

Abstract

Clinical perfectionism is the rigid pursuit of high standards, interfering with functioning. Little research has explored neural patterns in clinical perfectionism. The present study explores neural correlates of clinical perfectionism, before and after receiving ten 50-minute, weekly sessions of acceptance and commitment therapy (ACT), as compared to low-perfectionist controls, in specific cortical structures: the dorsolateral prefrontal cortex (DLPFC), medial prefrontal cortex (MPFC), right inferior parietal lobule (IPL). Participants in the perfectionist condition ($n = 43$) were from a randomized controlled trial evaluating ACT for clinical perfectionism and low-perfectionist controls were undergraduate students ($n = 12$). Participants completed three tasks (editing a passage, mirror image tracing, circle tracing) using functional near-infrared spectroscopy (fNIRS) to measure neural activation. Results indicate that only the mirror image tracing task was associated with reduced HbT in the DLPFC and MPFC of the perfectionists whereas activation in the other tasks were relatively similar. There were no differences were observed in the right DLPFC, MPFC, and right IPL between the posttreatment perfectionist and non-perfectionist control groups. Our findings suggest an unclear relationship between neural activation and perfectionism.

Keywords: perfectionism, neurological, functional near-infrared spectroscopy, acceptance and commitment therapy

An Examination of the Relationship Between Perfectionism and Neurological Functioning

Perfectionism is the continual and rigid pursuit of high personal standards combined with a desire for high achievement (Egan, Wade, & Shafran, 2012). Maladaptive or clinical perfectionism is a dysfunctional method of evaluating oneself (Shafran, Cooper, & Fairburn, 2002). Maladaptive perfectionists base their self-worth on achievement and engage in high levels of self-criticism, particularly if they do not achieve or meet their own standards (Egan et al., 2012; Shafran et al., 2002). However, even if standards are met, they are deemed insufficient and further increased (Shafran et al., 2002). Other aspects of maladaptive perfectionism include rigidity, rules, avoidance, procrastination, and positive perceptions of success (Riley & Shafran, 2005; Shafran et al., 2002). Maladaptive perfectionism is considered a transdiagnostic risk factor for the development of psychopathology including anxiety, eating disorders, and depression (Egan, Wade, & Shafran, 2010; Egan et al., 2012; Shafran et al., 2002). It is also implicated in the maintenance of obsessive-compulsive disorder (OCD), social anxiety, and depression (Egan et al., 2010).

In recent years, many fields have adapted the use of neuroimaging as a tool to better understand different clinical presentations such as anxiety, OCD, and depression (e.g., Fonzo & Etkin, 2017; Irani, Platek, Bunce, Ruocco, & Chute, 2007; Pauls, Abramovitch, Rauch, & Geller, 2014; Ritchey, Dolcos, Eddington, Strauman, & Cabeza, 2011). A number of neuroimaging studies have focused on disorders like anxiety and depression, but few have examined clinical perfectionism. Examining neural patterns and correlates in clinical perfectionism could corroborate hypothesized maintaining variables of psychopathology and clarify the functional or process-level presentation of clinical perfectionism (Crum, 2020). For example, if neural correlates of error monitoring are implicated in perfectionism, it suggests clinical perfectionism

may be tied to expending excessive cognitive resources on error monitoring at the expense of task-focused activity. Hypotheses like these may impact intervention development and planning as intervention development could start to target identified neural processes and streamline skills training (e.g., reducing cognitive burden through strategies like acceptance).

The few available neuroimaging studies have used fMRI and MRI to investigate neural correlates of nonclinical samples with subscales of perfectionism (concern over mistakes and doubts about actions). For example, Wu et al. (2017) found the two subscales of perfectionism were positively correlated with anxiety, depression, and grey matter volume in anterior cingulate cortex. Similarly, undergraduates with high personal perfectionism scores showed more neural activity in anterior cingulate cortex and medial-frontal gyrus while performing a digit flanker task designed to provoke errors (Barke et al., 2017). Another study reported maladaptive perfectionism as correlated with increased grey matter in the thalamus and left posterior parietal cortex of healthy adult participants (Karimizadeh, Mahnam, Yazdchi, & Besharat, 2015). These results collectively suggest perfectionistic processes may be associated with the anterior cingulate cortex, medial-frontal gyrus, thalamus, and left posterior parietal cortex. On the whole, however, researchers have yet to elucidate brain regions most relevant to perfectionism. Although these preliminary studies have shown the involvement of brain regions such as the anterior cingulate cortex and thalamus in subclinical perfectionistic populations, there is too little research to make reliable conclusions.

A limitation of the studies cited is their use of nonclinical samples, which may not adequately represent clinically significant presentations of perfectionism wherein individuals experience functional impairment and/or distress related to perfectionistic behavioral patterns. Thus, it is unclear if these findings will replicate in a clinical sample. Furthermore, these studies

examined a circumscribed group of brain regions, precluding a more global picture of neural functioning as it relates to clinical perfectionism. The current study aimed to add to the literature on perfectionism and neural activation

The present study explored neural correlates of clinical perfectionism in specific cortical structures of the brain: the dorsolateral prefrontal cortex (DLPFC), medial prefrontal cortex (MPFC), and right inferior parietal lobule (IPL). These regions were selected given their possible connection with cognitive processes implicated in clinical perfectionism.

Dorsolateral Prefrontal Cortex (DLPFC)

DLPFC activation may be associated with perfectionism through the processes of self-control (Hare, Camerer, & Rangel, 2000; Luijten et al., 2014)—related to the rigid and achievement-pursuing nature of clinical perfectionism—and self-rumination (Cooney, Joormann, Eugene, Dennis, & Gotlib, 2010), which may overlap with the self-criticism common among perfectionistic people.

The left and right regions of the DLPFC are hypothesized to be differentially associated with perfectionism. The left DLPFC appears to be involved in verbal processes such as self-monitoring and evaluation or self-talk more broadly during an anxiety-provoking task (Glassman et al., 2016). Left DLPFC activity has also been associated with greater self-criticism during a self-criticism/reassurance fMRI task (Longe et al., 2010)—consistent with the dysfunctional self-evaluation present in clinical perfectionism (Shafran et al., 2002). Increased left DLPFC activation could reflect the pervasive self-monitoring and evaluation central to clinical perfectionism. Higher left DLPFC activation has also been correlated with better cognitive set-shifting ability (MacDonald, Cohen, Stenger, & Carter, 2000), a form of executive functioning

that allows for switching between tasks or stimuli. Those with perfectionism may show decreased activation in this regard as fixation on errors may hinder adaptive set-shifting.

The right DLPFC is involved in emotion self-regulation, such as the suppression of sadness (Lévesque et al., 2003). Hyperactivity in the right DLPFC of patients with major depressive disorder (MDD) has also been correlated with depression severity (Grimm et al., 2008). In addition, right DLPFC activity is positively related to self-reported behavioral inhibition and sensitivity to punishment (Shackman, McMenamin, Maxwell, Greischar, & Davidson, 2009). Thus, perfectionism may be associated with higher right DLPFC activity as it is characterized by excessive emotional and cognitive control and inhibition of reward pathways (Kaye, Wagner, Fudge, & Paulus, 2011). Inhibition of reward perception may explain why perfectionists tend to view their achievements or standards as insufficient when met.

The right DLPFC is also implicated in other forms of self-regulation like inhibiting preplanned executive functions. For example, the right DLPFC had greater activation in adolescents with binge eating/purging disorders compared to anorexia restricting and healthy control groups in a go/no-go task (Lock, Garrett, Beenhakker, & Reiss, 2011). The increased right DLPFC activation might have been a result of a disinclination to make errors. That is, the increased cognitive effort might have been directed toward attempts to avoid errors to improve task performance; it is possible that the adolescents with binge eating/purging disorders struggle more with inhibition than their anorexia restricting counterparts, thereby putting in more effort to resist making mistakes on the task. This compensatory pattern is consistent with rigid responses to a fear of failure to meet set standards that is the hallmark trait of clinical perfectionism (Lock et al., 2011). Overall, perfectionism appears to be linked to excessive cognitive control, which is manifested by greater activation in the left and right DLPFC.

Medial prefrontal cortex (MPFC)

The MPFC helps individuals adapt and use information about context, responses, memory, and emotions to make decisions (Euston, Gruber, & McNaughton, 2012). The MPFC is particularly involved in the processing and expression of negative emotions as well as regulating emotional responses (Etkin, Egner, & Kalisch, 2011; Stevens, Gauthier-Braham, & Bush, 2018). More specifically, the MPFC is highly implicated in self-referential mental and emotional processing (Gusnard, Akbudak, Shulman, & Raichle, 2001; Stevens et al., 2018). Self-referential processes may be associated with high personal standards, self-evaluation, and self-criticism. These processes are grounded in the comparison of self to others as perfectionistic individuals frequently use comparison to evaluate performance and pursue high levels of achievement. Research has also indicated the MPFC becomes more activated when mistakes are made (Barke et al., 2017). Sensitivity to error making may lead to MPFC activation even in response to seemingly small mistakes among perfectionistic people. Thus, MPFC activation is likely to be positively associated with clinical perfectionism.

Right inferior parietal lobule (IPL)

The right IPL may be involved in perfectionistic processes through its role in self-other comparison. In one study, the right IPL was activated in response to third-person perspective, suggesting the right IPL is involved in mapping out self-movements and representations, particularly from the perspective of others (Ruby & Decety, 2001). In addition, the IPL may be involved in a dysfunctional system of negative self-appraisal (Feusner, Yaryura-Tobias, & Saxena, 2008). As such, the right IPL may be related to clinical perfectionism as it could reflect the concern over others' perception of performance and negative self-appraisal core to clinical perfectionism (Egan et al., 2012; Shafran et al., 2002).

Present Study

In the present study, we explored neural activation (measured with functional near-infrared spectroscopy [fNIRS]) in the context of error-prone tasks (e.g., passage editing, mirror image tracing) between perfectionists, before and after receiving acceptance and commitment therapy (ACT), and low-perfectionist controls. These tasks were specifically designed to elicit error detection and generation in participants. Given the novelty of these behavioral tasks and lack of neurological research on the presentation of clinical perfectionism, the present study attempts to provide preliminary data that contribute to clarifying the neural picture of clinical perfectionism while acknowledging more convergent data are needed to more fully elucidate neurological patterns consistently related to perfectionism.

Based on the extant literature, we predicted those in the pre-ACT perfectionist group would have greater brain activation as compared to low-perfectionist controls on behavioral tasks. Because the DLPFC as a whole is implicated in self and emotional control (Hare et al., 2000; Lévesque et al., 2003), with the left DLPFC involved in task-shifting and right DLPFC involved in cognitive and emotional control, we predicted higher activation in perfectionistic participants who may implement greater cognitive control in order to regulate unpleasant emotions and avoid making mistakes. Because the MPFC is implicated in self-referential processing and perception of mistake making, we predicted the MPFC would show greater activation during error-prone behavioral tasks in the perfectionist group (Barke et al., 2017; Gusnard et al., 2001). Lastly, the potential involvement of the right IPL in self-other comparisons and relation to OCD and eating disorder severity suggests there might be greater activation in more perfectionist brains during tasks that result in greater errors as perfectionistic participants fail to meet high task standards and engage in self-other comparisons (Feusner et al., 2008; Roth

et al., 2007). In terms of predictions for comparisons between post-ACT perfectionists and low-perfectionist controls, we predicted no activation differences in the DLPFC, MPFC, and right IPL. On the whole, this study aimed to illuminate the cognitive processes associated with clinical perfectionism to improve precision of intervention targets.

Method

Recruitment

The sample consisted of 43 perfectionistic participants and 12 low-perfectionism control participants (N = 55) from a mountain west town in the United States. Participants in the perfectionist condition were from a randomized controlled trial (RCT) evaluating acceptance and commitment therapy for clinical perfectionism (Ong et al., 2019). These participants were recruited via flyers and announcements specifically calling for individuals struggling with “procrastination, spending a lot of time planning/organizing, and difficulty starting/completing tasks because you need to get them exactly right.” In the present study, the perfectionist group included all eligible study participants from a the prior RCT (Ong et al., 2019) who completed the fNIRS assessment, including those assigned to the waitlist condition. Participants in the perfectionist condition were recruited via flyers and announcements from a town in the mountain west required to meet the following eligibility criteria: score a five on the Dimensional Obsessive Compulsive Scale (DOCS) symmetry subscale (Abramowitz et al., 2010), report significant impairment from clinical perfectionism, willing and able to complete all study procedures, and not be receiving therapy or any changes in medication. Participants in the control condition were from undergraduates recruited from introductory psychology courses. Control participants were added to the sample to increase our ability to detect meaningful differences in neural activation between perfectionists and low-perfectionist controls.

Participants in the control condition were required to meet the following eligibility criteria: a 0 or 1 score on the DOCS Symmetry subscale, willingness to complete a neurological assessment, fluent in English, no prior receipt of acceptance and commitment therapy before, older than 18, and no recent changes in medication. All participants were required to be right-handed with good scalp conditions in order to avoid confounds of handedness in results and allow for reliable fNIRS data recording (Cuzzocreo et al., 2009). Participants were recruited using newspaper, online, and flyer-based advertisements, as well as class announcements.

Procedures

All study procedures were reviewed and approved by an institutional review board. All participants first completed an online eligibility questionnaire (Dimensional Obsessive-Compulsive Scale symmetry subscale) and phone screening (brief clinical interview). Participants then completed several self-report measures and the initial fNIRS assessment. Participants in the perfectionism condition were then randomized to receive 10, weekly 50-minute sessions of ACT or waitlist. In brief, the study treatment was adapted from an ACT for OCD manual (Twohig et al., 2010); the ten sessions covered creative hopelessness, acceptance, defusion, and values-based work. For more details on the treatment and study methods, please see Ong et al., 2019.

Neurological Assessment

The present study used functional near-infrared spectroscopy (fNIRS) to explore activation in the DLPFC, MPFC, and right IPL in perfectionists and low-perfectionist controls. fNIRS detects the physiological changes in blood concentration (oxy-hemoglobin and deoxy-hemoglobin) during brain activation by measuring the absorption of different wavelengths (Baker et al., 2017; Boas et al., 2001; Irani et al., 2007). The fNIRS is limited to the cortical

structures of the brain but can detect multiple sites at once (Ferrari & Quaresima, 2012; Irani et al., 2007). Compared to a fMRI, the fNIRS is non-invasive, mobile, and inexpensive (Baker et al., 2017; Cui, Bray, Bryant, Glover, & Reiss, 2011; Irani et al., 2007). Furthermore, fNIRS activation correlates with fMRI activation measurements and thereby can validly act as a noninvasive tool to assess blood flow in cortical structures (Cui et al., 2011; Irani et al., 2007). With this in mind, fNIRS is particularly useful in functional and changing environments (Baker et al., 2017) and affords more flexibility in tasks participants can complete during neural assessment. fNIRS has been used to study schizophrenia, mood disorders, anxiety disorders, and attention-deficit/hyperactivity disorder, as well as a range of neuropsychological conditions like Alzheimer's and traumatic brain injury (Boas, Elwell, Ferrari, & Taga, 2014; Irani et al., 2007).

Neurological Procedure

All instructions were presented on monitor 46x28-cm using E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002). Hemodynamic activity was recorded using a 44-channel montage Hitachi ETG-4000 system with a sampling rate of 10Hz. The two probe sets were placed on the front and right side of the head and channels between each transmitter and receiver were placed with reference to the 10-20 system and maintained a 3cm channel length. The left corner of probe set one covered coordinate F9 and the right corner of probe set two covered coordinate T8. Prior to recording a NIRS gain, quality check was performed to ensure data acquisition was neither under-gained nor over-gained according to the Hitachi ETG-4000 calibration guidelines (Hitachi Medical Group, Tokyo). Data were recorded at 695 and 830 nm. Following the delivery of instructions, two trained researchers fit the 3x5 probes to the participants' head before initiating experimental task.

Participant completed three experimental behavioral tasks: editing (editing passages with errors), mirror image tracing (tracing the mirror image of a geometric shape; Brown et al., 2018), and circle tracing (tracing a circle counterclockwise). Mirror image tracing and editing were selected to elicit error generation and error detection while circle tracing served as a simple mechanical control task.

The experiment consisted of two blocks with each block containing three two-minute tasks (i.e., editing, mirror image tracing, and circle tracing). Within the blocks, each task was separated by a 15-second inter-stimulus interval (ISI), which was a fixed cross displayed on the screen. Rest periods were placed before each block and after the final block. During rest periods participants were instructed to look at the fixed cross in the middle of the screen. Task order was randomized to minimize potential order effects.

Regions of interest (ROIs) were identified based on conversions of 3D spatial area into Montreal Neurological Institute coordinates (Singh, Okamoto, Dan, Jurcak, & Dan, 2005) using the Polhemus PATRIOT digitizer channel registration software. After the task was completed, participants were instructed to keep the cap on while researchers carefully removed optodes. Measurements in centimeters were taken from (1) from the left auricular lobule to the right auricular lobule over the top of the head and (2) from the nasion to the inion over the top of the head. Once the location of the center of the scalp was determined, a magnet was positioned on it. Participants were positioned so the inion was 10 cm away from the transmitter. Using the Polhemus stylus, five head base reference points were measured: nasion, left tragus, right tragus, inion, and CZ (center point of head). ROIs were the left and right DLPFC (Brodmann area 9 and 46), MPFC (Brodmann area 10), and right IPL (Brodmann area 39 and 40). All channels with

50% or greater area overlap within a region of interest were averaged together based on MRICro registration (Rorden & Brett, 2000).

Data Processing

Processing of the signal measurements of total hemoglobin concentration (HbT = HbO₂ + HbR) were conducted using NIRS-SPM (Ye, Tak, Jang, Jung, & Jang, 2009). First data were converted to hemoglobin concentration changes using the modified Beer-Lambert Law, data were then filtered using wavelet MDL (Gaussian low-pass FWHM at 4s), and precolored and prewhitened. The signal analyzed was based on the following formula:

$$\frac{TASK - \overline{ISI}}{rms} \times 100$$

A baseline correction was performed by removing the mean of the 15-second local ISI before each task from the signal. This was then normalized by the square root of the signal power of the entire channel. NIRS-SPM registration process report (Ye et al., 2009) was used to determine the channels for each participant. Channel selection for each ROI was established using a >50% channel overlap threshold.

Statistical Analyses

Statistical analyses were performed in R version 3.6.1 (R Core Team, 2019) and RStudio version 1.2.5019 (RStudio Team, 2019) using the following packages: blme (Chung, Rabe-Hesketh, Dorie, Gelman, & Liu, 2013), tidyverse (Wickham, 2017), texreg (Leifeld, 2013), and furniture (Barrett & Brignone, 2017).

Linear mixed effects (i.e., multilevel) models were used to analyze group differences in total hemoglobin concentration (HbT), which is a measure of recruitment of neurons in a cortical region or, more broadly, neural activation. Area under the curve for HbT was used to obtain numerical values for HbT and represents the sum of oxygenated and deoxygenated concentration

at each 10msec for each region of interest. The period of the waveforms needed to calculate HbT was determined for each task per participant individually (Wan, Hancock, Moon, & Gillam, 2018).

We tested two sets of between-group comparisons: (1) perfectionist at pretreatment versus control and (2) perfectionist at posttreatment versus control. Multilevel models were built hierarchically. The first model only included group as a main effect, the second model only included task as a main effect, the third model included both group and task as independent main effects, and the fourth model included a group \times task interaction term. To select the most parsimonious model for each region, likelihood ratio tests assessed for differences between the subsequent, more complex model and the current model. If there was no significant difference at $\alpha = .05$ between the models, the more parsimonious model was retained. The random effects structure in the multilevel models specified a random intercept for each participant, thereby allowing the model to account for individual variability in neural data.

Results

Participants

Demographic details for each group are presented in Table 1. For all groups, the majority of participants identified as European American/White, cis-female, single, and members of The Church of Jesus Christ of Latter-day Saints. The perfectionist group included all eligible study participants who completed the fNIRS assessment including those assigned to the waitlist condition ($n = 43$). The posttreatment perfectionist group only included perfectionist participants who were assigned to the study intervention condition and completed the fNIRS assessment at posttreatment ($n = 14$).

Control and Perfectionist Group Comparison

Left DLPFC. Because the DLPFC is involved in forms of control, with the left DLPFC specifically implicated in task shifting, we predicted higher activation in the left DLPFC for the perfectionistic participants who may implement greater cognitive control (Hare et al., 2000; Lévesque et al., 2003). Our results indicated that the best-fitting model for the left DLPFC included a group × task interaction effect, indicating between-group differences in neural activity (HbT) depended on task (see Table 2). The moderation effect is illustrated in Panel A of Figure 1 wherein the perfectionist group demonstrated higher HbT in the circle tracing task but lower HbT in the mirror image tracing task compared to the non-perfectionist control group.

Right DLPFC. The right DLPFC is implicated in cognitive and emotional control; thus, we predicted higher activation in perfectionistic participants as they utilized greater cognitive control (Hare et al., 2000; Lévesque et al., 2003). The best-fitting model for the right DLPFC included a group × task interaction effect, indicating between-condition differences in neural activity depended on task (see Table 2). Panel B in Figure 1 shows no group differences during rest, circle tracing, or editing but lower HbT for mirror tracing in the perfectionist group.

MPFC. Because the MPFC is implicated in perceptions of mistake making, we predicted the MPFC would show greater activation during the error-prone tasks in the perfectionist group (Barke et al., 2017; Gusnard et al., 2001). However, the best-fitting model for the MPFC included a group × task interaction effect, indicating between-condition differences in neural activity depended on task (see Table 2). Similar to the activation profile for the right DLPFC, there were no group differences for rest, circle tracing, and editing. HbT appeared to only be higher for both groups in the mirror tracing task.

Right IPL. Because there is some evidence for the right IPL's involvement in self-other comparisons, we predicted there might be greater activation in perfectionist brains during error-

prone tasks as perfectionistic participants make mistakes and potentially compare themselves to others (Feusner et al., 2008; Roth et al., 2007). The best-fitting model for the right IPL only included a main effect of task, indicating there were differences in HbT among tasks but not between groups overall (see Table 2). Model coefficients reflected significantly higher HbT in the circle tracing, editing, and mirror image tracing tasks relative to rest (see Figure 1).

Control and Posttreatment Group Comparison

We broadly predicted no activation differences in the DLPFC, MPFC, and right IPL.

Left DLPFC. The best-fitting model for the left DLPFC included a group × task interaction effect, indicating between-group differences in neural activity (HbT) depended on task (see Table 3). Based on Panel A in Figure 2, the posttreatment group displayed lower HbT at rest but higher HbT in the circle tracing task. There were no observed group differences on the editing or mirror image tracing tasks.

Right DLPFC. The best-fitting model for the right DLPFC only included a main effect of task, indicating there were differences in HbT among tasks but not between groups overall (see Table 3). Specifically, participants generally showed higher HbT in the circle tracing and mirror image tracing tasks compared to at rest. No differences were observed in HbT between editing and rest.

MPFC. The best-fitting model for the MPFC only included a main effect of task, indicating there were differences in HbT among tasks but not between groups overall (see Table 3). Similar to activation in the right DLPFC, participants overall showed higher HbT in the circle tracing and mirror image tracing tasks compared to at rest. There were no differences in HbT between editing and rest.

Right IPL. The best-fitting model for the right IPL only included a main effect of task, indicating there were differences in HbT among tasks but not between groups overall (see Table 3). Editing and mirror image tracing showed higher HbT relative to rest. There were no significant differences in HbT between circle tracing and rest.

Discussion

The current study examined differences between pre-treatment perfectionist and low-perfectionist control groups to determine if perfectionists display discrepant neural patterns from low-perfectionist controls across various behavioral tasks: circle tracing, passage editing, and mirror image tracing. We additionally compared posttreatment perfectionist and low-perfectionist control groups to provide convergent validity and context to our primary findings.

We found significant group by task moderation effects in the left DLPFC, right DLPFC, and MPFC for the perfectionist and low-perfectionist groups that indicate group differences depended on task. Generally, only the mirror image tracing task elicited reduced HbT in the perfectionist group whereas activation in the other three tasks were relatively similar between groups. These results are contrary to our predictions that active experimental tasks (i.e., editing and mirror image tracing) would result in greater activation in brain regions of interest in the perfectionist group; we expected perfectionists to expend more cognitive effort to complete the tasks. Instead, our findings potentially suggest perfectionists performed similarly to controls on the editing task and may have been less cognitively engaged in the mirror image tracing task. It is possible that the latter observation could be due to premature task termination related to frustration with this counterintuitive task. In the mirror image tracing task, movements produce effects in the opposite direction, and greater effort is not necessarily rewarded with greater success, making it unique as, in most tasks, effort is reliably correlated with better performance

(Holper, Shalóm, Wolf, & Sigman, 2011). Thus, with this task, we speculate that the common pattern in clinical perfectionism of giving up on tasks to avoid distress (e.g., feelings of failure, feeling overwhelmed, frustration) might have translated to lower neural activation in the DLPFC and MPFC.

We did not find significant group differences on the other tasks (i.e. circle tracing, passage editing) in the DLPFC and MPFC, which could suggest low-perfectionist controls put in similar amounts of effort to perfectionists. In the passage editing task, it could be that perfectionist participants were less bothered by mistakes generated by others and so were not different from controls in terms of task performance and, accordingly, neural activation. Given that self-criticism and personal striving are hallmarks of perfectionism, we speculate that perfectionists may be more bothered by personal, rather than others', mistakes and were therefore not sufficiently elicited in this study (Egan et al., 2012). Overall, it is also possible low-perfectionist controls were sufficiently motivated to complete these brief (two minutes long) experimental tasks—just as perfectionists would be—producing similar neural profiles. This theoretical interpretation is supported by the relatively higher cognitive effort demonstrated by controls in the mirror task that similarly reflects task engagement.

No significant group differences were observed in the right IPL for either set of comparisons; only expected differences between tasks were observed. This could be because the tasks used did not sufficiently elicit theory-of-mind perspective taking, the process in which the right IPL is implicated (Ong et al., 2019). The lack of a significant association between the perfectionist group and activation in right IPL may again suggest that the tasks did not sufficiently elicit perfectionistic tendencies, despite previous studies reporting higher neural

activation in these regions in association with similar tasks (e.g., Feusner et al., 2008; Longe et al., 2010).

Comparisons between the posttreatment perfectionist and low-perfectionist control groups indicated no differences were observed in the right DLPFC, MPFC, and right IPL—consistent with predictions. This pattern potentially reflects a greater similarity between the perfectionist group to controls at posttreatment than at pretreatment. These differences were primarily driven by similar HbT between groups during the mirror image tracing task at posttreatment in contrast to lower HbT in the perfectionist group at pretreatment. This could possibly be because, following treatment, perfectionist participants were able to remain engaged in the mirror image tracing task in spite of error generation. Subsequently, this engagement could be represented by higher levels of neural activation. Alternatively, practice effects on the mirror image tracing task might have reduced error generation such that perfectionist participants were able to perform the task with fewer mistakes and so were not experiencing distress similar to pretreatment. Task performance data would clarify which of these explanations is more plausible. Unfortunately, we did not collect these data in this study and our interpretations are therefore conjectural.

Given treatment in this study was found to be efficacious on an aggregate level (Ong et al., 2019), we expected perfectionists at posttreatment to present similarly to low-perfectionist controls as they should have learned to maintain task engagement even when they encounter instances of failure. Although the meaning of the few group differences between perfectionists and controls was unclear, this set of comparisons provides some converging evidence that there are neural differences between self-reported perfectionists and low-perfectionists in response to behavioral tasks at baseline; it seems the implementation of an intervention designed to reduce

clinical perfectionism may have led to more similar neural profiles between initial perfectionists and controls. The only group differences remaining after treatment were in the left DLPFC for rest and circle tracing wherein perfectionists showed less activation at rest and more activation during the circle tracing task.

Limitations

It is possible our relatively small sample size and high individual variability inherent in neural data led to Type II error, obscuring real relationships between perfectionism and neural activation across experimental tasks. While smaller samples are often used in fNIRS research (e.g., Holper et al., 2011), the small size of our control and posttreatment samples is a significant limitation, and future studies should include larger samples. Furthermore, because of the gross inconsistencies across neurological profiles, our results have limited generalizability more broadly. Additionally, we did not collect behavioral data for task performance, making it difficult to ascertain our interpretations. For example, if we found higher-perfectionism participants performed worse than control participants at the mirror image tracing task, that would corroborate our interpretation that they gave up on the task halfway. However, it is also possible perfectionist participants performed just as well as controls. In this case, the more logical interpretation would be the perfectionist participants performed the mirror image tracing task with greater cognitive efficiency.

Conclusion and future directions

In sum, the present study examined the relationships between perfectionists and low-perfectionist controls' activation in brain regions of interest across various behavioral tasks designed to elicit perfectionistic concerns and/or behaviors. Generally, only the mirror image tracing task elicited reduced HbT in the DLPFC and MPFC the perfectionist group whereas

activation in the other three tasks were relatively similar between groups. There were no differences were observed in the right DLPFC, MPFC, and right IPL between the posttreatment perfectionist and low-perfectionist control groups. Future investigations may consider utilizing different forms of treatment for clinical perfectionism (e.g., traditional cognitive behavioral therapy) in order to further elucidate possible neural changes across treatment. Collectively, these findings point towards the need for further research on the neural elements of clinical perfectionism, along with the need for standardization and greater precision in experimental tasks and neurological assessments aiming to expand this area of knowledge.

Funding Source

This study was supported by a grant from the International OCD Foundation.

References

- Abramowitz, J. S., Deacon, B. J., Olatunji, B. O., Wheaton, M. G., Berman, N. C., Losardo, D., . . . Adams, T. J. P. a. (2010). Assessment of obsessive-compulsive symptom dimensions: Development and evaluation of the Dimensional Obsessive-Compulsive Scale. *Psychological Assessment, 22*(1), 180.
- Baker, J. M., Rojas-Valverde, D., Gutiérrez, R., Winkler, M., Fuhrmann, S., Eskenazi, B., . . . Mora, A. M. (2017). Portable functional neuroimaging as an environmental epidemiology tool: A how-to guide for the use of fNIRS in field studies. *Environmental Health Perspectives, 125*(9), 094502-094502. doi:10.1289/EHP2049
- Barke, A., Bode, S., Dechent, P., Schmidt-Samoa, C., Van Heer, C., & Stahl, J. (2017). To err is (perfectly) human: Behavioural and neural correlates of error processing and perfectionism. *Social Cognitive and Affective Neuroscience, 12*(10), 1647-1657. doi:10.1093/scan/nsx082
- Barrett, T. S., & Brignone, E. (2017). Furniture for quantitative scientists. *R Journal, 9*, 142-148.
- Boas, D. A., Elwell, C. E., Ferrari, M., & Taga, G. (2014). Twenty years of functional near-infrared spectroscopy: Introduction for the special issue. *NeuroImage, 85*, 1-5. doi:10.1016/J.NEUROIMAGE.2013.11.033
- Boas, D. A., Gaudette, T., Strangman, G., Cheng, X., Marota, J. J. A., & Mandeville, J. B. (2001). The accuracy of near infrared spectroscopy and imaging during focal changes in cerebral hemodynamics. *NeuroImage, 13*(1), 76-90. doi:10.1006/NIMG.2000.0674
- Brown, R. C., Overstreet, C., Sheerin, C., Berenz, E., Hawn, S., Pickett, T., . . . Amstadter, A. B. J. (2018). The nomological network of a behavioral distress tolerance task in veterans. *Journal of Traumatic Stress, 31*(6), 876-885.

- Chung, Y., Rabe-Hesketh, S., Dorie, V., Gelman, A., & Liu, J. (2013). A nondegenerate penalized likelihood estimator for variance parameters in multilevel models. *Psychometrika*, *78*(4), 685-709.
- Cooney, R., Joormann, J., Eugene, F., Dennis, E. L., & Gotlib, I. H. (2010). Neural correlates of rumination in depression. *Cognitive, Affective and Behavioral Neuroscience*, *10*(4), 470-478. doi:10.3758/CABN.10.4.470
- Crum II, J. E. (2020). Future applications of real-world neuroimaging to clinical psychology. *Psychological Reports*, 0033294120926669.
- Cui, X., Bray, S., Bryant, D. M., Glover, G. H., & Reiss, A. L. (2011). A quantitative comparison of NIRS and fMRI across multiple cognitive tasks. *NeuroImage*, *54*(4), 2808-2821. doi:10.1016/J.NEUROIMAGE.2010.10.069
- Cuzzocreo, J. L., Yassa, M. A., Verduzco, G., Honeycutt, N. A., Scott, D. J., & Bassett, S. S. J. H. b. m. (2009). Effect of handedness on fMRI activation in the medial temporal lobe during an auditory verbal memory task. *30*(4), 1271-1278.
- Egan, S. J., Wade, T. D., & Shafran, R. (2010). Perfectionism as a transdiagnostic process: A clinical review. *Clinical Psychology Review*, *31*, 203-212. doi:10.1016/j.cpr.2010.04.009
- Egan, S., Wade, T., & Shafran, R. (2012). The transdiagnostic process of perfectionism. *Revista de psicopatología y psicología clínica*, *17*(3), 279-294.
- Etkin, A., Egner, T., & Kalisch, R. (2011). Emotional processing in anterior cingulate and medial prefrontal cortex. *Trends in Cognitive Sciences*, *15*(2), 85-93. doi:10.1016/J.TICS.2010.11.004

- Euston, David R., Gruber, Aaron J., & McNaughton, Bruce L. (2012). The role of medial prefrontal cortex in memory and decision making. *Neuron*, *76*(6), 1057-1070.
doi:10.1016/J.NEURON.2012.12.002
- Ferrari, M., & Quaresima, V. (2012). A brief review on the history of human functional near-infrared spectroscopy (fNIRS) development and fields of application. *NeuroImage*, *63*(2), 921-935. doi:10.1016/J.NEUROIMAGE.2012.03.049
- Feusner, J. D., Yaryura-Tobias, J., & Saxena, S. (2008). The pathophysiology of body dysmorphic disorder. *Body Image*, *5*(1), 3-12. doi:10.1016/J.BODYIM.2007.11.002
- Fonzo, G. A., & Etkin, A. J. D. i. c. n. (2017). Affective neuroimaging in generalized anxiety disorder: An integrated review. *Dialogues in Clinical Neuroscience*, *19*(2), 169.
- Glassman, L. H., Forman, E. M., Herbert, J. D., Bradley, L. E., Foster, E. E., Izzetoglu, M., & Ruocco, A. C. J. B. m. (2016). The effects of a brief acceptance-based behavioral treatment versus traditional cognitive-behavioral treatment for public speaking anxiety: An exploratory trial examining differential effects on performance and neurophysiology. *Behavior Modification*, *40*(5), 748-776.
- Grimm, S., Beck, J., Schuepbach, D., Hell, D., Boesiger, P., Bermpohl, F., . . . Northoff, G. (2008). Imbalance between left and right dorsolateral prefrontal cortex in major depression is linked to negative emotional judgment: An fMRI study in severe major depressive disorder. *Biological Psychiatry*, *63*(4), 369-376.
doi:10.1016/J.BIOPSYCH.2007.05.033
- Gusnard, D. A., Akbudak, E., Shulman, G. L., & Raichle, M. E. (2001). Medial prefrontal cortex and self-referential mental activity: Relation to a default mode of brain function. *PNAS*, *98*(7), 4259-4264.

- Hare, T. A., Camerer, C. F., & Rangel, A. (2000). Self-control in decision-making involves modulation of the vmPFC valuation system. *Science*, *324*(5927), 646-648.
doi:10.1126/science.1169957
- Holper, L., Shalóm, D. E., Wolf, M., & Sigman, M. (2011). Understanding inverse oxygenation responses during motor imagery: A functional near-infrared spectroscopy study. *European Journal of Neuroscience*, *33*(12), 2318-2328.
- Irani, F., Platek, S. M., Bunce, S., Ruocco, A. C., & Chute, D. (2007). Functional near infrared spectroscopy (fNIRS): An emerging neuroimaging technology with important applications for the study of brain disorders. *The Clinical Neuropsychologist*, *21*(1), 9-37.
doi:10.1080/13854040600910018
- Karimizadeh, A., Mahnam, A., Yazdchi, M. R., & Besharat, M. A. (2015). Individual differences in personality traits: Perfectionism and the brain structure. *Journal of Psychophysiology*, *29*(3), 107-111. doi:10.1027/0269-8803/a000141
- Kaye, W. H., Wagner, A., Fudge, J. L., & Paulus, M. (2011). Neurocircuitry of eating disorders. In R. A. H. Adan & W. H. Kaye (Eds.), *Behavioral neurobiology of eating disorders* (pp. 37-58). Heidelberg, Germany: Springer.
- Leifeld, P. (2013). texreg: Conversion of statistical model output in R to LaTeX and HTML tables. *Journal of Statistical Software*, *55*(8), 1-24. doi:10.18637/jss.v055.i08
- Lévesque, J., Eugène, F., Joannette, Y., Paquette, V., Mensour, B., Beaudoin, G., . . . Beaugard, M. (2003). Neural circuitry underlying voluntary suppression of sadness. *Biological Psychiatry*, *53*, 502-510. doi:10.1016/S0002-3223(03)01817-6

- Lock, J., Garrett, A., Beenhakker, J., & Reiss, A. L. (2011). Aberrant brain activation during a response inhibition task in adolescent eating disorder subtypes. *American Journal of Psychiatry, 168*(1), 55-64. doi:10.1126/sciadv.aaq0500
- Longe, O., Maratos, F. A., Gilbert, P., Evans, G., Volker, F., Rockliff, H., & Rippon, G. J. N. (2010). Having a word with yourself: Neural correlates of self-criticism and self-reassurance. *NeuroImage, 49*(2), 1849-1856.
- Luijten, M., Machielsen, M. W., Veltman, D. J., Hester, R., de Haan, L., Franken, I. H. J. J. o. p., & neuroscience. (2014). Systematic review of ERP and fMRI studies investigating inhibitory control and error processing in people with substance dependence and behavioural addictions. *Journal of psychiatry & neuroscience, 39*(3), 149–169. <https://doi.org/10.1503/jpn.130052>
- MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science, 288*, 1835-1838.
- Ong, C. W., Lee, E. B., Krafft, J., Terry, C. L., Barrett, T. S., Levin, M. E., & Twohig, M. P. (2019). A randomized controlled trial of acceptance and commitment therapy for clinical perfectionism. *Journal of Obsessive-Compulsive and Related Disorders, 22*, 100444.
- Pauls, D. L., Abramovitch, A., Rauch, S. L., & Geller, D. A. J. N. R. N. (2014). Obsessive–compulsive disorder: An integrative genetic and neurobiological perspective. *Nature Reviews Neuroscience, 15*(6), 410-424.
- R Core Team. (2019). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Riley, C., & Shafran, R. (2005). Clinical perfectionism: A preliminary qualitative analysis.

Behavioural and Cognitive Psychotherapy, 33(3), 369-374.

doi:10.1017/S1352465805002122

Ritchey, M., Dolcos, F., Eddington, K. M., Strauman, T. J., & Cabeza, R. J. J. o. p. r. (2011).

Neural correlates of emotional processing in depression: changes with cognitive behavioral therapy and predictors of treatment response. *Journal of Psychiatric Research*, 45(5), 577-587.

Rorden, C., & Brett, M. (2000). Stereotaxic display of brain lesions. *Behavioural Neurology*,

12(4), 191-200.

Roth, R. M., Saykin, A. J., Flashman, L. A., Pixley, H. S., West, J. D., & Mamourian, A. C.

(2007). Event-related functional magnetic resonance imaging of response inhibition in obsessive-compulsive disorder. *Biological Psychiatry*, 62(8), 901-909.

doi:10.1016/J.BIOPSYCH.2006.12.007

RStudio Team. (2020). RStudio: Integrated Development for R. Retrieved from

<http://www.rstudio.com/>

Ruby, P., & Decety, J. J. N. n. (2001). Effect of subjective perspective taking during simulation

of action: a PET investigation of agency. *Nature Neuroscience*, 4(5), 546-550.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime: User's guide*: Psychology

Software Incorporated.

Shackman, A. J., McMenamin, B. W., Maxwell, J. S., Greischar, L. L., & Davidson, R. J. (2009).

Right dorsolateral prefrontal cortical activity and behavioral inhibition. *Psychological Science*, 20(12), 1500-1506.

- Shafran, R., Cooper, Z., & Fairburn, C. G. (2002). Clinical perfectionism: A cognitive-behavioural analysis. *Behaviour Research and Therapy*, *40*(7), 773-791.
doi:10.1016/S0005-7967(01)00059-6
- Singh, A. K., Okamoto, M., Dan, H., Jurcak, V., & Dan, I. (2005). Spatial registration of multichannel multi-subject fNIRS data to MNI space without MRI. *NeuroImage*, *27*(4), 842-851.
- Stevens, L., Gauthier-Braham, M., & Bush, B. (2018). The brain that longs to care for itself: The current neuroscience of self-compassion. In *The Neuroscience of Empathy, Compassion, and Self-Compassion* (pp. 91-120): Elsevier.
- Twohig, M. P., Hayes, S. C., Plumb, J. C., Pruitt, L. D., Collins, A. B., Hazlett-Stevens, H., & Woidneck, M. R. (2010). A randomized clinical trial of acceptance and commitment therapy versus progressive relaxation training for obsessive-compulsive disorder. *Journal of Consulting and Clinical Psychology*, *78*(5), 705.
- Wan, N., Hancock, A. S., Moon, T. K., & Gillam, R. B. (2018). A functional near-infrared spectroscopic investigation of speech production during reading. *Human Brain Mapping*, *39*(3), 1428-1437.
- Wickham, H. (2017). tidyverse: Easily install and load 'Tidyverse' packages. R package version 1.1.1. Retrieved from <http://CRAN.R-project.org/package=tidyverse>
- Wu, D., Wang, K., Wei, D., Chen, Q., Du, X., Yang, J., & Qiu, J. (2017). Perfectionism mediated the relationship between brain structure variation and negative emotion in a nonclinical sample. *Cognitive, Affective, & Behavioral Neuroscience*, *17*(1), 211-223.
doi:10.3758/s13415-016-0474-8

Ye, J. C., Tak, S., Jang, K. E., Jung, J., & Jang, J. (2009). NIRS-SPM: Statistical parametric mapping for near-infrared spectroscopy. *NeuroImage*, *44*(2), 428-447.

