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Modulation of Global and Local Processing Biases in Adults with Autistic-like Traits

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Abstract Previous work shows that doing a continuous performance task (CPT) shifts attentional biases in neurotypical individuals towards global aspects of hierarchical Navon figures by selectively activating right hemisphere regions associated with global processing. The present study examines whether CPT can induce similar modulations of attention in individuals with high levels of autistic traits who typically show global processing impairments. Participants categorized global or local aspects of Navon figures in pre- and post-CPT blocks. Post-CPT, high trait individuals showed increased global interference during local categorization. This result suggests that CPT may be useful for temporarily enhancing global processing in individuals with high levels of autistic traits and possibly those diagnosed with autism.

Keywords Attention · Global processing · Local processing · Autistic traits · Autism · Hierarchical figures · Continuous performance task · Attentional training

Introduction

Autism is a disorder well-known to be characterized by repetitive patterns of behavior, restricted interests and impaired social functioning (American Psychiatric Association 2000). Less well known is that autism is also commonly associated with a bias to preferentially process individual ("local") components over holistic ("global") constructs (Behrmann et al. 2006a, b; Isomura et al. 2014; see; Happé and Frith 2006, for a review). For example, in the Embedded Figures Test (Witkin 1971), which requires locating a smaller target shape (e.g., a triangle) that forms part of a larger, more complex image (e.g., a grandfather clock), individuals with autism spectrum conditions (ASC) are reliably faster at locating the smaller target than neurotypical individuals (for a meta-analysis see Muth et al. 2014). Similarly, for hierarchical figures–stimuli that consist of a larger character and multiple embedded characters (Navon 1977)—individuals with ASC show faster identification of the smaller characters and/or slowed identification of the larger character compared to neurotypical individuals (also see Muth et al. 2014).

According to the "weak central coherence" theory (Shah and Frith 1983), the enhanced ability to attend to local-level stimuli in ASC arises from an impairment in the usual automatic propensity to process information in a holistic fashion seen in neurotypical individuals. Consequently, when attending to local-level stimuli, individuals with ASC are less distracted by holistic, global-level inputs, leading to improved performance. However, when attending to global-level stimuli, the relatively weaker drive for coherence results in greater interference from local-level stimuli, leading to poorer performance. While Shah and Frith's argument posits a potential deficit in global processing in ASC, many studies have found that individuals with ASC can actually process global information with comparable performance to neurotypical individuals, especially if their attention is explicitly directed to the global construct with a prime or instruction (López et al. 2004; Plaisted et al. 1999). This suggests that rather than having a structural deficit in global processing, individuals with ASC simply display a preference for prioritizing local information.

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The present work explores the possibility that processing in ASC could be shifted towards global constructs using a behavioral task that increases right hemisphere (RH) activation. There is substantial evidence that activation of cortical regions in the RH is associated with global processing (Evans et al. 2000; Flevaris et al. 2010; Hübner and Studer 2009; Malinowski et al. 2002; Volberg and Hübner 2004; Weissman and Woldorff 2005; Yamaguchi et al. 2000). Moreover, the RH has also been linked to variations in tonic (sustained) and phasic (short-term) attention. For example, increases in tonic attention lead to greater activation in the right inferior frontal, inferior parietal, and anterior cingulate regions (Bartolomeo 2014; Singh-Curry and Husain 2009; Sturm and Willmes 2001; Thiel et al. 2004), while phasic attentional changes modulate activity in the right ventral fronto-parietal network and anterior cingulate (Corbetta and Shulman 2002). Together, this suggests that a shift towards processing global constructs might be accomplished using a task that increases tonic and phasic awareness.

Recent work by Degutis and Van Vleet (2010) directly supports this suggestion. They had RH-damaged stroke patients complete a continuous performance task (CPT) over 9 days that required participants to withhold a response to the presentation of pre-designated target images (teapots; 10% of trials), but to quickly respond to non-targets (all other objects; 90% of trials). This task is similar to the *sustained attention to response task* (Robertson et al. 1997) in terms of response ratios, but differs in that the CPT used by Degutis and Van Vleet (2010) has variable and unpredictable inter-trial intervals, as opposed to fixed and predictable intervals. The combination of relatively rare inhibited responses and random inter-trial intervals demanded a high level of task engagement, thereby enhancing tonic and phasic attention. Consistent with the link between tonic/phasic attention and RH activity, left visuospatial neglect in the RH damaged stroke patients decreased following CPT but was unchanged by a similar training task that did not modulate tonic or phasic attention. Subsequently, Van Vleet et al. (2011) showed that CPT training could also modulate global and local attentional biases to hierarchical figures (Navon 1977) in a neurotypical sample. Following a brief period of CPT, participants were better able to ignore local distractors when directed to identify the global aspect of hierarchical stimuli, measured as a significant decrease in the difference between RTs to trials with and without the local distractor. Simultaneously, participants were worse at ignoring global distractors when tasked with identifying the local aspect. Again, these changes were not present following a training task that did not modulate tonic or phasic attention.

The work of Van Vleet et al. strongly suggests that behavioral training, in the form of a CPT, can increase RH activation and global preference in RH-damaged and neurotypical individuals. However, to our knowledge, no study has yet attempted to produce similar results using an ASC sample. Thus, we do not know if behavioral training can modulate attentional biases for individuals with ASC. It is entirely possible that processing preferences are relatively rigid for individuals with ASC, and may exhibit resistance to behavioral training. However, in light of evidence linking atypical behaviors and functioning in ASC to cortical abnormalities specific to the RH (Di Martino et al. 2011; Jou et al. 2010; Lazarev et al. 2009; Orekhova et al. 2009; Ozonoff and Miller 1996; Siegal et al. 1996), in the present work, we conducted two experiments to assess whether processing in individuals with high levels of autistic traits could be shifted towards a global aspect using CPT training that increases tonic and phasic attention.

In the first experiment, we began by replicating the experimental findings reported by Van Vleet et al. (2011) using a modified version of their paradigm adapted for our laboratory. This is critical not only because it shows the benefits of CPT are generalizable across laboratories and minor variations in methodology, but also because the experimental outcome provides a baseline against which to compare subsequent findings. In the second experiment, we sought to determine how CPT training influences global and local processing in neurotypical individuals with low or high levels of autistic traits. An increasing body of research has found that low and high autistic-trait comparisons reveal similar patterns of results as found in neurotypical and clinical ASC comparisons, especially with regard to global/local processing (for a meta-analysis see Cribb et al. 2016; see also:; Bayliss and Kritikos 2011; Grinter et al. 2009a, b; Rhodes et al. 2013; Russell-Smith et al. 2012; Sutherland and Crewther 2010). Thus, we expected the findings here to provide broad indications about the effectiveness of CPT training in altering local processing biases in neurotypical individuals high in autistic traits, and potentially by extension, individuals with ASC.

Experiment 1

In this experiment, we aimed to replicate the main findings presented by Van Vleet et al. (2011). To achieve this, we modified the experimental procedure laid out by these authors using our own stimuli and equipment. Participants began by categorizing the global and local aspects of a series of hierarchical figures (e.g. Fig. 1; Navon 1977) to obtain measures of task interference in global-categorization and local-categorization task conditions. Task interference was calculated by taking the difference in RTs between trials that were "congruent" (i.e., the global and local aspect of the hierarchical figure

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E E E E   3 3 3 3   2 2 2 2   A A A A
E     E         3   2     2         A
E E E E   3 3 3 3   2 2 2 2   A A A A
E     E   3         2     2   A
E     E   3 3 3 3   2     2   A A A A
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Fig. 1 Examples of hierarchical figures (Navon 1977) adapted from Van Vleet et al. (2011); the two on the left are form-congruent (the global and local features are the same; *both letters* or *both numbers*) and the two on the right are form-incongruent (the global and local features are mismatched; *letters and numbers* are simultaneously present)

were the same category—both numbers or both letters) and trials that were "incongruent" (i.e., the global and local aspect of the hierarchical figure were different categories—one letters and the other numbers). This difference provides a measure of how well individuals can maintain their attention on the aspect of the hierarchical figure that they were instructed to attend to. Larger interference scores, corresponding to longer RTs on incongruent trials relative to the congruent trials, therefore represent a relatively greater tendency to attend to the to-be-ignored aspect of the task.

Participants then completed training consisting of the CPT, or a categorization control task (CCT) that used similar stimuli but does not invoke changes to tonic/phasic attention (Van Vleet et al. 2011). Finally, participants repeated the hierarchical figures task to assess changes in global and local processing. We predict that, following a period of CPT, participants' attention to global details will be relatively greater than prior to training; specifically, local interference for global-categorization should be reduced, and global interference for local-categorization should be increased. In contrast, participants who complete CCT should experience no significant changes in interference for either categorization type.

Method

Participants

Seventy-two first year psychology students (CPT group: n = 36 (10 male), mean age 18.39 (SD = 1.59); CCT group: n = 36 (18 male), mean age 19.31 (SD = 2.75)) at the University of Western Australia participated in the study in exchange for partial credit towards a course requirement. Participants were selected to complete either the CPT or CCT by order of attendance to the laboratory.

Materials

Participants were seated approximately 500 mm in front of BenQ XL2420T displays (refreshing at 100 Hz) that were connected to computers running Windows 7. Presentation 17.0 software (Neurobehavioral Systems) was used to generate and display task stimuli and record participant responses.

The Hierarchical Figure Task (HFT)

Stimuli comprised the letters A, E, F, H, L and P, and the numbers 2, 3, 4, 6, 7 and 9. For each stimulus, one letter or number was randomly chosen as the larger global form and was created using a different randomly-chosen smaller letter or number as the local form arranged on a 4 × 5 grid (see Fig. 1). Every combination of letters and numbers as the global and local forms was used to create 132 figures. Half of the figures were congruent, with global and local forms chosen from the same category (i.e., global letter constructed from local letters, or global number constructed from local numbers), while the other half were incongruent, with the global and local forms chosen from different categories (i.e., global letter constructed from local numbers or vice-versa).

The task was divided into two blocks, with participants required to categorize (letter or number) the global form in one, and categorize the local form in the other. The blocks were presented in counterbalanced order. Each unique hierarchical figure was presented twice, yielding 264 trials per block. In the global-categorization block, the hierarchical figure's global forms were 1.90° wide × 2.53° high and were created using font size 10 characters. In the local-categorization block, the hierarchical figure's global forms were 1.43° wide × 1.90° high and were created using font size 9 characters. In a pilot study, Van Vleet et al. (2011) found that these stimulus sizes produced optimal interference from the task-irrelevant global or local form.

Each trial began with a fixation cross presented in the center of the display for 500 ms, followed by a hierarchical figure presented for 750 ms, and then a blank screen. Participants were directed to categorize either the global or local form of the hierarchical figure using two keys on a keyboard—the 'Z' key if the target form was a letter or the '/' key if the target form was a number. Participants were prompted to make their responses as quickly as possible whilst also retaining high task accuracy. Responses could be made during the presentation of the hierarchical figure or the blank screen, with a response immediately ending the trial. The fixation cross then reappeared marking the start of the next trial.

Continuous Performance Task (CPT)

The CPT was based on the paradigm previously used by Degutis and Van Vleet (2010), and Van Vleet et al. (2011). Task stimuli were 90 images (6.97° wide × 3.49° high) selected from the Caltech-256 Object Category dataset (Griffin et al. 2007), which was used due to the diverse nature of the images in the dataset, and was also the source of CPT stimuli in Degutis and Van Vleet (2010), and Van Vleet et al. (2011). Eight of the images were of teapots and were designated as targets, while the remaining 82 images were distractors comprised of random, everyday objects. Participants were instructed to withhold responses to target images, whilst dismissing all non-targets with a response.

Each trial began with a fixation cross presented in the center of the display for 600, 1800 or 3000 ms (randomly chosen on each trial) to prevent participants from anticipating the onset of the image. An image then replaced the fixation cross and remained onscreen for 500 ms or until a response was recorded. Participants were directed to press a response key (either 'Z' or '/') as quickly as possible if a distractor image appeared, but to withhold a response if a target image (a teapot) appeared and wait for the image to disappear. Images were presented in random order, with each image appearing four times, yielding 360 trials. The task took participants approximately 16 min to complete.

Continuous Categorization Task (CCT)

The CCT required participants to view a series of images and respond to each by indicating its orientation. Images were identical to those used in the CPT, except that 50% of the images (randomly-chosen) were inverted prior to presentation. Stimulus presentation conditions were also identical to the CPT. However, participants were directed to make a non-speeded orientation response when an image was displayed, pressing the 'Z' key if the image was upright, or the '/' key if the image was inverted. The equal frequencies of presentation of upright and inverted images and non-speeded responses result in a task that is less focused on tonic and phasic modulations of attention than the CPT.

Procedure

The experimental structure was broken into three main parts. Participants began with two HFT blocks (pre-training), which were followed by the CPT or CCT, and then two further HFT blocks (post-training). To control for task order effects, the four possible orders in which HFT blocks (local vs global classification) could be completed were counterbalanced across participants. Participants received instructions for all tasks at the beginning of the experimental session and were also presented with task-specific instructions on the computer immediately before beginning each task. In addition, each task began with 40 practice trials so that participants could adjust to the task demands.

Results

Training Task Performance

Participants who completed the CPT responded to non-targets with a mean RT of 376 ms (SD = 26 ms), missed responding to 15.95% (SD = 10.06%) of non-targets, and incorrectly responded (false alarm) to 40.54% (SD = 15.13%) of target images. Participants who completed the CCT had comparable accuracy for upright and inverted images (respectively, M = 93.69%, SD = 4.68% and M = 94.11%, SD = 4.29%).

General Hierarchical Figure Task Performance

Trials for the Hierarchical Figure were excluded from the calculation of interference scores if they were outside the range of the mean RT ± 3SD for a given participant (if the lower bound of the acceptable range fell below 200 ms for a participant, the lower bound was set to 200 ms). Additionally, RT analyses excluded incorrect trials.

Hierarchical Figure Task accuracy was examined using a Training Group (CPT vs CCT) × Session (pre- vs post-training) × Categorization Type (global-categorization vs local-categorization) repeated measures analysis of variance (ANOVA). The results are summarized in Table 1. A main effect of Session was found, $F(1, 35) = 16.37$, $p < 0.001$, $\eta_p^2 = 0.19$, which indicated that accuracy was lower across tasks in the post-training session. A main effect of Categorization Type was also present, $F(1, 35) = 5.63$, $p = 0.02$, $\eta_p^2 = 0.07$, which indicated that participants completed the local-categorization task with greater accuracy than the global-categorization task. No other significant main effects or interactions were obtained. This suggests that HFT accuracy was comparable for the CPT and CCT groups, meaning that potential differences found in RTs between the groups is likely the result of different training conditions.

Identical analyses were conducted on HFT RTs. A main effect of Session was found, $F(1, 35) = 88.76$, $p < 0.001$, $\eta_p^2 = 0.56$, with RTs faster during the post-training session. A main effect of Categorization Type was also present, $F(1, 35) = 17.58$, $p < 0.001$, $\eta_p^2 = 0.20$, with RTs faster for local-categorization compared to global-categorization. A Session × Categorization Type interaction was present, $F(1, 35) = 19.23$, $p < 0.001$, $\eta_p^2 = 0.22$, which indicated that

Table 1 Hierarchical figure task performance (means and SDs) for global and local-categorization summarized across Session (pre- and post-training), Training Group (CPT and CCT) and, for reaction times, congruency (congruent (c) and incongruent (i))

	Accuracy		Reaction time (ms)			
	Pre-CPT	Post-CPT	Pre-CPT (c)	Pre-CPT (i)	Post-CPT (c)	Post-CPT (i)
Global categorization	92.03% (3.60%)	90.47% (4.15%)	618 (112)	637 (118)	528 (73)	538 (69)
Local categorization	92.86% (2.99%)	91.39% (3.94%)	576 (84)	586 (82)	518 (50)	535 (54)
	Pre-CCT	Post-CCT	Pre-CCT (c)	Pre-CCT (i)	Post-CCT (c)	Post-CCT (i)
Global categorization	92.36% (4.16%)	91.11% (4.40%)	582 (73)	605 (74)	522 (60)	541 (61)
Local categorization	92.58% (4.31%)	91.92% (3.94%)	546 (94)	554 (77)	510 (63)	522 (62)

RTs for global-categorization were slower relative to local-categorization prior to training, but were comparable following training. Finally, a Training Group × Categorization Type interaction was also found, $F(1, 35) = 4.02$, $p = 0.05$, $\eta_p^2 = 0.05$, though interpretation of this interaction is not particularly germane to the present study given that RTs were collapsed across pre- and post-training sessions.

Global/Local Interference Changes Following Training

Finally, to determine if CPT or CCT influenced participant's ability to direct their attention to the global or local aspect of the hierarchical figure, task RTs were then subjected to further analysis to examine differences in HFT stimuli with congruent or incongruent global and local levels between CPT and CCT training groups, and pre- and post-training sessions (see Table 1). To determine the specific effect of CPT or CCT training on the ability to focus on relevant global or local forms, global and local interference scores were then calculated from the raw RTs. A measure of local interference was created by subtracting RTs on global-categorization congruent trials from RTs on global-categorization incongruent trials. A measure of global interference was calculated by subtracting RTs on local-categorization congruent trials from RTs on local-categorization incongruent trials. Interference scores were calculated separately for pre- and post-training sessions, and then were contrasted with each other to determine the impact that CPT or CCT training had on participants' ability to ignore the distracting information presented at either the local or global level.

Levels of task interference are summarized in Fig. 2. Change in task interference following attentional training was assessed using a Training Type (CPT vs CCT training) × Categorization Type (local vs global-categorization) × Session (pre- vs post-training) × Categorization Order (global-categorization first vs local-categorization first in post-training test blocks) mixed-design analysis of variance (ANOVA). The Categorization Order variable was included to evaluate Van Vleet et al.'s (2011) suggestion that training effects may be short-lived and thus only present in the first post-training HFT block. A main effect

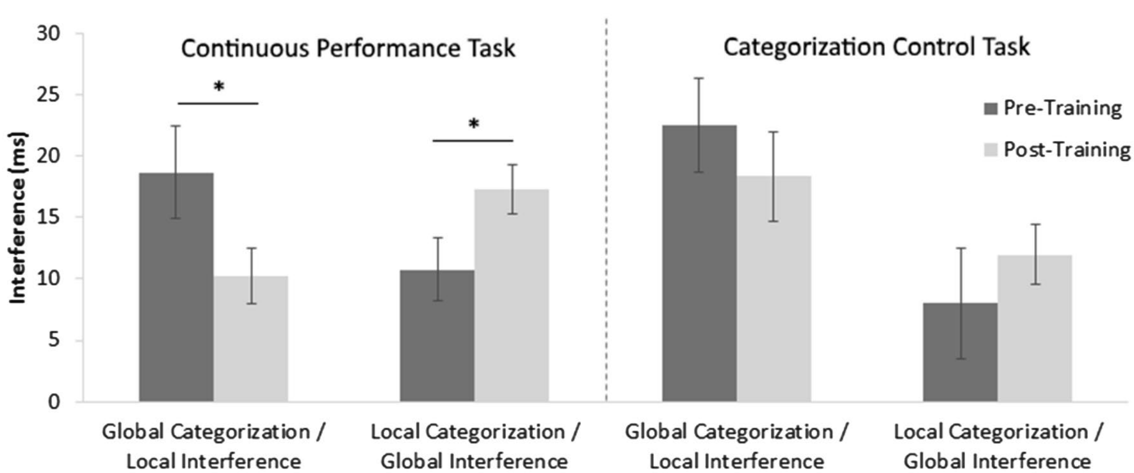

Fig. 2 Interference pre- and post-CPT and CCT training (*error bars* represent mean standard error). Paired sample *t* tests with $p < 0.05$ indicated with a*

of Categorization Type was revealed, $F(1, 68) = 4.42$, $p = 0.04$, $\eta_p^2 = 0.06$, which indicated that greater levels of interference were present during the global task relative to the local task across all conditions. The ANOVA also revealed a significant interaction between Session and Categorization Type, $F(1, 68) = 8.36$, $p < 0.01$, $\eta_p^2 = 0.11$, indicating that interference levels for global and local-categorization showed substantially dissimilar changes as a result of attentional training. The ANOVA revealed no other main effects or interactions (all ps > 0.06, all $\eta_p^2 < 0.06$).

The absence of a Training Type × Categorization Type x Session interaction suggests that effects did not differ across different types of training. However, examination of Fig. 2 appears to indicate that while training effects had a similar pattern across conditions, effects were more pronounced in the CPT compared to the CCT condition. For this reason, we also conducted two follow-up ANOVAs on the CPT and CCT data separately, following the analytical procedure of Van Vleet et al. (2011). The notable result of these additional analyses was a significant Categorization Type × Session interaction that was present in the CPT training condition only, $F(1, 35) = 8.20$, $p < 0.01$, $\eta_p^2 = 0.19$, and not in the CCT training condition, $F(1, 35) = 1.82$, $p = 0.19$, $\eta_p^2 = 0.05$.

Finally, in keeping with Van Vleet et al.'s (2011) analytical procedure, a priori t tests were conducted to examine potential changes in task interference as a result of attentional training. A paired samples t test on the global-categorization task comparing pre- and post-CPT performance revealed a significant decrease in local interference following CPT training, $t(35) = 2.27$, $p = 0.03$. An identical t-test on the local-categorization task revealed a significant increase in global interference following CPT training, $t(35) = 2.17$, $p = 0.04$. In contrast, identical analyses comparing pre- and post-CCT performance showed no changes (both ps > 0.34, both rs < 0.09).

Discussion

The present experiment successfully replicated the chief findings of Van Vleet et al. (2011) using our own equipment and modified experimental design. Similar to their study, following CPT training, there was a significant increase in global interference and a significant decrease in local interference for the local and global-categorization tasks respectively. Importantly, similar changes were not reported in the CCT group, indicating that the increased tonic and phasic attention were responsible for shifts in global preference rather than general characteristics of the task or stimuli. In short, the results validate our instantiation of the CPT training, replicate the benefits to global processing found in previous work, and provide a useful baseline against which to judge performance in "Experiment 2".

That said, our results did depart from Van Vleet et al.'s (2011) in one respect. While they found the effects of CPT training dissipated after a single block of trials, training effects in our experiment persisted throughout the HFT. Participants in both studies completed a similar number of training trials, so this difference cannot be explained in terms of training length. However, it does appear that there were differences in engagement with the CPT training between the studies. Specifically, our participants made faster responses to non-target images (376 vs 462 ms) at the cost of reduced correct response omissions to target images (59 vs 77%). This suggests that a focus on making speeded responses in the CPT, presumably reflecting a relative reduction in inhibition to targets, leads to a relatively larger global shift observed post-training.

Experiment 2

As outlined earlier, neurotypical individuals high in autistic-like traits and those with ASC both show an atypical bias towards local processing relative to their neurotypical, low autistic trait peers (for a meta-analysis see Cribb et al. 2016; see also:; Bayliss and Kritikos 2011; Grinter et al. 2009a, b; Rhodes et al. 2013; Russell-Smith et al. 2012; Sutherland and Crewther 2010). In this experiment, using the same paradigm as in Experiment 1, we aimed to determine whether CPT training increases global processing in neurotypical individuals with high levels of autistic traits, and compare this to effects on individuals with low levels of autistic traits. This study may be the first to show that behavioral training designed to increase RH functioning can shift processing towards global constructs in individuals high in autistic-like traits. It would also provide preliminary insight into potential effects of training on a clinical ASC sample.

Method

Participants

Participants were 128 right-handed, first-year psychology students at the University of Western Australia who participated in the study in exchange for partial credit towards a course requirement. Because non-right-handed individuals show reduced lateralization of brain functions (Banich 1997), we recruited only right-handed participants to ensure that any atypical lateralization reflected the contribution of autistic traits only. A measure of autistic traits, the Autism-spectrum Quotient (AQ; Baron-Cohen et al.

Table 2 Descriptive statistics for participants in Experiment 2 (standard deviations in parentheses)

	CPT		CCT	
	Low AQ	High AQ	Low AQ	High AQ
N	32; 7 male	32; 12 male	32; 6 male	32; 5 male
Age	19.63 (4.38)	21.69 (7.46)	22.56 (8.95)	19.16 (1.44)
AQ	89.91 (6.55)	125.47 (6.71)	90.28 (7.35)	127.17 (8.30)

Table 3 Overall CPT and CCT performance (standard deviations in parentheses)

	Low AQ	High AQ
CPT		
Reaction Time (non-targets)	379 ms (23 ms)	376 ms (29 ms)
Misses (non-targets)	14.95% (8.47%)	14.04% (11.94%)
False Alarms (targets)	42.76% (15.67%)	46.75% (17.07%)
CCT		
Accuracy (upright)	81.10% (16.76%)	79.48% (19.47%)
Accuracy (inverted)	82.75% (17.67%)	84.88% (11.53%)

2001) was obtained in a separate screening procedure completed by the entire first-year cohort, and participants were invited to the study if their AQ scores were in the upper or lower quartile of the cohort. Participants were selected to complete either the CPT or CCT by order of attendance to the laboratory. No participants had completed Experiment 1. Descriptive statistics for the participants are summarized in Table 2.

Materials

Questionnaires

Experiment 2 used the same materials as Experiment 1 with the addition of the AQ (Baron-Cohen et al. 2001), and the Edinburgh Handedness Inventory (EHI; Oldfield 1971). The AQ is a 50-item self-report questionnaire that assesses traits and characteristics associated with autism in neurotypical individuals. Items were scored using the 1–4 method described by Austin (2005) with higher scores indicating greater levels of autistic-like traits. This scoring method was used to take advantage of the range of potentially useful information in each item, increasing the variability of total AQ scores. The EHI is a 10-item self-report questionnaire used to assess handedness of participants.

Procedure

Apart from the preliminary screening with the AQ and EHI, the procedure was identical to that of Experiment 1.

Results

Training Task Performance

Low and High AQ performance on the CPT and CCT was comparable (summarized in Table 3), with independent samples *t*-tests comparing response times, misses and false alarms showing no significant differences between the groups (all $ps > 0.33$, all $rs < 0.04$).

General Hierarchical Figure Task Performance

Similar to the first experiment, trials for the Hierarchical Figure Task (HFT) were excluded from the calculation of interference scores if they were outside the range of the mean RT ± 3SD for a given participant (if the lower bound of the acceptable range fell below 200 ms for a participant, the lower bound was set to 200 ms). Additionally, RT analyses excluded incorrect trials.

HFT accuracy was examined using a Training Group (CPT vs CCT) × AQ Group (Low vs High AQ) × Session (pre- vs post-training) × Categorization Type (global-categorization vs local-categorization) repeated measures ANOVA, with results summarized in Table 4. A main effect of Session was found, $F(1, 124) = 34.22$, $p < 0.001$, $\eta_p^2 = 0.22$, which indicated that accuracy was lower in the post-training session. No other effects reached significance (all $ps > 0.10$, all η_p^2s < 0.02). Critically, HFT accuracy for the CPT and CCT groups is comparable between training groups and AQ groups across the session, meaning that any differences in RTs are the result of different training tasks.

Identical analyses were conducted on HFT RTs. A main effect of Session was found, $F(1, 124) = 110.01$, $p < 0.001$, $\eta_p^2 = 0.47$, with RTs significantly faster during the post-training session. A main effect of Categorization Type was also present, $F(1, 124) = 14.36$, $p < 0.001$, $\eta_p^2 = 0.10$, with faster responses recorded for the local-categorization task. A Session x Categorization Type interaction effect was found, $F(1, 124) = 19.49$, $p < 0.001$, $\eta_p^2 = 0.14$, which indicated that participants were initially slower on global-categorization prior to training, but performed both categorization tasks comparably in the post-training session. Further statistically significant effects included a Categorization Type x Session × AQ Group interaction, $F(1, 124) = 4.18$, $p = 0.04$, $\eta_p^2 = 0.03$, as well as a Categorization Type × Session × Training Group interaction $F(1, 124) = 10.37$, $p < 0.01$, $\eta_p^2 = 0.08$. The first interaction indicated that both AQ groups performed similarly on both categorization tasks, except prior to training when the Low AQ group was slower at the local-categorization task. The second interaction indicated groups receiving CPT and CCT training performed similarly on both categorization tasks, except prior to training when the CPT group was

Table 4 Hierarchical figure task performance (means and SDs) for global and local-categorization summarized across Session (pre- and post-training), Training Group (CPT and CCT), AQ Group (Low and High AQ) and, for reaction times, congruency (congruent (c) and incongruent (i))

	Accuracy		Reaction Time (ms)			
	Pre-CPT	Post-CPT	Pre-CPT (c)	Pre-CPT (i)	Post-CPT (c)	Post-CPT (i)
Global categorization						
Low AQ	92.73% (4.08%)	91.34% (4.24%)	577 (55)	600 (61)	526 (75)	538 (73)
High AQ	91.20% (6.99%)	90.46% (7.48%)	607 (129)	620 (125)	548 (105)	560 (120)
Local categorization						
Low AQ	93.07% (3.42%)	91.43% (4.48%)	602 (78)	617 (76)	534 (58)	553 (58)
High AQ	92.31% (5.80%)	90.51% (7.81%)	560 (99)	567 (92)	521 (83)	536 (82)
	Pre-CCT	Post-CCT	Pre-CCT (c)	Pre-CCT (i)	Post-CCT (c)	Post-CCT (i)
Global categorization						
Low AQ	92.41% (4.38%)	91.34% (4.24%)	614 (98)	633 (96)	546 (77)	555 (83)
High AQ	91.51% (4.90%)	88.29% (7.51%)	599 (104)	617 (112)	524 (91)	542 (91)
Local categorization						
Low AQ	92.64% (4.59%)	91.25% (5.92%)	557 (70)	573 (73)	525 (77)	542 (80)
High AQ	91.08% (4.96%)	91.43% (4.73%)	551 (76)	564 (81)	539 (94)	549 (92)

slower at the local-categorization task. Finally, a Categorization Type × AQ Group × Training interaction was found, $F(1,124) = 11.73$, $p < 0.01$, $\eta_p^2 = 0.09$, but was not examined further as the effects were meaningless due to the collapsing of pre- and post-training RTs for this comparison.

Global/Local Interference Changes Following Training

Finally, to determine if CPT or CCT influenced participant's ability to direct their attention to the global or local aspect of the hierarchical figure in the presence of competing information from the to-be-ignored aspect, task RTs were subject to further analysis to examine differences in HFT stimuli with congruent or incongruent global and local levels between CPT and CCT training groups, between AQ groups, and pre- and post-training sessions (see Table 4). Global and local task interference was calculated in the same way as detailed in Experiment 1 to compare the effects of CPT and CCT training on the ability to focus on relevant global or local forms across AQ groups. Before conducting the critical analysis, a preliminary analysis was conducted to determine if pre-CPT training differences existed between the AQ groups using a repeated measures ANOVA with the factors Categorization Type (local vs global) and AQ Group (Low vs High AQ). If pre-existing differences between the AQ groups were present, it could affect the interpretation of subsequent analyses. The only statistically significant result from the analysis was a main effect of AQ Group, $F(1, 62) = 4.81$, $p = 0.03$, $\eta_p^2 = 0.07$, indicating that interference was greater for the Low AQ group relative to the High AQ group across both global and local-categorization. The other effects did not reach statistical significance (both $ps > 0.09$, both $\eta_p^2 s < 0.05$).

Levels of task interference are illustrated in Fig. 3. Changes in task interference following attentional training was assessed using a Training Type (CPT vs CCT) × Categorization Type (local vs global) × Session (pre- vs post-training) × AQ Group (Low AQ vs High AQ) × Categorization Order (global-categorization first vs local-categorization first in post-training test blocks) mixed-design ANOVA. Replicating the results of Experiment 1, a significant interaction was found between Session and Categorization Type, $F(124, 1) = 4.26$, $p = 0.04$, $\eta_p^2 = 0.03$, indicating that interference changed following attentional training. All other comparisons were non-significant (all $ps > 0.19$, all $\eta_p^2 = 0.01$).

AQ group was not found to interact with any of the variables and the critical Training Type × Categorization Type × Session × AQ Group interaction only reached $p = 0.51$, $\eta_p^2 < 0.01$. However, as noted earlier, baseline levels of CPT differed between AQ Groups, which may have masked subsequent interaction effects. Furthermore, the results of Experiment 1 demonstrated that similarities in training effects across the two training tasks obscured otherwise significant interactions in the CPT condition. As such, and in keeping with Van Vleet et al.'s (2011) analytical procedure, a priori t-tests were conducted to determine if CPT training yielded interference changes similar to Experiment 1 for each of the AQ groups; specifically, if CPT reduced local interference for global-categorization, and increased global interference for local-categorization. In the Low AQ group, local interference on the global-categorization HFT

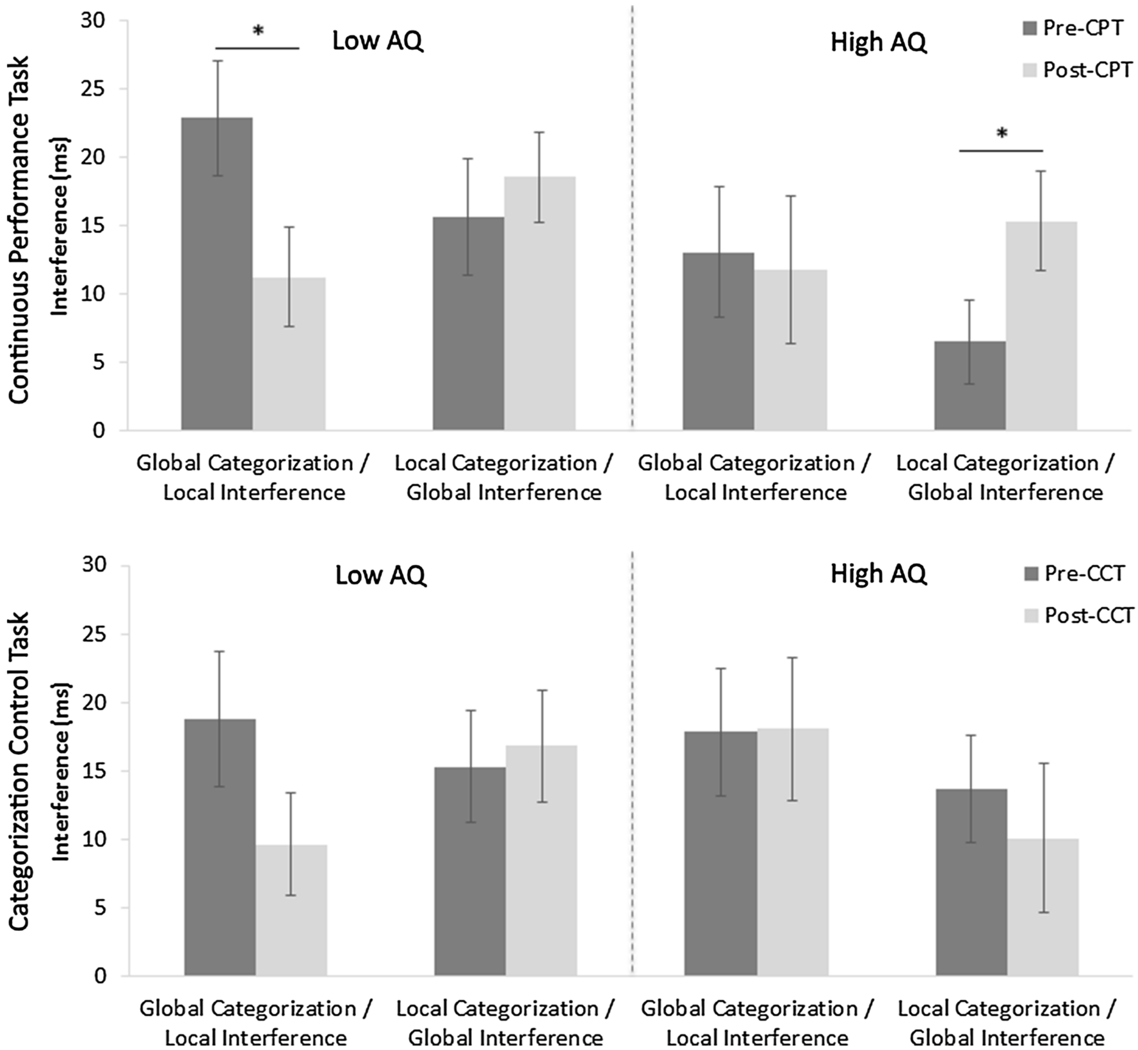

Fig. 3 Interference pre- and post-CPT and CCT training for the Low and High AQ groups (*error bars* represent mean standard error). Paired sample *t* tests with $p < 0.05$ indicated with a*

decreased following CPT training, $t(31) = 2.05$, $p < 0.05$, $r = 0.25$, while global interference on the local-categorization task did not change ($p = 0.64$, $r = 0.07$). In the High AQ group, global interference on the local-categorization HFT increased following CPT training, $t(31) = 2.28$, $p = 0.03$, $r = 0.22$, while local interference on the global-categorization HFT showed no change ($p = 0.84$, $r = 0.02$). Follow-up tests to examine the specific changes in interference following CCT training failed to reveal any significant differences between AQ groups (all *p*s > 0.14, all *r*s < 0.18).

Discussion

The chief aim of this experiment was to determine whether CPT training could modulate global processing bias in individuals high in autistic-like traits and to compare these changes to those seen in individuals low in autistic-like traits. As in earlier studies using RH-damaged and neurotypical participants, there was substantial evidence that CPT training shifted processing towards a global aspect in both Low and High AQ participants. This is consistent with the suggestion that CPT increases RH activation via changes in tonic and phasic attention. However, Low and High AQ individuals did not show the same pattern of benefits from CPT-training. Specifically, the Low AQ group showed only a decrease in local interference during global-categorization, while the High AQ group showed only an increase in global interference during local-categorization.

It should also be noted that, as in Experiment 1, the Categorization Order variable did not influence the pattern of results. This is a positive outcome, as it indicates that CPT training benefits may persist for significantly longer than found by Van Vleet and colleagues. Also, as in Experiment

1, we found that our participants completed the CPT with faster RTs and fewer correct response omissions to target images compared to Van Vleet et al.'s (2011) participants. This provides further evidence that emphasizing response speed over accurately withholding responses to items to be ignored may prolong the effects of CPT training on global processing bias.

General Discussion

ASC is associated with a preference for processing stimuli in a manner that emphasizes the local features relative to the global, coherent aspect (Behrmann et al. 2006, 2006a; Isomura et al. 2014a, see Happé and Frith (2006) for a review). Importantly, this processing bias seems to be associated with the social processing deficits that characterize the disorder. For example, greater difficulty on face and emotion recognition tasks has been linked to a reduced preference for globally organized stimuli (Behrmann et al. 2006; Gross 2005; Rutherford and McIntosh 2007; Walsh et al. 2014).

The present investigation stems from studies that associate global processing with regions primarily located in the RH (Evans et al. 2000; Flevaris et al. 2010; Hübner and Studer 2009; Lux et al. 2004; Malinowski et al. 2002; Volberg and Hübner 2004; Weissman and Woldorff 2005; Yamaguchi et al. 2000) and evidence linking atypical behaviors and functioning in ASC to cortical abnormalities specific to the RH (Di Martino et al. 2011; Jou et al. 2010; Lazarev et al. 2009; Orekhova et al. 2009; Ozonoff and Miller 1996; Siegal et al. 1996). The goal of the present work was to determine whether global processing could be increased in neurotypical individuals with high levels of autistic traits using CPT training (Van Vleet et al. 2011). This task increases tonic and phasic attention and thus is thought to boost RH activation (Bartolomeo 2014; Corbetta and Shulman 2002; Singh-Curry and Husain 2009; Sturm and Willmes 2001; Thiel et al. 2004).

In Experiment 1, we replicated the results of Van Vleet et al. (2011) using a modified experimental design with an unselected neurotypical sample. This allowed us to verify our methodology and ensured that the results from Experiment 2, which included separate groups of Low and High AQ neurotypical individuals, could be directly attributed to variations in autistic traits rather than any variations in methodology from prior work. Indeed, in Experiment 2, consistent with the possibility that CPT increases global processing, we found that the High AQ group showed increased global interference on the local-categorization HFT.

While the key finding from the present experiments is that CPT increased global preference in neurotypical participants who were high in autistic-like traits, it is interesting that this change manifested itself exclusively in increased global interference in the local-categorization condition. This contrasts with the pattern shown in the Low AQ group who manifested increased global preference as decreased local interference in the global-categorization condition. The differential effects of CPT training for the two forms of categorization across the Low and High AQ groups could be due to differences in pre-training performance across AQ groups. Because of this group difference in pre-CPT interference, it was comparatively more difficult to detect a significant increase in already-high global interference for the Low AQ group and a significant decrease in already-low local interference in the High AQ group following CPT training. However, if pre-training differences were not present, as was the case between AQ groups in the CCT condition, it is possible that CPT effects on local and global categorization would have been similar for the two AQ groups if baseline interference levels had been comparable. Given the absence of ASC-related research in regard to behavioral training of global and local processing, at this point in time there is no strong prior basis for a particular profile of attentional training effects for the different AQ groups. Regardless, the fact that CPT was effective at increasing global interference for local categorization, and the potential remains for CPT to be effective at reducing levels of local interference for global categorization, highlights the need for further investigations in this area.

That said, other options aside from pre-training group differences could also account for this pattern of results. For example, the impact of CPT could differ across AQ groups. However, for this dissociation to be true, it would require that CPT-related changes of decreased local interference during global-categorization and increased global interference during local-categorization to be attributed to two different mechanisms, with one operating in Low AQ participants and the other in High AQ participants. Perhaps this notion could be plausible if there were indication that CPT affected attention to both globally and locally presented stimuli, but this is unlikely given prior evidence that it selectively activates RH regions, which are more likely to be substantially involved in global rather than local processing.

Another possibility is that significant differences in both global and local interference across AQ groups would have been found with additional CPT training. Here, we used a single 16-min session of CPT as outlined in Van Vleet et al. (2011) as it was sufficient to produce a measurable change in a neurotypical group. However in Degutis and Van Vleet's study (2010) with neglect patients, a decrease in left neglect severity was observed after a much longer training regimen consisting of 9 days of 36 min sessions. Given that several papers have suggested that individuals with ASC may also have RH abnormalities (Di Martino et al. 2011; Jou et al. 2010; Lazarev et al. 2009; Orekhova et al. 2009; Ozonoff and Miller 1996; Siegal et al. 1996), this might imply that additional training would have led to greater benefits, particularly in the High AQ group. While this is clearly a topic for future research, it is still apparent from the present findings that even a single session of CPT is sufficient to increase global processing in a High AQ sample.

A final possible account involves the relative size of the attentional spotlight or window for our Low and High AQ groups. The attentional spotlight has been described as moveable "beam" that can be expanded and narrowed to facilitate processing of visual stimuli (Eriksen and Yeh 1985; Posner 1990). Previous work has demonstrated that children with ASC show an impaired ability to widen the attentional spotlight relative to typically developing children (Mann and Walker 2003) and, assuming our Low AQ group in Experiment 2 had generally broader attentional windows than our High AQ group, this could account for their relatively longer RTs for local-categorization, as their wider spotlight is more likely to be captured by the global information rather than local-level detail.

Importantly, the size of the attentional window can be altered. For example, a LH-damaged patient with right neglect were better at detecting right-sided targets presented on a small circle stimulus when their attentional window was broadened by including trials with larger circles (Hillis et al. 1999). CPT training may similarly broaden the size of the attentional window, suggesting an alternative account for CPT training benefits reported by Degutis and Van Vleet (2010). Rather than CPT increasing RH activation and consequently shifting attention leftward, CPT may have broadened the attentional spotlight resulting in more 'leftward' parts of landmark stimuli being attended. Applying a similar logic to the present study, CPT training may have broadened the attentional spotlight, making global-level information more accessible. This could explain why training increased global interference for local-categorization in our High AQ group, but not in our Low AQ group. This explanation is, of course, speculative at this point, but clearly warrants more detailed investigation in future work.

A separate analysis of CPT and CCT training effects, identical to the analytic procedure used by Van Vleet et al. (2011), indicated that only CPT training significantly shifted processing towards global aspects of the HFT. However, in combined analyses, neither the relevant three-way (Experiment 1) or four-way (Experiment 2) interaction involving training type were significant, suggesting both types of training yielded similar behavioral change. One likely explanation for this discrepancy is simply that our analyses lacked adequate statistical power to detect these higher-order interactions. Nevertheless, the similar patterns of change across tasks clearly visible in Figs. 2 and 3 suggests that other factors may also be at work. In particular, the tonic and phasic attentional effects arising from CPT may also be generated by the CCT, albeit in a weaker form, given the absence of CCT-related training effects. Importantly, this does not diminish the relevance of the present findings, which clearly show that behavioral training can alter global processing in individuals with high AQ. However, it does suggest that more appropriate control tasks be used instead of CCT as low levels of attentional training effects induced by CCT may otherwise mask group differences between CPT and CCT training groups. Such similarities reduce the ability to detect CPT training effects and may explain why our higher-order interactions that included training type did not reach significance.

Due to the substantively similar pattern of results across studies that have compared ASC versus neurotypical individuals, and high versus low autistic trait individuals (for a meta-analysis "see Cribb et al. 2016; see also:; Bayliss and Kritikos 2011; Grinter et al. 2009a, b; Rhodes et al. 2013; Russell-Smith et al. 2012; Sutherland and Crewther 2010), the results of this study can be interpreted as a preliminary indication that CPT may also increase global processing in clinically diagnosed individuals with ASC. These training effects could potentially benefit people with ASC by encouraging the use of global processing styles when they might otherwise employ a default local processing style. As an illustration of how such training might manifest itself in changes in task performance, consider the study of Rutherford and McIntosh (2007) who demonstrated that individuals with ASC show a greater tolerance for faces with exaggerated facial features which could be the result of depending upon strategies that use rule-based, piecemeal processing to identify shapes and infer emotions, rather than a holistic strategy that compares the face stimulus to a known gestalt or template. Applying the findings of our study to this context, we would hypothesize that if the ASC participants were administered a session of CPT before the face processing task, they would be more inclined to use a global strategy rather than a rule-based strategy, potentially reducing their tolerance for unrealistic emotional expressions. Naturally, the precise ability for CPT to influence the processing of face stimuli has yet to be examined, with demonstrations of the effectiveness of CPT currently limited to hierarchical Navon figures. The degree to which this behavioral task could influence perceptions of face stimuli should be explored.

This study provides the first evidence, to our knowledge, that local attentional biases can be modulated in individuals with high levels of autistic traits. In so doing, it suggests that CPT, or other techniques to enhance RH activation, such as transcranial direct current stimulation, might be useful in enhancing global processing and potentially related skills such as face recognition and emotion identification. Of course, the implications of these results for ASC are necessarily speculative at this point. Further research into the usefulness of CPT in the context of autism is needed.

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Author Contributions Conceived and designed the study: MCWE, TAWV. Performed the study: MCWE. Analyzed the data: MCWE. Wrote the paper: MCWE, MTM and TAWV.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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