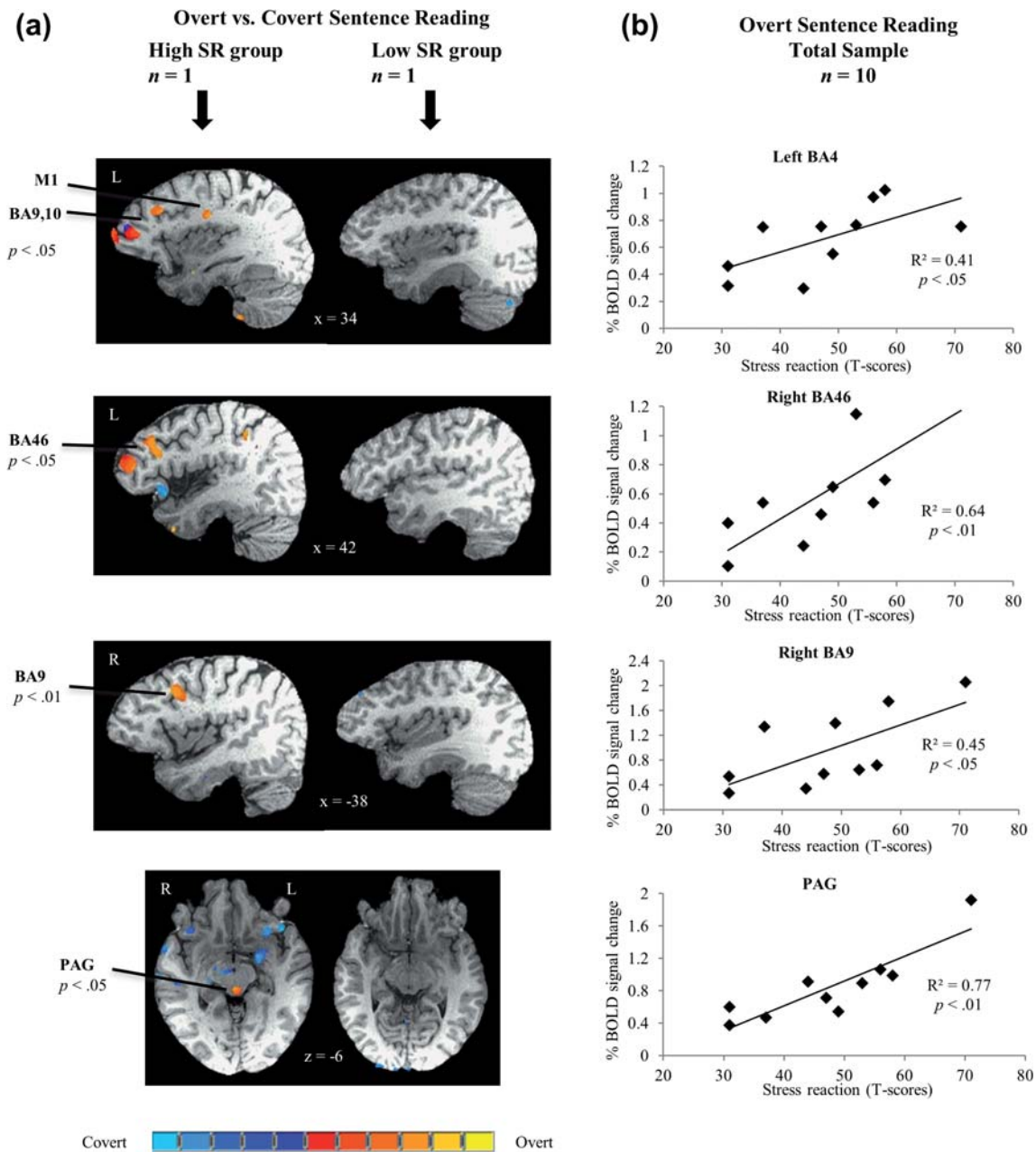


Figure 3. (a) Differential brain activity for overt sentence reading vs covert sentence reading (significant activations for the overt condition in red to yellow) in one participant in the high stress reaction (SR) group and one participant in the low SR group. The personality profile of the selected participant in the high SR group was SR 56, social potency 51, and harm avoidance 49 (*T*-scores based on *Multidimensional Personality Questionnaire-Brief Form [MPQ-BF]*) and the profile of the participant for the low SR group was SR 31, social potency 57, and harm avoidance 52. The slices and regions from the original data were labelled based on corresponding Talairach co-ordinates. (b) Scatterplots for the total study sample ( $n = 10$ ) showing mean percentage BOLD signal changes during overt sentence reading as a function of a participant's score on the scale SR (MPQ-BF) for the left primary motor cortex (BA4), right dorsolateral prefrontal cortex (BA46/9), and periaqueductal gray (PAG). This figure is available in colour at [www.informahealthcare.com/ijslp](http://www.informahealthcare.com/ijslp)

Correlations were also calculated among ROIs with an emphasis on regions that significantly correlated with SR scores. The correlations that emerged were greater in the left hemisphere than the right hemisphere. Left M1 activity was moderately-to-strongly correlated with S1 ( $r = .89$ ,  $p < .01$ ), dlPFC (BA46  $r = .72$ , BA9  $r = .68$ , both  $p < .05$ ) and BA10 activity ( $r = .79$ ,  $p < .01$ ). Bilateral PAG activity was moderately-to-strongly correlated with regions in the right hemisphere only: S1  $r = .79$ ,  $p < .01$ ; BA46  $r = .69$ ,  $p < .05$ ;

and HC  $r = .68$ ,  $p < .05$ . Figure 3(a) shows selected brain activations observed in our study and contrasts brain activity for two participants, one from the high SR group and one from the low SR group.

### Discussion

The purpose of the study was to investigate (a) whether the personality trait of SR influences pre-frontal and limbic area activity during overt sentence

reading, and (2) whether SR and associated individual differences in prefrontal and limbic activations correlate with sensorimotor cortical activity during overt sentence reading. Both initial hypotheses were confirmed. First, at a descriptive level, the high SR group showed heightened BOLD activations during overt sentence reading across prefrontal and limbic ROIs compared to the low SR group. Significant correlations emerged between SR scores and both dlPFC and PAG activity. Second, the high SR group also showed elevated S1-M1 and premotor activity during sentence reading compared to the low SR group, with significant correlations between SR scores and S1-M1 activation levels.

With regard to our first research question, the correlations between SR scores and dlPFC and PAG activity are suggestive of heightened working memory and appraisal processes with effects on autonomic processing. The dlPFC is an important region involved in attention, perception, and appraisal of the environment, and operates to shape motivation and behaviour (Kober et al., 2008; Miller & Cohen, 2001). Elevated activity in the dlPFC is consistent with the psychological dispositions of individuals ranking high on SR. These dispositions include greater vigilance and evaluation of their environment (e.g., novelty of fMRI environment), appraising more situations as negative, overreacting emotionally, and recovering more slowly from affect (Cohen, Kessler, & Underwood Gordon, 1995; Patrick, et al., 2002; Suls & Martin, 2005). A recent meta-analysis of emotion studies has shown that activity in the dorsomedial PFC (dmPFC BA9/32) reflected cognitive appraisals that generated emotion (Kober et al., 2008). It should be noted that dmPFC, PAG, and HY activity are rarely observed in studies that do not involve emotion and that dmPFC was also found to be the only PFC region that co-activated with both PAG and HY (Kober et al., 2008) further suggests that individual differences in emotional state may have played a role in our study.

The processing of emotion is often coupled with physiological consequences for which PAG activity is an indicator. The PAG is a common neural correlate of physiological arousal such as stressor-induced autonomic cardiovascular reactivity (Gianaros et al., 2005; Kober et al., 2008; Wager et al., 2009). Interestingly, we did not observe any correlation between ACC and PAG activity, two key components of the limbic vocal control pathway. A study by Schulz et al. (2005) previously reported that such a correlation during narrative speech did exist and may have operated to introduce more emotionality to their speech task compared to the sentence reading task in our study. The PAG has been characterized as an important area that modulates the emotional intonation of voice production (Simonyan & Horwitz, 2011). However, the interpretation of PAG activity is confounded by its concurrent mediation of cardiovascular activity. Thus, in the absence of

emotional state and behavioural data, a plausible re-interpretation of PAG activation during voicing may be related to appraisal processes and arousal in individuals high on SR.

With regard to the second research question, the positive correlations between SR scores and S1-M1 activity are interesting when viewed in conjunction with brain indicators for heightened states of perceptual processing and arousal. M1 activity was correlated with dlPFC activity. In particular, area BA46 of the dlPFC integrates cognitive processes with behavioural motivations (e.g., approach and avoidance) and modulates motor control (Amodio et al., 2008; Miller & Cohen, 2001). Moreover, the dlPFC has been shown to specifically possess structural connectivity with the laryngeal motor cortex, thus providing an anatomical pathway for the modulation of motor cortical activity (Simonyan et al., 2009). At this point, the nature of the observed heightened M1 activity during sentence reading remains undefined, considering that BOLD activity does not reveal whether neuronal activity is either excitatory or inhibitory. Related literature may allow for some insights. For example, one study noted that heightened motor cortical excitability was prominent in individuals psychometrically identified as neurotics (Wassermann et al., 2001), while other studies were able to link increased M1 activity (along with cingulate and insula over-activity) to increased speech effort in individuals who stutter compared to those who do not stutter (Brown, Ingham, Ingham, Laird, & Fox, 2005; Brown et al., 2008; Chang, Kenney, Loucks, & Ludlow, 2009). It is noteworthy that M1 activity was also correlated with one other personality trait, social potency. Social potency (socially dominant, persuasive) (Patrick et al., 2002) was negatively correlated with M1 activity, indicating that a person who prefers to remain in the background socially would likely show increased M1 activity.

It is striking how our current early results are in keeping with the predictions and empirical data previously attributed with the trait theory (Dietrich & Verdolini Abbott, 2012; Roy & Bless, 2000; Roy et al., 2000a). The trait theory suggested that introversion (in particular low social potency) plays a key role in individual differences in motor control and behaviour (inhibition) to cues of novelty or threat (mediating role). If a person also scored high on neuroticism, then behavioural tendencies would be magnified through autonomic arousal (moderating role). Our preliminary findings are intriguing and call for continued research to discover if these traits influence M1 activity synergistically, if they compete, or if M1 activity is influenced by yet unknown psychologically-based factors.

### *Limitations*

The correlational nature of our study limits interpretation of our data with regard to cause and effect

relations between trait SR and observed variations in brain activity. Research has yet to identify to what extent SR systematically modulates S1 and M1 activity underlying voice production and if, for example, limbic activity may act as a mediator or moderator of such effects. This preliminary study is also limited by its small sample size. Nonetheless, the SR scores were well distributed across the entire test range, which facilitated meaningful interpretations into individual-difference data that would otherwise be masked by total-average analyses. However, our small sample size precluded further analysis of our sample by quartiles for manipulation checks. Consequently, the outcomes of this study should be considered simply preliminary and, thus, require independent replication.

### Conclusion and future directions

To the best of our knowledge, this was the first study to investigate the influence of personality traits, specifically the personality trait of SR, on the central control of voice and speech. Our data preliminarily suggest that heightened appraisal and arousal during sentence reading, as indicated by greater prefrontal and limbic activity, may differentially influence sensorimotor control for voice production. The findings are significant because they shed light on the little known role of the limbic system in human voice for speech. Our data complement our current understanding of the normal variability of vocal control in the human. The potential clinical significance of our findings is premature. However, if limbic-motor pathways underlying vocal control could be directly linked with vocal dysfunction, then voice therapy approaches could be modified in evidence-based ways to capitalize on limbic system neuroplasticity to modulate sensorimotor control for voice production (e.g., top down strategies: inclusion of cognitive-behavioural therapy, application of mindfulness meditation) (McEwen & Gianaros, 2010).

Findings from the present study encourage future research on stress reactivity, emotion, and the central control of voice. Future studies should manipulate emotional state to investigate cause and effect relations in brain functioning and account for psychophysiological factors (e.g., emotional state, autonomic reactivity, biomarkers such as cortisol). Such data in conjunction with functional and structural connectivity analyses will increase our understanding of the limbic vocal control pathway in human voice for speech and provide the background for studies on the functional implications of individual differences in limbic activity during voice production.

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