A Preliminary Investigation of the Effect of Acceptance and Commitment Therapy on
Neural Activation in Clinical Perfectionism

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Abstract

Clinical perfectionism is associated with various cognitive processes including performance monitoring and emotion regulation. This exploratory study analyzed neurological data from a randomized controlled trial for clinical perfectionism that compared acceptance and commitment therapy (ACT) to a waitlist control. The objective was to assess the effect of ACT on neural activation. Twenty-nine participants underwent a functional near-infrared spectroscopy assessment during which they completed behavioral tasks designed to elicit error detection and error generation at pre- and posttreatment. The hemodynamic response function (HRF) in the dorsolateral prefrontal cortex, dorsomedial prefrontal cortex, and right inferior parietal lobe was analyzed using mixed effects models. In all areas, we found reductions or smaller increases in the total HRF for experimental tasks from pre- to posttreatment in the ACT condition compared to the waitlist condition. Decreases in total oxygenated hemoglobin are consistent with diminished recruitment of neurons in response to previously emotionally salient stimuli, possibly representing greater cognitive processing efficiency. Our preliminary findings tentatively support the processes of change posited by the theory underlying ACT and highlight the need for more precise methodology in neurological assessment to adequately evaluate how treatment affects neurological function. Limitations include lack of an active comparison condition and behavioral data.

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

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Clinical perfectionism is characterized by rigid striving for unrealistically high personal standards and experiencing distress when these standards are not met (Shafran & Mansell, 2001). Features of clinical perfectionism include self-criticism, rigid adherence to rules (e.g., “I need to be perfect,” “I cannot be seen as a failure”), and avoidance of perceived failure that lead to impairment and/or significant distress. Clinical perfectionism is a risk and maintenance factor in clinical conditions like obsessive-compulsive disorder (OCD), depression, eating disorders, and anxiety disorders and contributes to poorer treatment outcomes (Egan, Wade, & Shafran, 2011).

Clinical trials focused on clinical perfectionism have found support for the efficacy of cognitive-behavioral therapy (CBT; Riley, Lee, Cooper, Fairburn, & Shafran, 2007; Shafran et al., 2017) and acceptance and commitment therapy (ACT; Ong, Lee, et al., 2019) for self-report outcomes. ACT is a modern acceptance-based CBT that aims to improve psychological flexibility, which is the ability to be open to internal experiences as they occur in the present moment while intentionally choosing to engage in meaningful activities (Hayes, Luoma, Bond, Masuda, & Lillis, 2006).

Understanding how psychotherapy influences neurological outcomes in clinical perfectionism is important because it gives insight into potential neural mechanisms associated with perfectionistic behaviors that could then be used to refine existing interventions (Fletcher, Schoendorff, & Hayes, 2010). For example, neurological data may point to pertinent processes of change, like executive functioning abilities, that cannot be easily detected with self-report measures. These data may then identify elements on which to focus or deemphasize in treatment depending on neurological shifts observed.

One metric of neurological activity is the hemodynamic response function (HRF), which depicts increases or decreases in total oxygenated hemoglobin as a function of increases or decreases in the recruitment of neurons in a cortical area. Thus, HRF data have the potential to test theory-driven hypotheses about how treatment works. Furthermore, measurement of the HRF represents assessment data on another level of scientific analysis, facilitating interdisciplinary coherence in the psychological treatment literature and providing depth to existing conceptualizations of the presentation and treatment of clinical perfectionism (Hayes, Barnes-Holmes, & Wilson, 2012). Yet, to our knowledge, no studies have examined the HRF among individuals with clinical perfectionism who have received psychological treatment.

Performance monitoring, which relies on detection and correction of discrepancies between an intended and actual response (i.e., an error; Taylor, Stern, & Gehring, 2007), may be especially salient to the presentation of clinical perfectionism as hypersensitivity to such discrepancies is one of its defining characteristics. This hypothesis is indirectly supported by evidence showing that patients with OCD show excessive neural activities in regions associated with error monitoring (Taylor et al., 2007). Thus, people who struggle with clinical perfectionism may exhibit hyperactivity in performance monitoring regions, which include the posterior medial frontal cortex, dorsolateral prefrontal cortex (dlPFC), and lateral parietal cortex (Sosic-Vasic, Ulrich, Ruchow, Vasic, & Gron, 2012; Taylor et al., 2007).

The dlPFC and medial prefrontal cortex (mPFC) have also been linked to use of cognitive and emotion regulation strategies such as suppression and reappraisal (Ochsner & Gross, 2005; Quirk & Beer, 2006).

Activation in the mPFC has been found to be related to self-referential processing especially in relation to negative affectivity (D'Argembeau et al., 2007; Lemogne et al., 2011;

Modinos, Ormel, & Aleman, 2009), making it particularly relevant to the self-critical thoughts and evaluative concerns frequently observed in clinical perfectionism. In addition, the mPFC is part of the default mode network, which comprises parts of the brain that are more active during “resting” state than attention-demanding, non-self-referential tasks (e.g., goal-directed activity; Raichle, 2015). Hyperactivation in the default mode network has been associated with depression (Fletcher et al., 2010), possibly through negative rumination (Whitfield-Gabrieli & Ford, 2012). The dlPFC has also been positively associated with self-reported self-criticism (Longe et al., 2010), making both the dlPFC and mPFC relevant areas of study.

The right inferior parietal lobe (IPL) has been implicated in perspective taking and empathy (Decety & Jackson, 2006; Ruby & Decety, 2003). Given that self-compassion—an antidote to self-criticism—may rely on self-directed empathy (Neff, 2003), the right IPL could be activated during use of self-compassion strategies.

The effect of CBT for emotional disorders generally point to decreased neural activation following treatment. For example, CBT for OCD and phobia appears to attenuate dlPFC activation, which may indicate less effort put into controlling obsessions or engaging in maladaptive cognitive strategies (Li et al., 2018; Paquette et al., 2003). In addition, CBT for major depression has been associated with decreases in dlPFC, ventrolateral PFC, and inferior parietal cortex activation, suggesting CBT resulted in reduction in rumination and excessive cognitive processing of irrelevant stimuli (Goldapple et al., 2004). In other words, CBT may help to downregulate the hyperactivity associated with certain forms of psychopathology.

Neural outcomes in ACT have been mixed. Researchers have investigated the effect of ACT on neural activation among individuals with public speaking anxiety (Glassman et al., 2016), disordered gambling (Dixon, Wilson, & Habib, 2016), chronic pain (Smallwood, Potter,

& Robin, 2016), and fibromyalgia (Jensen et al., 2012). Glassman et al. (2016) found *less* activation in the left dlPFC among individuals who received acceptance-based behavioral treatment, which possibly reflected less need to inhibit impulses—consistent with use of non-reactive acceptance strategies. Similarly, patients with opioid addiction and chronic pain demonstrated decreased activation in the IPL during painful stimulation after receiving ACT compared to those who received health education, indicating muted neural responsiveness to painful stimuli following a course of ACT (Smallwood et al., 2016).

In contrast, other studies on the effect of ACT on neural activation reported increased brain activation in regions of interest. For example, Dixon et al. (2016) found increased activation in frontal and parietal brain regions including the right IPL among college students with disordered gambling when they were presented with winning stimuli (i.e., matching images on a jackpot machine) after receiving ACT. In addition, Jensen et al. (2012) found higher activation in the ventrolateral prefrontal cortex and lateral orbitofrontal cortex among patients with fibromyalgia who completed ACT versus a waitlist condition. These regions are associated with executive functioning (Alvarez & Emory, 2006), suggesting that ACT led to greater recruitment of cognitive resources during processing of familiar stimuli .

These ostensibly discrepant findings on changes in brain activation could be related to the extent to which individuals have mastered acceptance-based strategies. That is, relevant brain regions (e.g., mPFC, dlPFC) may initially show increased activation due to greater cognitive engagement as new concepts are applied (Stevens, Gauthier-Braham, & Bush, 2018). However, decreased activation may be expected over time as individuals successfully disengage from the cognitive burden of regulating emotionally salient stimuli (Fletcher et al., 2010; Stevens et al.,

2018). These mixed findings underscore the need for more data to clarify the neural effects of ACT in order to delineate reliable patterns of neurological response to psychotherapy.

Present Study

The present study used HRF data (proxy measure of brain activity) collected from a randomized controlled trial testing the efficacy of ACT for clinical perfectionism relative to a 14-week waitlist control group (Ong, Lee, et al., 2019). In the current report, functional near-infrared spectroscopy (fNIRS), a form of neuroimaging assessment, was used to assess the HRF in preselected regions of interest including the left and right dlPFC, dorsomedial PFC (dmPFC), and right IPL during tasks designed to elicit error detection and error generation. The dlPFC and dmPFC are related to performance monitoring, emotion regulation, and self-referential processes, and the right IPL is related to perspective taking.

The objective of this study was to conduct exploratory analyses on the effect of ACT on measures of neural activation from pre- to posttreatment among individuals with clinical perfectionism. We predicted decreases in the total HRF in the dlPFC and dmPFC and increases in the total HRF in the right IPL from pre- to posttreatment in the ACT group compared to the waitlist group.

Method

Participants

Participants were recruited from a western U.S. town with newspaper and online advertisements, flyers, and class announcements. Recruitment materials stated individuals needed to be struggling with “procrastination, spending a lot of time planning/organizing, and difficulty starting/completing tasks because [of a] need to get them exactly right.” To be included in the treatment trial, participants had to: (1) score at least five on the Dimensional Obsessive-

Compulsive Scale (DOCS) Symmetry subscale (Abramowitz et al., 2010), (2) report significant distress and/or functional impairment due to clinical perfectionism in a clinical interview with a trained assessor, (3) be willing to complete 10 sessions of therapy, (4) be cognitively and physically able to complete study procedures, (5) not be currently seeking therapy for clinical perfectionism, and (6) report no change in psychotropic medication in the past 30 days.

A cutoff score of five on the DOCS Symmetry subscale was selected based on a mean score of 6.13 ($SD = 5.50$) in an OCD sample (Abramowitz et al., 2010). Individuals who scored at least five on the DOCS Symmetry subscale were invited to a baseline assessment session in which they also had to report significant distress and/or impairment related to perfectionism in a clinical interview to proceed with the study. A more liberal screening cutoff was selected given the heterogeneous topographical presentation of clinical perfectionism and further evaluation with a clinical interview. Given we specifically recruited participants who were seeking treatment for clinical perfectionism and the intervention focus was on clinical perfectionism over specific diagnoses, a DSM-5 diagnosis was not required to participate in the current study. However, participants had to report clinically significant distress and/or functional impairment related to perfectionism to qualify for the study (see criterion 2 above).

Additional eligibility criteria for the fNIRS assessment were: (7) righthandedness (to avoid the confounding influence of handedness on neuroimaging results; Cuzzocreo et al., 2009; Klöppel et al., 2007) and (8) scalp conditions allowed reliable fNIRS data recording (hair pigmentation and density affect light transmission; Khan et al., 2012; McIntosh, Shahani, Boulton, & McCulloch, 2010).

Fifty-three of 80 people who completed an initial phone screening enrolled in the clinical trial. Reasons for exclusion included ineligible based on phone screening ($n = 2$), not interested

in participating ($n = 12$), no-showed for intake appointment ($n = 10$), did not complete baseline assessment ($n = 1$), and did not report perfectionism as primary presenting concern ($n = 2$).

Among the 53 who were randomized, 24 participants were excluded from fNIRS analyses due to lefthandedness or unsuitable scalp conditions for reliable data recording ($n = 2$ in ACT, $n = 2$ in waitlist), inability to attend the fNIRS assessment at posttreatment in person ($n = 3$ in ACT, $n = 1$ in waitlist), and dropout from the study ($n = 9$ in ACT, $n = 7$ in waitlist), leaving 29 participants (14 in ACT condition, 15 in waitlist condition) who completed the fNIRS assessment at pre- and posttreatment. There were no significant baseline differences between completers and dropouts on any demographic variable, clinical perfectionism, psychological inflexibility, self-compassion, or quality of life. However, participants who did not complete the NIRS assessments (some of who did complete the study and self-report assessment) reported more symptom distress and functional impairment ($p = .046$) and less progress toward values ($p = .022$).

Study Procedures

Procedures were approved by a university institutional review board and participants signed an informed consent document prior to study participation. Following screening procedures (i.e., DOCS Symmetry administered online, phone interview, clinical in-person interview), participants completed a pretreatment assessment that included the fNIRS and self-report measures. Eligible participants were randomly assigned to either the treatment (10 sessions of ACT) or the control (14-week waitlist) condition. fNIRS assessment was conducted at pre- and posttreatment (after 10 weeks) and self-report measures were administered at pretreatment, posttreatment, and one-month follow-up. Student participants received course

credit for their participation in the study if offered by their instructor; no other form of compensation was provided.

Intervention. Participants assigned to the treatment condition received 10 weekly 50-minute sessions of ACT. Therapy sessions covered the six ACT processes of change with greater emphasis on acceptance, defusion, values, and committed action. The final two sessions focused on skills review, planning for maintenance of gains, and relapse prevention. Therapy was provided by a clinical psychologist or graduate student supervised by the clinical psychologist (MPT). Therapy delivered in the study was consistent with ACT principles and of excellent quality overall based on treatment fidelity ratings completed by two trained raters (Ong, Lee, et al., 2019). Information on the treatment manual used in the current study can be found at <https://www.utahact.com/treatment-protocols.html>.

In the trial, participants in the ACT condition showed greater improvements over time in clinical perfectionism (concern over mistakes; Hedges' $g = -1.03$, 95% CI [-1.73, -0.32]), symptom distress and functional impairment (Hedges' $g = -0.67$, 95% CI [-1.36, 0.03]), quality of life (Hedges' $g = 0.80$, 95% CI [0.10, 1.49]), progress toward valued living (Hedges' $g = 1.39$, 95% CI [0.64, 2.13]), psychological inflexibility (Hedges' $g = -0.73$, 95% CI [-1.42, -0.04]), and self-compassion (Hedges' $g = 1.06$, 95% CI [0.33, 1.80]) compared to those in the waitlist condition, supporting the efficacy of ACT over no active treatment (Ong, Lee, et al., 2019).

Waitlist. Participants assigned to the waitlist condition did not receive any intervention for 14 weeks, after which they were offered the study intervention.

Neurological Assessment

Neuroimaging method. fNIRS is a noninvasive neuroimaging technology that assesses cortical hemodynamic responding in real-time by measuring changes in oxygenated,

deoxygenated, and total hemoglobin concentration levels in the cortical structures of the brain (i.e., the HRF) using near-infrared spectroscopy (Ferrari & Quaresima, 2012; Quaresima & Ferrari, 2016). Its primary advantages include (1) reliance on low-cost, portable equipment and (2) mobility afforded to participant during assessment, expanding the range of experimental tasks that can be performed (Quaresima & Ferrari, 2016). Thus, fNIRS is particularly suitable for neurological investigations using relatively common tasks (e.g., writing) that may not be feasible with other neuroimaging methods such as fMRI. Furthermore, because changes in activation reflecting higher-level emotional processing can be measured in the prefrontal cortex, fNIRS may have clinical utility with respect to investigating emotional responding in clinical populations (Liu et al., 2014; Matsubara et al., 2014; Yokoyama et al., 2015).

Data collection. Participants were seated 50 cm away from a 46×28-cm computer screen on which task instructions were delivered using E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002) prior to the start of the fNIRS assessment. In addition, because movement is associated with fNIRS signal noise (Cui, Baker, Liu, & Reiss, 2015), participants were instructed to move as little as possible during the experiment. Following delivery of instructions, two trained researchers fit a fNIRS cap to participants' head before initiating experimental tasks.

The experiment consisted of two blocks with each block containing three two-minute tasks (described in the following section). Participants were instructed to work on the tasks for the entire duration until they heard the sound of a bell, which was programmed in E-Prime. No other instructions were provided for the tasks. Within the blocks, each task was separated by a 15-second inter-stimulus interval (ISI), which was a fixed cross displayed on the screen, also presented in E-Prime. Rest periods were placed before each block and after the final block (three total). During rest periods, participants were instructed to look at a fixed cross in the middle of

the screen. E-Prime was used to send markers to the fNIRS machine to obtain precise temporal markers for each task. Task order was randomized to minimize potential order effects. A flow diagram illustrating the fNIRS procedures is provided in Figure 1.

After the assessment was completed, participants were instructed to keep the cap on while researchers carefully removed the optodes so a channel registration analysis could be done using the Polhemus PATRIOT digitizing software. Measurements in centimeters were taken (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 moved 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).

fNIRS data were acquired using a Hitachi ETG-4000 system with two probe sets adapted to a 3×5 44-channel montage. 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. The left corner of probe set one covered coordinate F9 and the right corner of probe set two covered coordinate T8 (see Figure 2). 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 over the course of the experiment were recorded at 695 and 830 nm and sampled at 10Hz.

Polhemus PATRIOT digitizer channel registration analyses were used to check the accuracy of the cap placement and to provide individualized channel locations for each participant. NIRS-SPM toolbox was used to register the 3D spatial coordinates and transformed according to the Montreal Neurological Institute coordinates (Singh, Okamoto, Dan, Jurcak, &

Dan, 2005). After that, a text file containing detailed information about anatomical labeling and Brodmann areas was exported. ROIs identified for the analysis were the left and right dlPFC (Brodmann area 9 and 46), dmPFC (Brodmann area 8 and 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). Participants had an average coverage of five channels for the left dlPFC, four channels for the right dlPFC, seven channels for dmPFC, and five channels for the right IPL.

Experimental tasks. Participants completed three behavioral tasks: editing a passage with errors, tracing the mirror image of a geometric shape, and tracing a circle counterclockwise (see Figure 1). For all tasks, stimuli were presented on an 8×11-inch sheet of paper in front of participants; a pen was provided for use in each task. Prior to the start of the experiment, participants ascertained the stimuli were placed within a comfortable range of motion and easily accessible; tape markers were used to position stimuli consistently across tasks for each participant. In the editing task, participants were presented with a passage that was approximately 400 words long (range = 393 to 415); each passage contained 45 grammatical and spelling errors (see Appendix A for examples). Participants were asked to identify and correct as many errors as possible, encouraging error detection. In the mirror image tracing task, participants could only see the mirror image of a geometric shape (star, double-headed arrow, cross, and square with concave corners; see Appendix B). They were instructed to trace the shape on paper while looking at the mirror image; direct visual access to their hand and shape were blocked off with a wooden screen. The counterintuitive nature of this task (the mirror image of their hand goes in the opposite direction to their hand movement) was designed to force error generation and elicit frustration associated with not being able to complete a task perfectly.

In the circle tracing task, participants were instructed to trace over the image of a circle in a counterclockwise direction as many times as possible.

The two tasks designed to elicit error detection and error generation relevant to clinical perfectionism were editing and mirror image tracing respectively. Specifically, error detection and generation are part of performance monitoring, which is the broader process of evaluating task performance with respect to specific goals (Taylor et al., 2007). Circle tracing served as a simple mechanical control task that could have elicited error making but without explicit task expectations and requiring as much cognitive effort as editing and mirror image tracing. In other words, we wanted to ensure the active behavioral tasks (i.e., editing, mirror image tracing) actually engaged deliberate perfectionistic tendencies and cognitive striving relative to the simpler circle tracing task.

Data processing. Signal measurements of total hemoglobin concentration ($HbT = HbO_2 + HbR$) were filtered using wavelet MDL (Gaussian low-pass FWHM at 4s; Brigadoi et al., 2014) and precolored and prewhitened using NIRS-SPM (Ye, Tak, Jang, Jung, & Jang, 2009). Wavelet filtering has been found to be the most effective way to adjust for motion artifacts in fNIRS data (Brigadoi et al., 2014). 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. Following this, each channel was visually inspected. 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.

HbT concentration, indirectly representing the recruitment of neurons in a cortical region, was the outcome of interest. HbT concentration was operationalized as area under the curve for total hemoglobin concentration (HbT), which represents the sum of oxygenated and deoxygenated concentration at each 10msec-interval for each region of interest. The period of the waveforms needed to calculate HbT was determined for each task per participant individually as per Wan, Hancock, Moon, and Gillam (2018).

Self-Report Measures

Dimensional Obsessive-Compulsive Scale (DOCS)—Symmetry (Abramowitz et al., 2010). The DOCS-Symmetry subscale evaluates severity of avoidance, distress, and interference due to a perceived need to make things “just right” (Abramowitz et al., 2010). Its five items are scored from 0 to 4 (anchors vary) with higher scores indicating higher severity (Abramowitz et al., 2010). Example items include: “When you have the feeling of something being “not just right,” how distressed or anxious did you become?” and “To what extent has your daily routine (work, school, self-care, social life) been disrupted by the feeling of things being ‘not just right,’ and efforts to put things in order or make them feel right?” The DOCS-Symmetry subscale has shown good to excellent internal consistency in both clinical and nonclinical samples and convergent, divergent and criterion validity (Abramowitz et al., 2010).

Demographic information. The self-report assessment included questions on age, gender, marital status, ethnicity, highest education level achieved, religion, and annual household income.

Frost Multidimensional Perfectionism Scale: Concern Over Mistakes (FMPS-CM; Frost, Marten, Lahart, & Rosenblate, 1990). Baseline scores on the FMPS-CM subscale were used to describe the baseline severity of clinical perfectionism in the present sample. It has been

used as a primary outcome measure of clinical perfectionism in previous clinical trials (e.g., Rozental et al., 2017; Shafran et al., 2017). The FMPS-CM contains nine items focused on maladaptive responses to mistakes and perceived failure. Example items include: “I should be upset if I make a mistake” and “If I fail partly, it is as bad as being a complete failure.” Items are rated from 1 (*strongly disagree*) to 5 (*strongly agree*). Higher scores reflect more clinical perfectionism. Internal consistency of the subscale in our sample was excellent ($\alpha = .92$).

Statistical Analyses

Multilevel modeling. Linear mixed effects models were used to assess changes in HbT in an intent-to-treat sample. The final models were built hierarchically, starting from the full model with three-way interactions (condition $\times$ time $\times$ task) to more parsimonious models. The decision to do model selection from complex to parsimonious was driven by the research questions, that the most complex models were expected to be the best fitting. To select the final models for each region, likelihood ratio tests assessed for differences between more complex models and more parsimonious models. That is, we compared models with a three-way interaction to models with each two-way interaction. If there was no significant difference (at $\alpha = .05$) between models, the more parsimonious model was compared to an even more parsimonious model. This produced four final models, one for each region of interest.

The random effects structure in the mixed effects models was selected based on the design of the experiment (Barr, Levy, Scheepers, & Tily, 2013). This involved a random intercept by individual participant within each time (pretest or posttest), thereby allowing the model to flexibly handle the repeated-measures design. All comparisons of fixed effects were done with REML. The residuals of the final models were checked for irregularities that could impact conclusions.

All statistical analyses were performed in R version 3.5.2 (R Core Team, 2018) and RStudio version 1.2.1114 (RStudio Team, 2020) using the lme4 (Bates, Maechler, Bolker, & Walker, 2015), lmerTest (Kuznetsova, Brockhoff, & Christensen, 2017), dplyr (Wickham, François, Henry, & Müller, 2019), furniture (Barrett & Brignone, 2017), rio (Chan, Chan, Leeper, & Becker, 2018), and janitor (Firke, 2018) packages.

Results

Sample Description

Of the 29 participants who completed the fNIRS assessment at both time points, 65.5% identified as female, 69.0% as single, 86.2% as European American/White, and 82.8% as members of The Church of Jesus Christ of Latter-day Saints. Forty-nine percent reported their highest education received was “some college,” and 27.6% reported a household income of \$50,000 or higher. The mean age of the sample was 26.6 years ($SD = 13.1$, range 18 to 70 years).

The mean FMPS Concern Over Mistake subscale score in our overall sample was 32.6 ($SD = 8.0$), which is comparable to scores reported in previous treatment studies for clinical perfectionism at baseline: 33.4 ($SD = 6.4$; Rozental et al., 2017) and 35.7 ($SD = 4.9$; Shafran et al., 2017). Descriptive statistics of the sample by condition are presented in Table 1.

Mixed Effects Models

Left dlPFC. The best-fitting model for predicting HbT in the left dlPFC was the two-way interaction model with condition interacting with task, condition interacting with time, and task interacting with time ($p = .006$; see Table 2). These interactions are depicted in Figure 3, panel a. For rest, neither group had substantial movement from pretest to posttest. However, for the editing and circle tracing tasks, there was a decrease in HbT for the treatment condition while the waitlist condition either remained steady or increased slightly. The mirror image tracking task

showed a similar pattern to the editing task, although there was a slight decrease for individuals in the treatment condition while the individuals in the waitlist condition evidenced a slight increase. Overall, the treatment condition showed more of a decrease in HbT for the editing, mirror image tracing, and circle tracing tasks than the waitlist condition in this sample from pretest to posttest while rest did not.

Right dlPFC. The best-fitting model for predicting HbT in the left dlPFC was the three-way interaction model with the interaction between condition, task, and time ($p = .005$; see Table 2). The three-way interaction is depicted in Figure 3, panel b. For rest, the treatment condition had an increase in HbT from pretest to posttest while the waitlist condition did not show much change. However, for the editing task, there was a decrease in HbT for the treatment condition while the waitlist condition slightly increased. The mirror image tracing task showed a similar pattern to the editing task, with a starker increase in HbT for the waitlist condition. The circle tracing task showed decreases for both the treatment and waitlist conditions. Generally, the editing and mirror image tracing tasks showed decreases in HbT for the treatment compared to the waitlist condition, which tended to have an increase in HbT.

dmPFC. The best-fitting model for predicting activation in the dmPFC was the two-way interaction model with condition interacting with task, condition interacting with time, and task interacting with time ($p = .009$; see Table 2). The meaning of these interactions is shown in Figure 3, panel c. For the dmPFC, the treatment condition showed a decrease in HbT in the editing task from pretest to posttest. For rest, mirror image tracing, and circle tracing, the treatment condition increased in HbT or remained steady from pretest to posttest. The waitlist condition increased or remained steady for each task across time with a bigger increase in HbT

for the mirror image tracing task compared to other tasks. Thus, for the mirror image tracing task, there was a relatively bigger increase in HbT in the waitlist than in the treatment condition.

Right IPL. The best-fitting model for predicting activation in the right IPL was the two-way interaction model with condition interacting with task, condition interacting with time, and task interacting with time ($p = .006$; see Table 2). These interactions are depicted in Figure 3, panel d. The treatment condition did not show much movement from pretest to posttest for the rest, editing, or mirror image tracing. For circle tracing, both the treatment and waitlist conditions showed similar decreases in HbT from pretest to posttest. For the other tasks, the waitlist condition showed increases or remained steady across time. Similar to the dmPFC, there was a bigger increase in HbT for the mirror image tracing task compared to other tasks in the waitlist condition, resulting in a bigger between-group contrast for the mirror image tracing task relative to other tasks.

Discussion

We observed decreases in HbT in the left and right dlPFC during active experimental tasks (i.e., editing, mirror image tracing) among participants in the ACT condition in contrast to increases in HbT in the waitlist condition. This pattern is consistent with mindfulness research on neurological outcomes and supports the hypothesis that an acceptance- and mindfulness-based intervention can lead to more efficient cognitive processing and reduced HbT responsivity to previously emotionally salient stimuli (e.g., fear of making mistakes; Lutz et al., 2014; Stevens et al., 2018). In addition, the decreased activation may reflect less cognitive effort toward performance monitoring, which typically could be heightened in clinical perfectionism (Taylor et al., 2007), after receiving ACT. Given the dlPFC has been associated with self-criticism and emotion regulation strategies like cognitive reappraisal (i.e., changing the meaning of

emotionally salient stimuli; Longe et al., 2010; Ochsner & Gross, 2005), the decreased HbT observed in the ACT condition relative to the waitlist condition also indirectly corroborates the hypothesized processes of change through which ACT effects meaningful change. Specifically, that ACT teaches clients to notice thoughts (e.g., “I need to do this perfectly”) as thoughts instead of buying into or arguing with them and to put less effort into controlling feelings (e.g., of imperfection) by simply allowing them to be present without fighting with them. If clients use these skills successfully, we would predict less recruitment of neurons in the dlPFC, corresponding to reduced HbT concentration, as was observed in this study.

The same general pattern of relatively less total oxygenation was replicated in the dmPFC among participants in the ACT condition. Whereas total HbT decreased for editing in the ACT condition (compared to increases in the waitlist condition), both conditions showed increased HbT for the mirror image tracing task, with the ACT group showing a smaller increase (see Figure 3, panel c). The dmPFC has been linked to performance monitoring, evaluative self-referential processing, negative self-relevant stimuli, self-reflection, and rumination (Cooney, Joormann, Eugene, Dennis, & Gotlib, 2010; D'Argembeau et al., 2007; Lemogne et al., 2011; Modinos et al., 2009; Taylor et al., 2007; Whitfield-Gabrieli & Ford, 2012), which means it is likely implicated in self-criticism. Thus, smaller HbT in the ACT condition may indicate fewer neural resources associated with negative self-focused processing relative to the waitlist group.

The discrepant patterns observed between the editing and mirror image tracing tasks are consistent with research on the task-dependent nature of neurological activation (Simmonds, Pekar, & Mostofsky, 2008), but it is unclear which factors differentiated the effects of tasks used in the present study on the dmPFC. Given the dmPFC is also associated with perspective taking (D'Argembeau et al., 2007), use of a mirror image may have elicited dmPFC activation related to

perspective taking (i.e., adopting the perspective of the mirror image of one's hand). Thus, if participants recruited a perspective taking strategy more successfully during their second attempt at the mirror image tracing task in the posttreatment assessment, this would result in an overall increase in total oxygenation in the dmPFC across groups. This explanation is speculative, and more research is needed to clarify specific task parameters that influence the recruitment of neurons in the dmPFC.

For the right IPL, there were no group differences during the editing task. Levels of HbT concentration remained constant in the ACT condition for the mirror image tracing task in contrast to increased levels of HbT concentration in the waitlist condition. The lack of a predictable pattern is consistent with previous research showing IPL activation is variable and highly context-dependent even after receiving the same type of intervention (Dixon et al., 2016; Smallwood et al., 2016). A key reason we examined the IPL was to see if ACT would produce neural changes in perspective taking and empathy (Decety & Jackson, 2006; Ruby & Decety, 2003), which could be linked to self-compassion. However, the experimental tasks might not have provided appropriate stimuli to prompt perspective taking as it relates to increased empathy. Rather, our results suggest the experimental tasks might have been more suited to the assessment of performance monitoring, emotion regulation, self-referential processing, and rumination as manifested in the dlPFC and dmPFC.

Despite the somewhat inconsistent patterns across tasks and regions of interest, our results generally favor decreases or relatively smaller increases in the HRF in the dlPFC, dmPFC, and right IPL among participants who received ACT, which broadly suggest ACT resulted in greater neural efficiency in response to error-prone tasks and reduced responsivity to emotionally salient stimuli. For example, reduced hyperactivation in the dmPFC, which is part of

the default mode network, may reflect acceptance, defusion, or perspective taking with respect to self-criticism, such that participants were better able to simply notice distracting stimuli while staying focused on the attention-demanding task at hand. As such, our results tentatively support the hypothesis that ACT targets specific acceptance and mindfulness processes of change, corroborating self-report data (Ong, Barney, et al., 2019) and the theoretical framework underlying ACT.

Still, the lack of precision in neuroimaging findings has been a consistent challenge in fNIRS research especially when measuring higher-order processes like emotions (Bendall, Eachus, & Thompson, 2016). Common issues include heterogeneity of the presenting concern of interest, complexity of cognitive processes inherent in psychopathology, inconsistency of experimental designs (e.g., tasks administered, regions examined), and individual-level differences in emotional processing. Clinical researchers evaluating the neurological effects of a psychological treatment should consider these variables in study planning.

Limitations

First, the lack of an active comparison condition (e.g., CBT) makes it impossible to determine if changes in HbT were specific to ACT or general to psychotherapy. While a previous study comparing ACT to CBT for public speaking anxiety found moderate neural differences between groups at posttreatment (Glassman et al., 2016), it is possible CBT approaches that emphasize distress tolerance will produce similar results.

Second, we did not collect data on task performance, which would have clarified the relationship between neural activation and behavioral performance (Schroder & Moser, 2014). Our interpretation of these results assumes task performance was similar between groups, as

there was no reason to predict otherwise. Nonetheless, it is possible the decreased HbT in the ACT group was linked with poorer task performance rather than greater cognitive efficiency.

Third, the behavioral tasks used in our study were not tested in previous studies. As such, their ability to elicit perfectionistic responses through error detection and error generation is unclear. In addition, circle tracing may not have been a neutral task for people with clinical perfectionism. It is possible participants reacted to standards they had about “tracing the circle perfectly” during the task. However, our pattern of findings that showed no group differences in three of four regions of interest provides support for criterion validity of the circle tracing task (see Figure 3). Furthermore, we designed these tasks based on a theoretical conceptualization of clinical perfectionism and tested them with pilot volunteers who self-identified as perfectionists and provided us with feedback, which we incorporated into the final task design. At the same time, lack of standardized tasks is a common issue in neuroimaging studies (Bendall et al., 2016), making it difficult to compare findings across studies. We recommend development of standardized tasks for specific presentations of interest to facilitate aggregation of neuroimaging results and improve our understanding of the neurological effects of psychotherapy.

Fourth, implementing acceptance-based strategies could involve more complex emotions that were not adequately captured by the ROIs. For example, studies on mindfulness show it is related to three interwoven mechanisms: intention, attention, and attitude (Shapiro, Carlson, Astin, & Freedman, 2006; Zhang et al., 2019). Thus, our findings may only have provided a partial picture of the effects of ACT on neural activation.

Fifth, although there was a difference in variance in age between groups, we did not include age as a covariate. This was because we did not have many older adults (≥ 60 years old) in our sample, which is the group typically associated with age-related neurocognitive

differences (Grady, Sarraf, Saverino, & Campbell, 2016; Salthouse, 2019). Including age could have given a false impression of statistical control when variability was insufficient.

Sixth, because this investigation was conducted within a larger clinical trial not a laboratory-based experiment, the independent variable of interest lacked precision (i.e., 10 sessions of ACT vs. 10 minutes of guided Vipssanna meditation). For neuroscientific data to have clinical implications, we need to precisely define the independent and dependent variables involved in the analysis. An explicit definition of the independent variable tells us the manipulation whose effect is being tested, whereas that of the dependent variable tells us exactly what process is being affected in the brain. Ambiguity in either definition threatens to weaken the clinical utility of such data. As such, while current data provide insight into how ACT influences neural processes, future research should clarify exactly which procedures in ACT are actively contributing to neural changes. Furthermore, while we attempted to measure narrowly defined behavioral performance through task constraints, we were unable to account for cognitive strategies participants used during the behavioral tasks as we did not instruct participants to use any specific strategy, potentially introducing heterogeneity to task performance and corresponding neurological data. Devising ways to further control the independent variable (e.g., instructing participants to use the skill of noticing feelings without fighting with them if they feel frustrated) would increase precision of neuroscientific evidence.

Seventh, while the fNIRS has numerous advantages as a neuroimaging assessment tool, its low spatial resolution and limited channels precluded observing changes in specific areas in regions of interest, deep brain structures, or other cortical structures of the brain (Quaresima & Ferrari, 2019). As such, this study was unable to account for more granular changes or those in other brain structures like the insula, which is associated with meditation (Fletcher et al., 2010),

or anterior cingulate cortex, which is associated with error monitoring (Schroder & Moser, 2014).

Finally, the current study was underpowered to identify potential moderators of neurological performance. Hence, our findings could have obscured divergent patterns in our sample and significant effects on an idiographic level of analysis. The small sample may also explain the nonsignificant but potential differences between groups for the rest periods and other small baseline differences. Future research should strive to be adequately powered to produce more robust results and permit moderation analyses (e.g., more participants, greater experimental control).

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Table 1
Sample Descriptives

	Waitlist (n = 15) Mean (SD)/Frequency (%)	ACT (n = 14) Mean (SD)/Frequency (%)
Age	23.1 (4.4)	30.4 (17.9)
Gender		
Female	8 (53.3%)	11 (78.6%)
Male	7 (46.7%)	3 (21.4%)
Marital status		
Single	10 (66.7%)	10 (71.4%)
Married	5 (33.3%)	3 (21.4%)
Divorced	0 (0%)	1 (7.1%)
Ethnicity		
European American	12 (80%)	13 (92.9%)
Latinx/Hispanic	3 (20%)	1 (7.1%)
Education		
M.A./M.S. or equivalent	0 (0%)	2 (14.3%)
Some graduate school	0 (0%)	1 (7.1%)
B.A/B.S. or equivalent	1 (6.7%)	1 (7.1%)
Associate degree	3 (20%)	4 (28.6%)
Some college	8 (53.3%)	5 (35.7%)
High school diploma or equivalent	3 (20%)	1 (7.1%)
Religion		
Catholic	1 (6.7%)	0 (0%)
LDS	12 (80%)	12 (85.7%)
Other	0 (0%)	1 (7.1%)
None	2 (13.3%)	1 (7.1%)
Annual household income		
\$50,000 or higher	4 (26.7%)	4 (28.6%)
\$40,001 to 50,000	0 (0%)	1 (7.1%)
\$30,001 to 40,000	1 (6.7%)	3 (21.4%)
\$20,001 to 30,000	2 (13.3%)	0 (0%)
\$15,001 to 20,000	3 (20%)	3 (21.4%)
\$10,001 to 15,000	1 (6.7%)	0 (0%)
\$5,001 to 10,000	1 (6.7%)	0 (0%)
\$5,000 or less	3 (20%)	3 (21.4%)
Clinical perfectionism (FMPS-CM)	32.6 (6.7)	32.6 (9.5)

Note. LDS = The Church of Jesus Christ of Latter-day Saints; FMPS-CM = Frost Multidimensional Perfectionism Scale Concern Over Mistakes subscale.

Table 2

Model Comparisons From Multilevel Analyses for Each Region of Interest

Model	χ^2	<i>p</i>
Left dlPFC		
Main Effects	-	
Condition $\times$ Time	4.179	0.041
Condition $\times$ Task	14.721	0.001
Condition $\times$ Task + Condition $\times$ Time	4.177	0.041
Condition $\times$ Task + Condition $\times$ Time + Time $\times$ Task	12.534	0.006
Condition $\times$ Task $\times$ Time	7.754	0.051
Right dlPFC		
Main Effects	-	
Condition $\times$ Time	0.581	0.446
Condition $\times$ Task	0.514	0.773
Condition $\times$ Task + Condition $\times$ Time	0.581	0.446
Condition $\times$ Task + Condition $\times$ Time + Time $\times$ Task	21.289	<.001
Condition $\times$ Task $\times$ Time	13.016	0.005
dmPFC		
Main Effects	-	
Condition $\times$ Time	1.315	0.252
Condition $\times$ Task	4.291	0.117
Condition $\times$ Task + Condition $\times$ Time	1.314	0.252
Condition $\times$ Task + Condition $\times$ Time + Time $\times$ Task	11.676	0.009
Condition $\times$ Task $\times$ Time	7.656	0.054
Right IPL		
Main Effects	-	
Condition $\times$ Time	2.366	0.124
Condition $\times$ Task	2.014	0.365
Condition $\times$ Task + Condition $\times$ Time	2.368	0.124
Condition $\times$ Task + Condition $\times$ Time + Time $\times$ Task	17.307	0.001
Condition $\times$ Task $\times$ Time	3.525	0.317

Note. Each model is compared to the model listed above it.

Figure 1. Flow diagram of fNIRS experimental procedures. Task order was randomized to minimize potential order effects. Participants completed the illustrated set of procedures twice (i.e., each task was performed twice) at each assessment point (pretreatment, posttreatment).

Figure 2. Placement of optodes and corresponding channel locations on front (top image) and right side (bottom image) of the head. The brain depicted in Figure 2 provides an example of the cap setup for the experiment and shows channel location and coverage for a specific participant.

Figure 3. Group means and standard errors of the area under the curve of HbT for each of the interactions with condition. Each panel represents the significant interactions for each region of interest with panels a to d representing the left dlPFC, right dlPFC, dmPFC, and right IPL respectively. The interactions with condition are shown at each time point by task for each region of interest.

Appendix A

Examples of Passages Used in Editing Task

Fidelis Umeh was born in Nigeria and lived there through his highschool years. Fidelis umeh grew up with strong family values of the traditions of the Ibos, a culture within Nigeria. “One thing that we Nigerian, particularly the Ibos, have taught us from youth is the value of Education. It is paramount. And the drive to succeed – my culture said that each person must work very hard and that is esential to success, which is very important. And we have support from family that keep us going when things are difficult. Some times perseverance can make the differences between success and failure.”

He moved to the united states when he went to College. After he finish college, he stayed connect to his family in Nigeria. He returned to Nigeria at least one a year. But he makes his home and career in this country. He became a Business Leader. Fidelis Umeh has succeeded in the business community, which some people see as a seperate culture all of it’s own. He planned projects. He designs systems. He brought new ideas to businesses. He has been president of a company that employ hundreds of highly skilled individual. At the same time, he kept his committment to his original culture.

In 1991, he founded a group to support Nigerians in chicago. “I formed a group of Nigerian to be an anchor for them that will fit into the American society but at the same time will give them something to fall back in times of adversty. I feel it is a strength, it allow us to be individuals.” S

“It has one goal, which are to bridge the gap between our people and the people in America. The target is to build an anchor where the nigerians can feel there identity and at the same time become more connected to the Chicago scene. The problem that we has with our Children is that either our children doesn’t have an understanding of the Nigerian culture or an understanding of the American culture. The focus is on children through adolescence. The adults get to benefit from the network.”

“We started with story telling. We are telling the children the stories that our family have told for generation. Each story has a morale, an idea that it teaches the children. The children learn the morals. They also learn more about their own heritage. They will apreciate their heritage. They will realize that they have too work hard, too, to achieve progres.”

The history of transportation is very long and full of changes and inventions. It starts with walking, which is not an invention; it just takes energy. People used to walk too far to get to other places. If you wanted to get somewhere quickly the only way to do that was to run. Actually, the first invention for transportation probably was the shoe. Centuries ago there were no shoes, people walked barefoot. Then people invented ways to transport themselves and materials from one place to another. In some cultures, people invented sledges, which is a kind of board that you dragged along the ground. You can tie things on the sledge to help carry them, but it's a challenging invention since if you hit a rock with the sledge as you pull it, the contents can slip off. In other cultures, people invented the wheel, which they use to make it easier to move things – and people. That was the beginning of many innovations in transportation.

Once people had wheels they could invent other ways to travel. They could put the wheel on a board and make it a wagon, and then they could hitch that wagon to an ox or a horse and ride as well as carry materials. That wheel led to what we have today; trucks, automobiles, and even boats and planes. It even was part of boats. There were steamboats that used giant wheels that turned with blades, pushing the water and pushing the boat forward.

How is the wheel part of planes. An airplane has to take off and land, so unless it is a plane that lands in water it needs to have wheels so it can start building speed as it takes off. Then when it lands it needs wheels to help it land safely. Even the space shuttle, a spaceship, needs wheels so it can land safely. Astronauts pilot the shuttle when it lands on a runway. Some planes have skids, which are like sleds. Those planes use these skids to land on water, but most planes require those wheels. The first planes were gliders, and they just sailed on the wind, but they have wheels, too. Then came the airplane with an engine, followed many years later by the jet plane. Today, we have spaceships, and people predicted that someday we will have cars that travel without a driver, that are driven by robots. They all started with that glider.

Appendix B
Shapes Used in Mirror Image Tracing Task