A Preliminary Investigation of the Effect of Acceptance and Commitment Therapy on

Neural Activation in Clinical Perfectionism

Clarissa W. Ong, M.S.[a]

Allison S. Hancock[a]

Tyson S. Barrett, Ph.D.[a]

Eric B. Lee, Ph.D.[a]

Nick Wan[a]

Ronald B. Gillam, Ph.D.[b]

Michael E. Levin, Ph.D.[a]

Michael P. Twohig, Ph.D.[a]

[a]Department of Psychology, Utah State University

[b]Department of Communicative Disorders and Deaf Education, Utah State University

Corresponding author:
Clarissa W. Ong
Department of Psychology
Utah State University
2810 Old Main Hill
Logan, UT 84322-2810
(435) 797-8303
clarissa.ong@usu.edu

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, Ruchsow, 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.

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Method

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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 × time × 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 α

$= .05$) 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).

References

Abramowitz, J. S., Deacon, B. J., Olatunji, B. O., Wheaton, M. G., Berman, N. C., Losardo, D., . . . Hale, L. R. (2010). Assessment of obsessive-compulsive symptom dimensions: Development and evaluation of the Dimensional Obsessive-Compulsive Scale. *Psychological Assessment 22*(1), 180-198. doi:10.1037/a0018260

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: a meta-analytic review. *Neuropsychology Review, 16*(1), 17-42. doi:10.1007/s11065-006-9002-x

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*(3). doi:10.1016/j.jml.2012.11.001

Barrett, T. S., & Brignone, E. (2017). Furniture for quantitative scientists. *R Journal, 9*, 142-148.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1–48. doi:10.18637/jss.v067.i01

Bendall, R. C., Eachus, P., & Thompson, C. (2016). A brief review of research using near-infrared spectroscopy to measure activation of the prefrontal cortex during emotional processing: The importance of experimental design. *Frontiers in Human Neuroscience, 10*, 529. doi:10.3389/fnhum.2016.00529

Brigadoi, S., Ceccherini, L., Cutini, S., Scarpa, F., Scatturin, P., Selb, J., . . . Cooper, R. J. (2014). Motion artifacts in functional near-infrared spectroscopy: A comparison of motion correction techniques applied to real cognitive data. *Neuroimage, 85*, 181-191. doi:10.1016/j.neuroimage.2013.04.082

Chan, C., Chan, G. C. H., Leeper, T. J., & Becker, J. (2018). *rio: A Swiss-army knife for data file I/O. R package version 0.5.16.*

Cooney, R. E., Joormann, J., Eugene, F., Dennis, E. L., & Gotlib, I. H. (2010). Neural correlates of rumination in depression. *Cognitive, Affective, & Behavioral Neuroscience, 10*(4), 470-478. doi:10.3758/CABN.10.4.470

Cui, X., Baker, J. M., Liu, N., & Reiss, A. L. (2015). Sensitivity of fNIRS measurement to head motion: An applied use of smartphones in the lab. *Journal of Neuroscience Methods, 245*, 37-43. doi:10.1016/j.jneumeth.2015.02.006

Cuzzocreo, J. L., Yassa, M. A., Verduzco, G., Honeycutt, N. A., Scott, D. J., & Bassett, S. S. (2009). Effect of handedness on fMRI activation in the medial temporal lobe during an auditory verbal memory task. *Human Brain Mapping, 30*(4), 1271-1278. doi:10.1002/hbm.20596

D'Argembeau, A., Ruby, P., Collette, F., Degueldre, C., Balteau, E., Luxen, A., . . . Salmon, E. (2007). Distinct regions of the medial prefrontal cortex are associated with self-referential processing and perspective taking. *Journal of Cognitive Neuroscience, 19*(6), 935-944. doi:10.1162/jocn.2007.19.6.935

Decety, J., & Jackson, P. L. (2006). A social-neuroscience perspective on empathy. *Current Directions in Psychological Science, 15*(2), 54-58. doi:10.1111/j.0963-7214.2006.00406.x

Dixon, M. R., Wilson, A. N., & Habib, R. (2016). Neurological evidence of acceptance and commitment therapy effectiveness in college-age gamblers. *Journal of Contextual Behavioral Science, 5*(2), 80-88. doi:10.1016/j.jcbs.2016.04.004

Egan, S. J., Wade, T. D., & Shafran, R. (2011). Perfectionism as a transdiagnostic process: A clinical review. *Clinical Psychology Review, 31*(2), 203-212. doi:10.1016/j.cpr.2010.04.009

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

Firke, S. (2018). janitor: Simple tools for examining and cleaning dirty data. R package version 1.1.1. . Retrieved from https://CRAN.R-project.org/package=janitor. https://CRAN.R-project.org/package=janitor

Fletcher, L. B., Schoendorff, B., & Hayes, S. C. (2010). Searching for mindfulness in the brain: A process-oriented approach to examining the neural correlates of mindfulness. *Mindfulness, 1*(1), 41-63. doi:10.1007/s12671-010-0006-5

Frost, R. O., Marten, P., Lahart, C., & Rosenblate, R. (1990). The dimensions of perfectionism. *Cognitive Therapy and Research, 14*(5), 449-468. doi:10.1007/BF01172967

Glassman, L. H., Forman, E. M., Herbert, J. D., Bradley, L. E., Foster, E. E., Izzetoglu, M., & Ruocco, A. C. (2016). The effects of a brief acceptance-based behavioral treatment versus traditional cognitive-behavioral treatment for public speaking anxiety. *Behavior Modification, 40*(5), 748-776. doi:10.1177/0145445516629939

Goldapple, K., Segal, Z., Garson, C., Lau, M., Bieling, P., Kennedy, S., & Mayberg, H. (2004). Modulation of cortical-limbic pathways in major depression: Treatment-specific effects of cognitive behavior therapy. *Archives of General Psychiatry, 61*(1), 34-41. doi:10.1001/archpsyc.61.1.34

Grady, C., Sarraf, S., Saverino, C., & Campbell, K. (2016). Age differences in the functional interactions among the default, frontoparietal control, and dorsal attention networks. *Neurobiology of Aging, 41*, 159-172. doi:10.1016/j.neurobiolaging.2016.02.020

Hayes, S. C., Barnes-Holmes, D., & Wilson, K. G. (2012). Contextual Behavioral Science: Creating a science more adequate to the challenge of the human condition. *Journal of Contextual Behavioral Science, 1*(1-2), 1-16. doi:10.1016/j.jcbs.2012.09.004

Hayes, S. C., Luoma, J. B., Bond, F. W., Masuda, A., & Lillis, J. (2006). Acceptance and commitment therapy: Model, processes and outcomes. *Behaviour Research and Therapy, 44*(1), 1-25. doi:10.1016/j.brat.2005.06.006

Jensen, K. B., Kosek, E., Wicksell, R., Kemani, M., Olsson, G., Merle, J. V., . . . Ingvar, M. (2012). Cognitive Behavioral Therapy increases pain-evoked activation of the prefrontal cortex in patients with fibromyalgia. *Pain, 153*(7), 1495-1503. doi:10.1016/j.pain.2012.04.010

Khan, B., Chester, W., Francis, R., Tian, F., Delgado, M. R., Liu, H., . . . Alexandrakis, G. (2012). Improving optical contact for functional near-infrared brain spectroscopy and imaging with brush optodes. *Biomedical Optics Express, 3*(5), 878-898. doi:10.1364/BOE.3.000878

Klöppel, S., van Eimeren, T., Glauche, V., Vongerichten, A., Münchau, A., Frackowiak, R. S. J., . . . Siebner, H. R. (2007). The effect of handedness on cortical motor activation during simple bilateral movements. *Neuroimage, 34*(1), 274-280. doi:10.1016/j.neuroimage.2006.08.038

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software, 82*(13), 1-26. doi:10.18637/jss.v082.i13

Lemogne, C., Gorwood, P., Bergouignan, L., Pelissolo, A., Lehericy, S., & Fossati, P. (2011). Negative affectivity, self-referential processing and the cortical midline structures. *Social Cognitive and Affective Neuroscience, 6*(4), 426-433. doi:10.1093/scan/nsq049

Li, P., Yang, X., Greenshaw, A. J., Li, S., Luo, J., Han, H., . . . Li, Z. (2018). The effects of cognitive behavioral therapy on resting-state functional brain network in drug-naive patients with obsessive-compulsive disorder. *Brain and Behavior, 8*(5), e00963. doi:10.1002/brb3.963

Liu, X., Sun, G., Zhang, X., Xu, B., Shen, C., Shi, L., . . . Liu, P. (2014). Relationship between the prefrontal function and the severity of the emotional symptoms during a verbal fluency task in patients with major depressive disorder: A multi-channel NIRS study. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 54*, 114-121. doi:https://doi.org/10.1016/j.pnpbp.2014.05.005

Longe, O., Maratos, F. A., Gilbert, P., Evans, G., Volker, F., Rockliff, H., & Rippon, G. (2010). Having a word with yourself: Neural correlates of self-criticism and self-reassurance. *Neuroimage, 49*(2), 1849-1856. doi:10.1016/j.neuroimage.2009.09.019

Lutz, J., Herwig, U., Opialla, S., Hittmeyer, A., Jancke, L., Rufer, M., . . . Bruhl, A. B. (2014). Mindfulness and emotion regulation--an fMRI study. *Social Cognitive and Affective Neuroscience, 9*(6), 776-785. doi:10.1093/scan/nst043

Matsubara, T., Matsuo, K., Nakashima, M., Nakano, M., Harada, K., Watanuki, T., . . . Watanabe, Y. (2014). Prefrontal activation in response to emotional words in patients with bipolar disorder and major depressive disorder. *Neuroimage, 85*, 489-497. doi:https://doi.org/10.1016/j.neuroimage.2013.04.098

McIntosh, M. A., Shahani, U., Boulton, R. G., & McCulloch, D. L. (2010). Absolute quantification of oxygenated hemoglobin within the visual cortex with functional near infrared spectroscopy (fNIRS). *Investigative Ophthalmology & Visual Science, 51*(9), 4856-4860. doi:10.1167/iovs.09-4940

Modinos, G., Ormel, J., & Aleman, A. (2009). Activation of anterior insula during self-reflection. *PLoS One, 4*(2), e4618. doi:10.1371/journal.pone.0004618

Neff, K. D. (2003). The development and validation of a scale to measure self-compassion. *Self and Identity, 2*(3), 223-250. doi:10.1080/15298860390209035

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences, 9*(5), 242-249. doi:10.1016/j.tics.2005.03.010

Ong, C. W., Barney, J. L., Barrett, T. S., Lee, E. B., Levin, M. E., & Twohig, M. P. (2019). The role of psychological inflexibility and self-compassion in acceptance and commitment therapy for clinical perfectionism. *Journal of Contextual Behavioral Science, 13*, 7-16. doi:10.1016/j.jcbs.2019.06.005

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*. doi:10.1016/j.jocrd.2019.100444

Paquette, V., Lévesque, J., Mensour, B., Leroux, J.-M., Beaudoin, G., Bourgouin, P., & Beauregard, M. (2003). "Change the mind and you change the brain": Effects of

cognitive-behavioral therapy on the neural correlates of spider phobia. *Neuroimage, 18*(2), 401-409. doi:10.1016/s1053-8119(02)00030-7

Quaresima, V., & Ferrari, M. (2016). Functional near-infrared spectroscopy (fNIRS) for assessing cerebral cortex function during human behavior in natural/social situations: A concise review. *Organizational Research Methods, 22*(1), 46-68. doi:10.1177/1094428116658959

Quaresima, V., & Ferrari, M. (2019). Functional near-infrared spectroscopy (fNIRS) for assessing cerebral cortex function during human behavior in natural/social situations: A concise review. *Organizational Research Methods, 22*(1), 46-68. doi:10.1177/1094428116658959

Quirk, G. J., & Beer, J. S. (2006). Prefrontal involvement in the regulation of emotion: Convergence of rat and human studies. *Current Opinion in Neurobiology, 16*(6), 723-727. doi:10.1016/j.conb.2006.07.004

R Core Team. (2018). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Raichle, M. E. (2015). The brain's default mode network. *Annual Review of Neuroscience, 38*(1), 433-447. doi:10.1146/annurev-neuro-071013-014030

Riley, C., Lee, M., Cooper, Z., Fairburn, C. G., & Shafran, R. (2007). A randomised controlled trial of cognitive-behaviour therapy for clinical perfectionism: A preliminary study. *Behaviour Research and Therapy, 45*(9), 2221-2231. doi:10.1016/j.brat.2006.12.003

Rorden, C., & Brett, M. (2000). Stereotaxic display of brain lesions. *Behavioural Neurology, 12*(4), 191-200. doi:10.1155/2000/421719

Rozental, A., Shafran, R., Wade, T., Egan, S., Nordgren, L. B., Carlbring, P., . . . Andersson, G. (2017). A randomized controlled trial of Internet-Based Cognitive Behavior Therapy for perfectionism including an investigation of outcome predictors. *Behaviour Research and Therapy, 95*, 79-86. doi:10.1016/j.brat.2017.05.015

RStudio Team. (2020). RStudio: Integrated Development for R. Retrieved from http://www.rstudio.com/

Ruby, P., & Decety, J. (2003). What you believe versus what you think they believe: A neuroimaging study of conceptual perspective-taking. *European Journal of Neuroscience, 17*(11), 2475-2480. doi:10.1046/j.1460-9568.2003.02673.x

Salthouse, T. A. (2019). Trajectories of normal cognitive aging. *Psychology and Aging, 34*(1), 17-24.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime User's Guide*. Pittsburgh, PA: Psychology Software Tools Inc.

Schroder, H. S., & Moser, J. S. (2014). Improving the study of error monitoring with consideration of behavioral performance measures. *Frontiers in Human Neuroscience, 8*, 178. doi:10.3389/fnhum.2014.00178

Shafran, R., & Mansell, W. (2001). Perfectionism and psychopathology: A review of research and treatment. *Clinical Psychology Review, 21*(6), 879-906. doi:10.1016/S0272-7358(00)00072-6

Shafran, R., Wade, T. D., Egan, S. J., Kothari, R., Allcott-Watson, H., Carlbring, P., . . . Andersson, G. (2017). Is the devil in the detail? A randomised controlled trial of guided internet-

based CBT for perfectionism. *Behaviour Research and Therapy, 95*, 99-106.
  doi:10.1016/j.brat.2017.05.014

Shapiro, S. L., Carlson, L. E., Astin, J. A., & Freedman, B. (2006). Mechanisms of mindfulness. *J
  Clin Psychol, 62*(3), 373-386. doi:10.1002/jclp.20237

Simmonds, D. J., Pekar, J. J., & Mostofsky, S. H. (2008). Meta-analysis of Go/No-go tasks
  demonstrating that fMRI activation associated with response inhibition is task-
  dependent. *Neuropsychologia, 46*(1), 224-232.
  doi:10.1016/j.neuropsychologia.2007.07.015

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.

Smallwood, R. F., Potter, J. S., & Robin, D. A. (2016). Neurophysiological mechanisms in
  acceptance and commitment therapy in opioid-addicted patients with chronic pain.
  Psychiatry Research: Neuroimaging, 250, 12-14. doi:10.1016/j.pscychresns.2016.03.001

Sosic-Vasic, Z., Ulrich, M., Ruchsow, M., Vasic, N., & Gron, G. (2012). The modulating effect of
  personality traits on neural error monitoring: evidence from event-related FMRI. *PLoS
  One, 7*(8), e42930. doi:10.1371/journal.pone.0042930

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).

Taylor, S. F., Stern, E. R., & Gehring, W. J. (2007). Neural systems for error monitoring: Recent
  findings and theoretical perspectives. *Neuroscientist, 13*(2), 160-172.
  doi:10.1177/1073858406298184

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. doi:10.1002/hbm.23932

Whitfield-Gabrieli, S., & Ford, J. M. (2012). Default mode network activity and connectivity in
  psychopathology. *Annual Review of Clinical Psychology, 8*(1), 49-76.
  doi:10.1146/annurev-clinpsy-032511-143049

Wickham, H., François, R., Henry, L., & Müller, K. (2019). dplyr: A Grammar of Data
  Manipulation. R package version 0.8.3. Retrieved from https://CRAN.R-
  project.org/package=dplyr.   https://CRAN.R-project.org/package=dplyr

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.
  doi:10.1016/j.neuroimage.2008.08.036

Yokoyama, C., Kaiya, H., Kumano, H., Kinou, M., Umekage, T., Yasuda, S., . . . Okazaki, Y. (2015).
  Dysfunction of ventrolateral prefrontal cortex underlying social anxiety disorder: A
  multi-channel NIRS study. *NeuroImage: Clinical, 8*, 455-461.
  doi:https://doi.org/10.1016/j.nicl.2015.05.011

Zhang, Q., Wang, Z., Wang, X., Liu, L., Zhang, J., & Zhou, R. (2019). The effects of different stages
  of mindfulness meditation training on emotion regulation. *Frontiers in Human
  Neuroscience, 13*, 208. doi:10.3389/fnhum.2019.00208

Table 1
Sample Descriptives

|	Waitlist (n = 15)	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	*p*
Left dlPFC		
Main Effects	-	
Condition × Time	4.179	0.041
Condition × Task	14.721	0.001
Condition × Task + Condition × Time	4.177	0.041
Condition × Task + Condition × Time + Time × Task	**12.534**	**0.006**
Condition × Task × Time	7.754	0.051
Right dlPFC		
Main Effects	-	
Condition × Time	0.581	0.446
Condition × Task	0.514	0.773
Condition × Task + Condition × Time	0.581	0.446
Condition × Task + Condition × Time + Time × Task	21.289	<.001
Condition × Task × Time	**13.016**	**0.005**
dmPFC		
Main Effects	-	
Condition × Time	1.315	0.252
Condition × Task	4.291	0.117
Condition × Task + Condition × Time	1.314	0.252
Condition × Task + Condition × Time + Time × Task	**11.676**	**0.009**
Condition × Task × Time	7.656	0.054
Right IPL		
Main Effects	-	
Condition × Time	2.366	0.124
Condition × Task	2.014	0.365
Condition × Task + Condition × Time	2.368	0.124
Condition × Task + Condition × Time + Time × Task	**17.307**	**0.001**
Condition × Task × Time	3.525	0.317

Note. Each model is compared to the model listed above it.
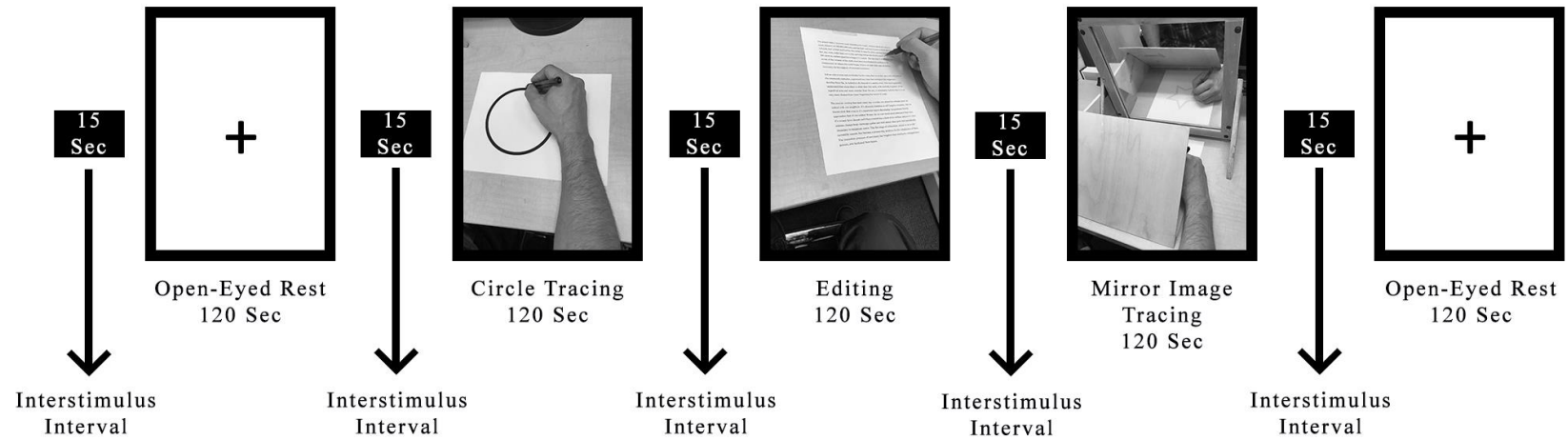
Figure 1. Flow diagram of fNIRS experimental procedures. Task order was randomized to minimize potential order effects. Participants completed the illustrated set of procedures twice (i.e., each task was performed twice) at each assessment point (pretreatment, posttreatment).
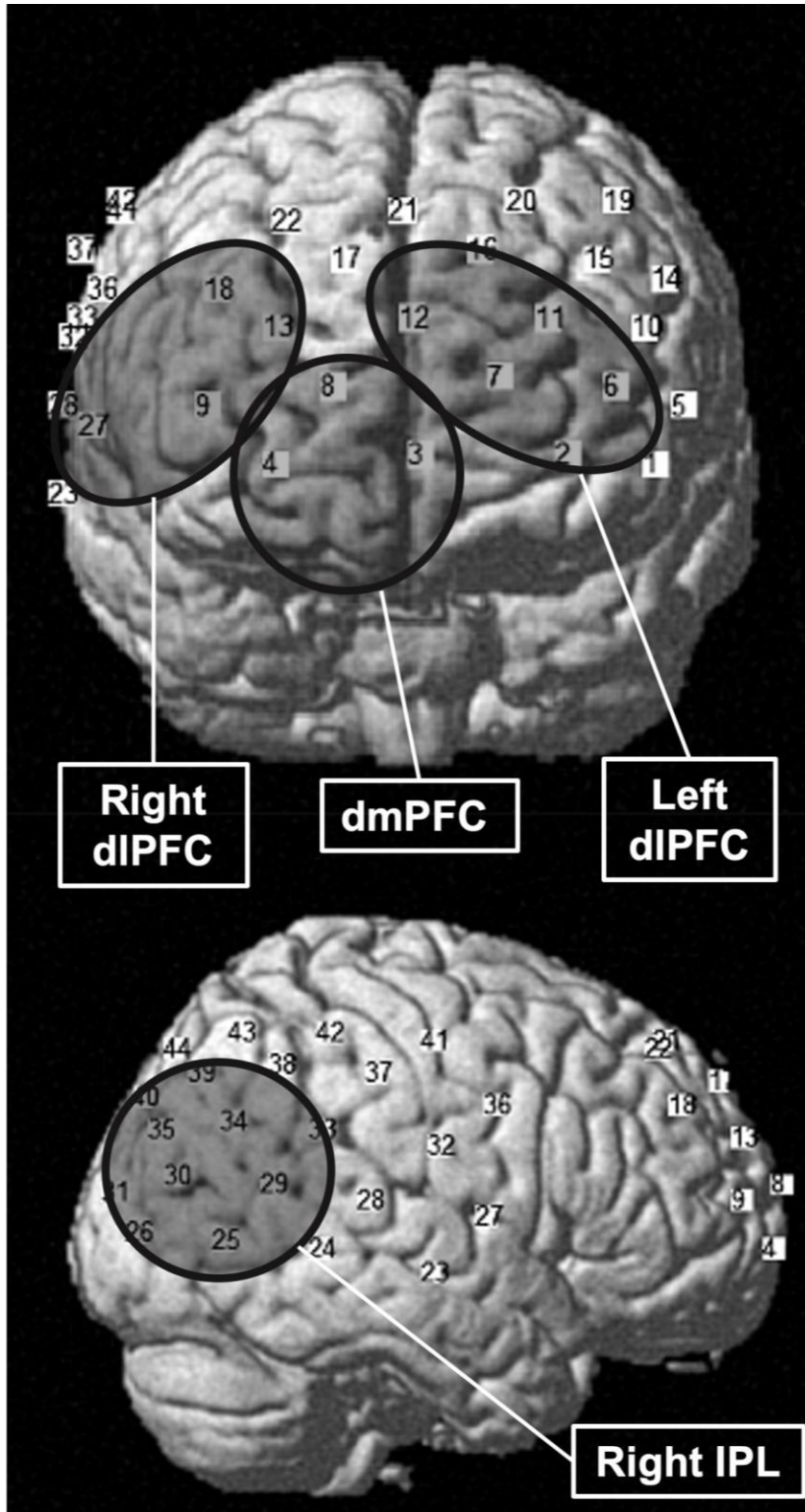
Figure 2. Placement of optodes and corresponding channel locations on front (top image) and right side (bottom image) of the head. The brain depicted in Figure 2 provides an example of the cap setup for the experiment and shows channel location and coverage for a specific participant.
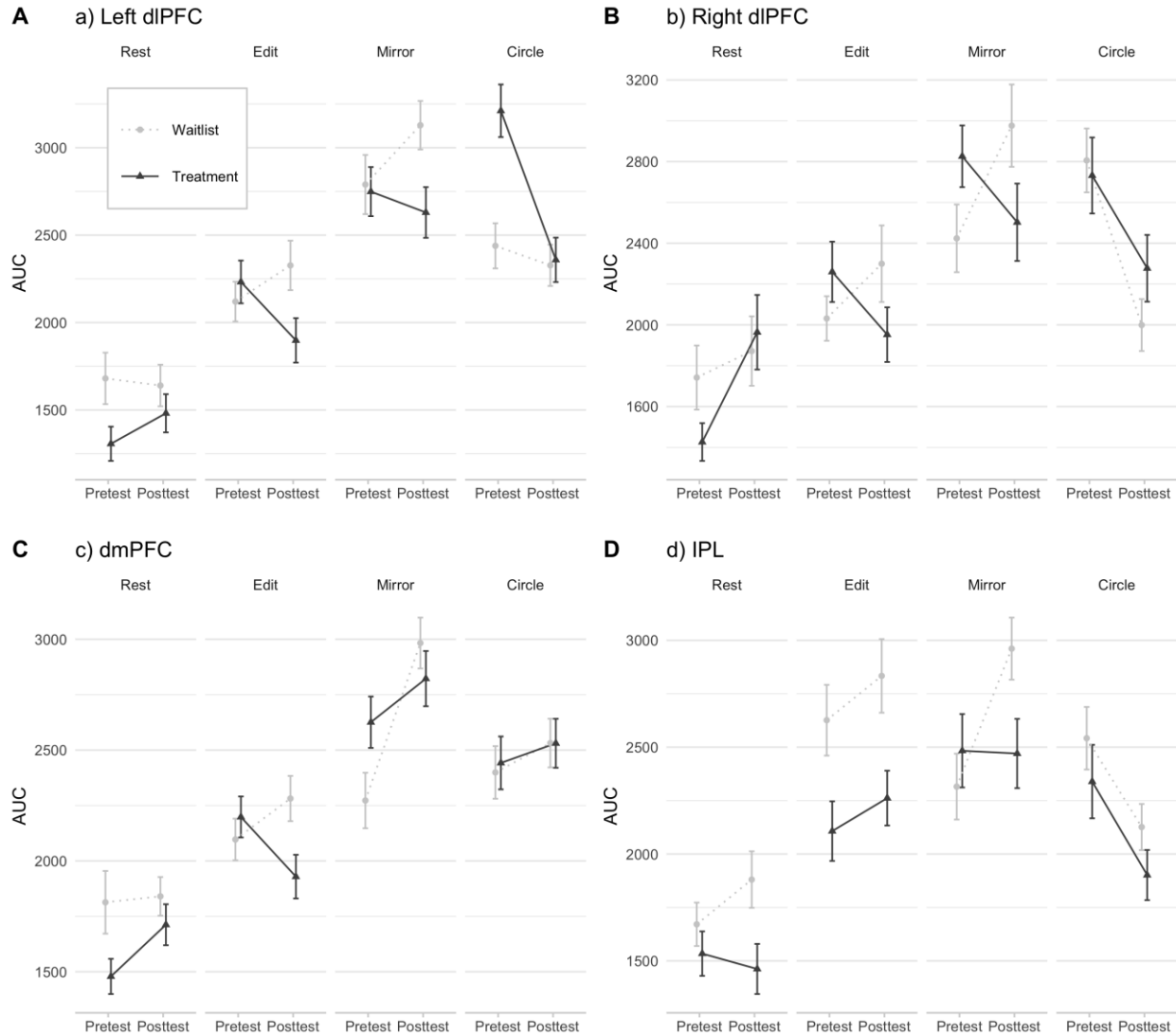
Figure 3. Group means and standard errors of the area under the curve of HbT for each of the interactions with condition. Each panel represents the significant interactions for each region of interest with panels a to d representing the left dlPFC, right dlPFC, dmPFC, and right IPL respectively. The 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 growed 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 suceed – 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 perseverence 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 succeded in the busness 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 adolesence. 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 histery of transportatation is very long and full off changes and inventions. It starts with walking, which is not any invention; it just take energy. People used to walk too get to other place. If you wanted to get some where quickly the only way to do that was to run. Actually, the first invntion for transportation probably was the shoo. Centuries ago there were no shoes, people walked bear foot. Then people invented ways to transport themself and materials from one place to another. In some cultures, people invent 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 its a challenging invention since if you hit a rocks with the sledge as you pull it, the contents can slip of. In other cultures, people invented the wheel, which they use to make it more easy to move things – and people. That was the begining of many inovations in transportation.

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

How is the wheel part of planes. An airplane has to takeoff and land, so unless it is a plane that lands in water it needs to have wheels so it can start building sped as it takes off. Then when it lands it needs wheel to help it land safely. Even the space shuttle, a spaceship, needs wheels so it can land safe. Astronaut pilot the shutle when it lands on a runway. Some planes have skids, which is like sleds. Those planes use these skids to land onwater, but most planes require those wheels. The first plane were gliders, and they just sailed on the wind, but they have wheels, to. Then came the airplane with a 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 roboots. They all started with that glider.

Appendix B
Shapes Used in Mirror Image Tracing Task