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Higher affective congruency in the approach-avoidance task is associated with insular deactivation to dynamic facial expressions

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Abstract

Individuals exhibit a natural bias to approach positive social cues (e.g., smiling face) and to avoid negative ones, which may be altered in psychiatric conditions. Computerized approach/avoidance training to promote affectively congruent behavior has proven useful in modulating such biases. Here, we investigate how exposure to a higher rate of congruency impacts neural processing of social-affective cues.

While undergoing functional magnetic resonance imaging (fMRI), twenty-four individuals completed two versions of the approach-avoidance task (AAT), in which they had to approach or avoid dynamic facial expressions of either happiness or disgust. In the high congruency condition, congruent responses (i.e. approaching happy faces, avoiding disgusted faces) were more frequent. The balanced condition had equal amounts of congruent and incongruent responses.

Processing of congruent approach-avoidance actions towards social cues was associated with lower recruitment of the right anterior insula in the congruency-intensive relative to the balanced condition. Differential activation between the high congruency and balanced condition in the right hippocampus was negatively related to individuals' trait avoidance tendency. These findings are consistent with reduced affective neural processing of social cues when being exposed to congruent AAT contexts. These neural foci could be important targets when assessing the effectiveness of affective congruency training protocols.

Keywords

approach-avoidance task; AAT; cognitive training; insula; fMRI; dynamic facial expressions

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1. Introduction

Although individuals vary in their tendency to approach and avoid emotionally salient social stimuli, on average they exhibit an overall bias to be oriented towards positive cues (e.g., smiling face) and away from negative ones (e.g., angry face). Such implicit, automatic action tendencies can be captured explicitly in individuals' behavior, e.g., being faster at moving closer to rather than away from to positive stimuli, and faster at moving away from rather than approaching negative stimuli (Chen & Bargh, 1999; Roelofs, Minelli, Mars, van Peer, & Toni, 2009; Vrijsen, van Oostrom, Speckens, Becker, & Rinck, 2013). These behavioral action tendencies have been well documented in euthymic individuals using behavioral paradigms such as the approach-avoidance task (AAT)(Rinck & Becker, 2007; Taylor & Amir, 2012), and have been shown to be selectively altered in clinical populations. For instance, depressed individuals are faster at pushing away, i.e., avoiding, negative stimuli than neutral ones (Derntl et al., 2011; Eisma et al., 2015; Seidel, Habel, Finkelmeyer, et al., 2010). Anxious individuals are slower at bringing fear-triggering stimuli closer to them (i.e., at approaching them) (Heuer, Rinck, & Becker, 2007; Najmi, Kuckertz, & Amir, 2010; Rinck & Becker, 2007).

Processing of emotionally salient social stimuli is supported by two interconnected neural systems: a) a saliency detection network including amygdala, the insula, and hippocampal/para-hippocampal area, and b) an affective regulation network, including lateral orbitofrontal and inferior frontal gyri (IFG), as well as the anterior cingulate cortex (ACC)(Adolphs, 2002; Davis & Whalen, 2001; Etkin, Büchel, & Gross, 2015; Ochsner & Gross, 2005; Strauss et al., 2005). Consistent with this literature, the saliency detection network appears to be key for processing emotionally salient social cues in the AAT. For instance, exposure to face stimuli in this task recruits the amygdala and insula, with greater activation of these regions during incongruent responses, i.e., approaching negative and avoiding positive emotional expressions, in both healthy controls and individuals with affective pathology (Bertsch et al., 2018; Ernst et al., 2013; Radke et al., 2017; Volman, Toni, Verhagen, & Roelofs, 2011; Yao et al., 2018). Insula and hippocampal regions receive early detection input signals from the amygdala, and are thus key early affective processing regions during the AAT (Menon & Uddin, 2010; Reinders et al., 2006; Seeley et al., 2007; Zheng et al., 2017).

Clinical interventions aiming to modulate maladaptive automatic behavioral tendencies have particular promise given their relevance to social-affective functioning and cognitive health. Cognitive bias modification (CBM) training aims to remediate individuals' attentional and processing biases via repeated performance of cognitive tasks designed to re-calibrate such biases. The AAT paradigm can be adapted for use as a CBM procedure by adapting contingencies, such that individuals are required to push or pull valenced cues at a specified rate (e.g., pull positive faces on 90% of trials). Although most work evaluating the efficacy of CBM with AAT paradigms has been done in the addiction domain, research suggests that such training has the potential to boost approach of positive cues and avoidance of negative cues in a range of affective pathology (Loijen, Vrijsen, Egger, Becker, & Rinck, 2020). Our group showed that a version of the AAT designed to increase approach of positive social stimuli by increasing the frequency of such pairings was effective in improving relationship-

building behavior (i.e., more engagement with and positive reactions from conversation partners) in individuals with elevated social anxiety (Taylor & Amir, 2012). A similar paradigm resulted in improved approach behavior and increased positive mood in socially anxious individuals (Rinck et al., 2013). Despite evidence of behavioral and psychological effects, it remains unclear how exposing individuals to a higher proportion of congruent or incongruent responses during approach/avoidance training may impact neuro-affective processing of social cues.

Recent studies investigating the neural effects of cognitive bias modification paradigms point to reductions in both affective salience processing regions (amygdala and insula) and in top-down emotion regulation areas (e.g., lateral prefrontal cortex; for a review see (Wiers & Wiers, 2017). However, the bulk of these studies, used attention modulation (e.g., dot probe) tasks rather than an approach-avoidance paradigm (e.g., AAT). Among AAT-based CBM training studies, alcohol-dependent individuals trained to implicitly avoid alcohol cues exhibited reduced recruitment of affective processing regions, including the amygdala, nucleus accumbens, and medial prefrontal cortex, in response to alcohol cues following training (Wiers, Ludwig, et al., 2015; Wiers, Stelzel, et al., 2015). However, such neural assessments focused on post-training changes instead of within-training activation patterns, highlighting the long-term neural impact of such training rather than potential mediating neural mechanisms. Moreover, to our knowledge, there have been no investigations of the neural mechanisms involved in social-affective congruency training in either healthy individuals or clinical groups (Wiers & Wiers, 2017).

To bridge this gap, we aimed to identify such neural substrates by comparing two versions of a computerized AAT using a within-subject design, wherein approach is operationalized as pulling cues toward oneself with a joystick, thereby simulating bringing them closer, and avoidance is operationalized as pushing away the stimulus, which becomes more distant (Rinck & Becker, 2007; Taylor & Amir, 2012). The emotional valence of faces was counterbalanced across approach and avoidance trials and included equal amounts of happy and disgusted faces. Relative to other negative emotions (e.g., anger), faces with disgusted expressions are particularly threat relevant and most likely to induce perception of negative evaluation among individuals with social anxiety for whom the present AAT paradigm would be most relevant in the context of CBM training (Amir, Najmi, Bomyea, & Burns, 2010; White, Maddox, & Panneton, 2015). To further increase the ecological validity of social-affective processing in the task, we used dynamic emotional faces (i.e., morphs) as target cues (Frijda, 1953; Jack, Garrod, & Schyns, 2014; Sato, Kochiyama, Yoshikawa, Naito, & Matsumura, 2004), which was a novel feature used in the AAT paradigm. Relative to static faces, dynamic facial expressions of emotion provide a more sophisticated signaling system to convey socially relevant information, i.e., supporting more complex signals that support categorization of a broader range of socially specific emotions (i.e., anger, disgust, happy; (Jack et al., 2014). Relative to static face controls of the same emotion, viewing dynamic facial expressions is also associated with more recruitment of salience network regions and premotor areas involved in motor mirroring, consistent with more complex affective processing (Sato et al., 2004).

In the present study, congruent responses (i.e. approaching a neutral face which morphs into a happy face, avoiding a neutral face which morphs into a disgusted face) occurred on the majority of trials in one task condition (high congruency), aiming to facilitate approach of positive and avoidance of negative social cues. In the other task condition (balanced), congruent and incongruent responses were presented in equal proportions. Based on the research outlined above, we hypothesized that a higher rate of congruency in the task would be associated with reduced activation in salience detection areas, including amygdala, insula, and hippocampus. We were also interested in exploring whether any of those neural changes may relate to trait affective and behavioral tendencies, which may help identify potential moderators of CBM effectiveness when a higher rate of affective congruency is used as the active treatment component. Specifically, we sought to investigate whether trait approach and trait avoidance would correlate with differential activation between high congruency and balanced condition (e.g., de-activation) in salience network areas, particularly on congruent trials (which are aligned with natural behavioral tendencies of approach and avoidance). We expected that more deactivation between high-congruency and balanced conditions (i.e., stronger neural response to a condition aimed at priming more adaptive behavioral tendencies to social stimuli) would be associated with lower trait approach and higher trait avoidance, both of which may reflect maladaptive behavioral tendencies and may thus respond more strongly to such condition.

2. Methods

2.1. Participants

Twenty-four individuals (mean age=26.8, SD=6.7; 55% female) were recruited through flyers and participated in this study, which was approved by the Human Research Protections Program at University of California, San Diego. Participants had an average of 15.8 (SD=1.9) years of education and the majority (75%) were non-Hispanic (25% Hispanic). All participants signed informed consent, and were compensated $50 for completing the study. Exclusion criteria included current use of psychotropic medications, reported history or diagnosis of psychosis, and not being safe to undergo fMRI for which participants were screened to rule out pregnancy, presence of any metal in the body, and common medical conditions incompatible with being fMRI safe).

2.2. Experimental Procedures

Each participant completed questionnaires assessing dispositional approach/avoidance tendencies (Approach and Avoidance Temperament Questionnaire (ATQ)(Elliot & Thrash, 2010), after which they underwent a one-hour scan while completing the experimental task. The ATQ is a 12-item measure designed to measure sensitivity to positive (i.e., reward; 6 items) and negative (i.e., punishment; 6 items) stimuli or contexts, and demonstrates good internal consistency (α=.74 for approach and α=.81 for avoidance)(Elliot & Thrash, 2010). Items within each of these domains measure temperament dimensions of affective reactivity, perceptual vigilance, and behavioral inclination.

In the scanner, participants completed two versions of the Approach-Avoidance Task (AAT; (Najmi et al., 2010; Rinck & Becker, 2007; Taylor & Amir, 2012), in which they are

presented on each trial with face pictures framed with a colored border while holding a joystick in their hand. On each trial, they have to either pull the joystick toward themselves (i.e., approach) if the border is green or push the joystick forward away from self (i.e. avoid) if the border is blue. The faces were selected from the Pictures of Facial Affect database (Ekman & Friesen, 1976) and conveyed emotional expressions of three different valence categories, including neutral expression, happiness, and disgust. To maximize the ecological validity of social affective processing in this task, the face stimuli were animated face morphs (30 frames/second over a 3-second window from the start of the trial). For both happy and disgust conditions, faces started in a neutral emotional expression and transformed over the 3 second window into either a happy or disgusted expression.

Each block included 72 trials and had equal numbers of push and pull trials. The order in which each condition block (balanced vs high congruency) was administered was randomized across participants. The balanced condition block included equal numbers of push/pull trials for each of the three valence categories, i.e., 24 trial per category. As a result, 50% of the valenced trials were affectively congruent and 50% were affectively incongruent trials. The high congruency condition had a higher proportion (83%) of congruent trials (n=40; i.e., 20 push/disgust, 20 pull/happiness) relative to incongruent trial (n=8; i.e., 4 push/happiness, 4 pull/disgust), and also 24 neutral face trials. There were an equal number of female and male faces across conditions and valence types. At the end of each trial, the joystick position (indicated visually on the screen by a cross) had to be re-initialized by moving its position back to an empty box appearing in the center of the screen.

2.3. fMRI Analyses

2.3.1. Image acquisition: Participants were scanned in a 3 Tesla General Electric (GE) scanner. For each AAT block, a T2*-weighted axially acquired echo-planar imaging (EPI) scan was acquired to measure blood oxygen level dependent (BOLD) signal during the task (parameters: 3.75mm × 3.75mm × 3mm; 64 × 64 acquisition matrix with a 1 mm gap, TR=1500 ms, TE=32ms, flip angle=80°, and 30 slices (covering the whole brain)). A high-resolution T1-weighted structural image was also collected (FOV 256 cm; matrix: acquired 192 × 256 matrix resampled to 256×256; 172 slices; thickness: 1 mm; TR=8 ms, TE: 3ms, flip angle: 12°, inversion time = 450ms). Each trial lasted about 5,500ms, including joystick repositioning and a jittered inter-trial interval (ITI) ranging from 1,500ms-2,000ms. Each block lasted about 7min (*M*=6.92min). Participants used a MRI-safe joystick, which they held in their hand. They had visual feedback via a projected screen visible through a mirror in the head coil.

2.3.2. Pre-processing and subject-level analysis: Preprocessing, normalization to MNI coordinates, and subsequent fMRI analyses were conducted using ANTsR (Avants et al., 2016) and Analysis of Functional NeuroImages (AFNI) software (Cox, 1996). Preprocessing steps included removal of temporal outliers, field inhomogeneity and slice time correction, motion correction, and a CompCor component-based noise correction (Behzadi, Restom, Liau, & Liu, 2007). Regressors were convolved with a canonical hemodynamic response function (HRF) and entered into a general linear model (GLM). Data were aligned to individual anatomical and MNI template. For each participant and

block condition (Assessment vs Training), six regressors were generated for specific event types locked to stimulus presentation onset and to its duration. Specifically, two regressors were generated for congruent (push/disgust or pull/happy) and incongruent (push/happy or pull/disgust) events. Neutral face trials were used as a reference baseline in the model to control for face processing related activity. Additional regressors of no interest included a (push-pull) contrast, a (happiness-disgust) contrast, error trials, and an overall task regressor. These were included to control for neural activity independently related to the type of motor action, the facial expression valence, performance error, and idleness, respectively.

2.3.3.   Group-level analysis: To assess any condition effect on neural activation, voxelwise paired t-tests (3dttest++) were conducted to compare both congruent and incongruent related activation (subject-level GLM coefficients) between balanced and high congruency conditions. Based on the AAT and approach/avoidance literature, we conducted a region-of-interest analysis (ROI) restricting the search to threat and affective processing regions based on a meta-analysis of 186 studies (https://neurosynth.org/analyses/topics/v5-topics-400/273). This mask includes both frontocingulate emotional regulation and inhibitory areas (e.g., IFG, lateral prefrontal cortex, ACC) and salience network regions (e.g., amygdala, insula, and hippocampal regions). To further assess the relationship between differential neural activation between assessment and training condition, we conducted two voxelwise robust regressions (using the R function rlm). Each regression model included ATQ approach and ATQ avoidance scores as independent variables, predicting the (High Congruency - Balanced) activation difference for congruent and incongruent trials, respectively. Condition order was also included as a covariate in both analyses and was not associated with any statistically significant effect. To correct for multiple comparisons, we used a cluster-based thresholding method based on Monte-Carlo simulations using the updated AFNI function 3dClustSim. A voxel-wise a priori probability of .005 was used, which resulted in a corrected cluster-wise activation probability of .05 using a minimum volume of 8 connected voxels.

3.   Results

3.1.   Behavioral Performance

Two miixed-effect generalized linear models were applied to participants' raw reaction times (RT) on correct trials as well as binary trial accuracy, each model treating subject as a random factor to account for with-subject effects (Baayen, Davidson, & Bates, 2008). Given the positive skew of the reaction times, an inverse Gaussian distribution was used to model RTs (Lo & Andrews, 2015). A binomial logit distribution was used for trial accuracy.

Consistent with previously observed congruency effects in the AAT, participants had longer reaction times when executing an incongruent relative to congruent response (i.e., Beta=30, t=3.3, p<.001; omnibus test: $\chi^2(2)$=11.6, p<.001). Experimental condition (Balanced vs High Congruency) did not have any additional effect of RTs (p=.869) and did not interact with congruency (p=.587; see Table 1 for mean reaction times by condition, valence, and congruency). For each experimental condition, we further conducted two mixed-effect generalized linear models assessing the effect of trait characteristics (ATQ Approach and

ATQ Avoidance) on reaction times for congruent and incongruent trials, respectively. Neither measure was significantly related to reaction times for either condition or trial type (ps>.050; range: [.315 .721]). As expected, accuracy was high (Mean=91.6%) and was not significantly related to either congruency or condition (ps>.050).

3.2. fMRI Analyses

3.2.1. Neural Differences associated with High Congruency vs Balanced conditions:
One area in the right anterior insula (BA 13; 11 voxels; Peak Voxel MNI Coordinates: 36,18,−1; z=4.8, p<.0001) was identified, in which activation was lower in the High Congruency relative to Balanced condition on congruent trials (see Figure 1A–B). Activation to congruent trials in either condition was not significantly related to affective or behavioral tendency measures (ps>.050). No differential activation for the High Congruency vs Balanced condition was identified for incongruent trials.

3.2.2. Relationship between High Congruency - Balanced differential neural recruitment and individual behavioral tendencies:
One area in the right hippocampus (BA 35; 10 voxels; Peak Voxel MNI Coordinates: 25,−11,−21; t=8.8, p<.0001) was identified, in which High Congruency - Balanced differential activation during congruent trials was significantly related to avoidance tendency but not approach tendency (see Figure 2A). Specifically, differential High Congruency - Balanced activation was negatively related to avoidance tendency (mean voxel correlation: r=−.73, p<.001; Figure 2B). When further assessing the relationship between condition-specific activation and avoidance tendency, both activations were correlated with avoidance tendency. Specifically, activation to congruent trial sin the Balanced condition was positively correlated with trait avoidance (mean voxel correlation: r=+.64, p=.002), whereas such activation was negatively correlated to trait avoidance in the High Congruency condition (mean voxel correlation: r= −.51, p=.013).

4. Discussion

In this study, we aimed to identify how performing a higher rate of affectively congruent responses to dynamic social cues, which could be implemented as a form of CBM training, impacts the neural processing of these cues. This assessment may provide insight into what neural systems support improved emotion regulation following such interventions. Using the AAT paradigm, we assessed whether individuals display a different neural signature when exposed to a higher proportion of congruent valence/action responses (i.e., approach and avoid happy and disgusted faces, respectively) relative to a balanced context in which they have to perform a similar amount of congruent and incongruent responses to those cues. We found that, relative to a balanced context of congruent and incongruent trials, they exhibited lower recruitment of the right anterior insula to congruent contexts when exposed to a higher level of congruency in the task. In addition, differential activation to high congruency vs balanced context in the right hippocampal region was specifically related to individuals' trait avoidance tendency.

Lower recruitment of the anterior insula was observed during the AAT when participants were asked to complete a higher proportion of congruent responses relative to a context with

equal levels of congruent and incongruent responses. The anterior insula is involved in salience detection (Menon & Uddin, 2010; Seeley et al., 2007) and is connected to other affective salience regions such as the amygdala. These salience network regions have been consistently involved in the regulation of incongruent responses to face stimuli in the AAT (Bertsch et al., 2018; Ernst et al., 2013; Radke et al., 2017; Volman et al., 2011; Yao et al., 2018). The anterior insula is also linked to interoceptive processing (Craig, 2002) and is reliably activated during affective anticipation of both positive and negative valence stimuli (Jensen et al., 2003; Simmons, Matthews, Stein, & Paulus, 2004). Overall, our findings are consistent with reduced affective processing when implementing a higher rate of emotionally congruent responses (i.e., approaching happy faces, withdrawing from disgusted faces). In contrast, such affective processing and salience detection function appears more involved in less predictable contexts, i.e., with equal levels of congruent and incongruent situations. From both reactive and interoceptive standpoints, reduced insula activation in the high congruency condition could reflect a form of calibration of emotional salience signals pertaining to congruent actions when these are being favored, relative to a more exploratory, less known environment in which incongruency is as frequent as congruency.

Relatedly, our finding may reflect a reduced level of conflict processing as individuals are exposed to a higher level of congruent behavior. In line with the research outlined above, within an approach-avoidance framework, the anterior insula has been shown to activate more with higher levels of decision conflict (Aupperle, Sullivan, Melrose, Paulus, & Stein, 2011). A recent study demonstrated a positive relationship between the level of unpredictability in threat level when approaching rewards and activation of a network including the subgenual and dorsal ACC and anterior insula/inferior frontal region (Schlund et al., 2016). The insula was also implicated in early response inhibition processes as suggested by N2 event-related potential (ERP) patterns in a joystick-based AAT during incongruent vs congruent responses to positive pictures (Ernst et al., 2013).

This finding on congruent trials was observed after controlling for an overall effect of valence and individuals saw equal amounts of disgusted and happy faces in both high congruency and balanced conditions. However, it is possible that face emotional valence may further modulate such condition difference. For instance, the anterior insula is activated with the experience and observation of disgust (Calder et al., 2007; Jabbi, Bastiaansen, & Keysers, 2008; Phillips et al., 1998; Wicker et al., 2003). Within congruent trials, the 'avoid disgusted face' response could preferentially modulate the observed differential activation to high congruency vs balanced condition. Future studies should investigate to what degree valence and/or emotion characteristics (e.g., angry vs sad faces) may modulate recruitment of the anterior insula or other salience regions when being exposed to higher affectively congruent responses.

Additional predictive analyses showed that the degree of differential activation in the high congruency relative to the balanced condition within the right hippocampus was negatively related to individuals' trait avoidance tendency on congruent trials. Thus, consistent with our hypothesis, higher trait avoidance was associated with larger deactivation in the high congruency condition relative to the balanced condition. However, we did not observe such pattern with trait approach. Activation of the hippocampal region in conflicting approach-

avoidance contexts has been observed in both rodent and human research (Bach et al., 2014; Ito & Lee, 2016; O'Neil et al., 2015). This is consistent with the role of this region in post-saliency detection affective processing, receiving input from the amygdala (Segal & Cahill, 2009; Zheng et al., 2017). Thus, trait avoidance characteristics may enhance the habituation, i.e., activation decrease, of the hippocampus in response to low-conflict congruent actions when these are being primed. The observed finding, however, was primarily driven by the balanced condition activation being positively correlated with trait avoidance. Therefore, this relationship may predominantly reflect a more persistent affective/conflict processing on congruent responses during less predictable contexts (with equal levels of congruent and incongruent responses) among individuals with higher trait avoidance.

Given the role of the hippocampus in emotional mnemonic processes (Kensinger & Corkin, 2004; Zheng et al., 2017), it is conceivable that our finding reflects the modulation of subtle differential encoding processes by trait avoidance. That is, avoidance tendencies may be associated with higher levels of contextual encoding in the balanced, less predictable condition, and with a lower encoding level in a context during which participants are accustomed to congruent responses. In other words, trait avoidant individuals may exhibit a more sensitive hippocampal processing of congruent behavior as a function of task certainty. Whereas individuals with higher trait avoidance may show enhanced affective/conflict processing when congruency is not the normative response, those individuals may be particularly responsive to a high congruency condition in terms of reducing such hippocampal recruitment. Future work is needed to determine whether a cognitive training with a similar emphasis on high congruency for high trait avoidance individuals may help reduce post-saliency detection mnemonic processing of congruent behavior in this region. Clinically, hippocampal congruency sensitivity may be associated with carryover effects on emotional and cognitive experience (e.g., decreased ruminations) in interpersonal situations. While this study was not designed to assess pre- to post- neural changes associated with the high congruency condition, the present results offer a potential direction for future research to test whether a congruency-focused AAT training may help address such clinical symptoms in the long-term.

The present study has several limitations, including a small sample size with a limited range of demographic characteristics, which limits the generalization of these findings to a relatively young and healthy population. The lack of clinical assessment in this sample further limits interpretation of the results in regards to psychiatric pathology beyond effects related to trait characteristics of approach and avoidance. In addition, given the nature of the research question, as well as participant fatigue considerations, the high congruency condition focused on congruent approach/avoidance responses, with a significantly higher proportion of congruent relative to incongruent trials. This imbalance could explain why we did not find any significant training-assessment neural differences on incongruent trials. Moreover, the present study was not designed to assess gender effects as well as the interaction of participant and/or face stimuli genders with face expression valence. However, such gender effects may further modulate behavioral tendencies. For instance, relative to their male counterparts, female depressed patients display stronger avoidance of social faces with various emotional expressions in the AAT (Seidel, Habel, Finkelmeyer, et al., 2010). In terms of poser/stimuli gender, both faster approach and faster avoidance responses to male

relative to female faces have been observed (Seidel, Habel, Kirschner, Gur, & Derntl, 2010), which may be particularly prominent among female participants towards angry male faces (Rotteveel & Phaf, 2004). Overall, this research highlights the relevance of gender effects and social learning influences on behavioral tendencies to social stimuli in the AAT paradigm, which should be tested in future research. Finally, it is important to stress that the present study in not a training study and did not evaluate pre- to post- changes in clinical and neural patterns associated with a high congruency AAT condition. Follow-up research is needed to disentangle how a cognitive training AAT focused on high congruency priming may further modulate neural and emotional response to incongruent social affective contexts.

In conclusion, relative to a balanced condition, a version of the AAT in which individuals are tasked to perform a higher proportion of congruent responses (i.e., approach happy and avoid disgusted faces) was associated with lower recruitment of the right anterior insula to those congruent contexts. In addition, differential activation in the right hippocampus to the high congruency relative to balanced condition was negatively related to individuals' trait avoidance tendency. These results have implications for a training version of the AAT aimed at priming affectively congruent responses to realistic, dynamic social cues. They provide a first glimpse of how experiencing a higher rate of congruent response in the AAT may modulate affective processing of these cues at the neural level. These neural changes, particularly over multiple training sessions, may in turn help shift individuals' emotional regulation and behavior towards social cues. In that respect, a high-congruency AAT condition may be useful as a form of cognitive enhancement intervention to regulate maladaptive social avoidance, although this will need to be tested in future research. Nonetheless, the experimental parameters of the high-congruency condition used in the present study are similar to those of active conditions used in AAT-based CBM interventions with demonstrated clinical effects on social anxiety, specifically improving the level of social engagement and mood in social contexts (Loijen et al., 2020; Rinck et al., 2013; Taylor & Amir, 2012). By increasing ecological validity of the social context, the use dynamic facial expressions in the present paradigm could help further enhance existing CBM training protocols to improve mood and social functioning. While the present findings should be replicated in larger, more clinically diverse samples and related to post-training clinical functioning, this study suggests that the right anterior insula and hippocampus could be important neural targets to consider when assessing the effectiveness and appropriateness of such congruency-focused interventions. Individual behavioral tendencies may further moderate the neural impact of such interventions, which should be tested further in subclinical and clinical groups with pre-existing cognitive biases (e.g., social avoidance, disinhibition).

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- Approach-avoidance action tendencies may be altered in psychiatric conditions

- Congruency-focused AAT may improve neural processing of social-affective cues

- High congruency AAT was associated with lower right anterior insula recruitment

- A high congruency AAT condition may help reduce affective processing of social cues
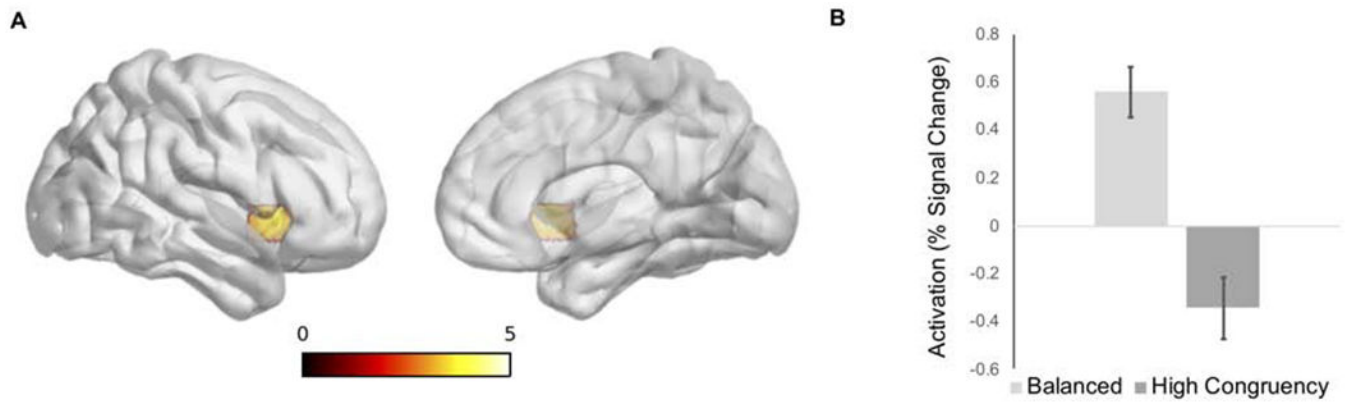
Figure 1.
A. BOLD signal associated with a significant condition effect (i.e., High Congruency vs Balanced) on congruent trials in the right anterior insula (Brodmann Area 13). Color scale=voxel z scores. **B.** In this region, significantly higher activation was observed in the Balanced relative to High Congruency condition (p<.001; error bars=SEM).
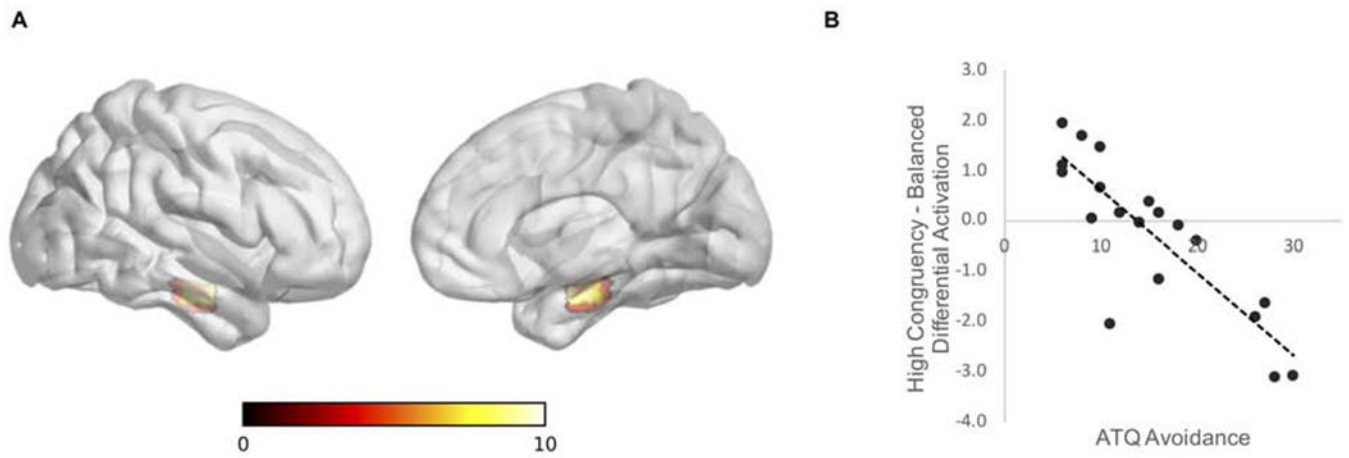
Figure 2.
A. Left: BOLD signal associated with a significant effect of avoidance tendency (measured with ATQ) on the differential (High Congruency- Balanced) activation on congruent trials in the right hippocampus (Brodmann Area 35). Color scale=voxel t scores. **B.** Negative relationship between differential (High Congruency- Balanced) activation on congruent trials in this right hippocampus cluster (based on extracted individuals' robust coefficient t statistics) and ATQ Avoidance scores. ATQ= Approach and Avoidance Temperament Questionnaire.

Table 1.

Valence	Congruency	All		Balanced		High Congruency	
		RT (ms)	SD	RT (ms)	SD	RT (ms)	SD
Disgust	Congruent	640	(207)	630	(205)	647	(208)
	Incongruent	656	(266)	658	(278)	649	(224)
Neutral		634	(204)	634	(209)	634	(199)
Happiness	Congruent	620	(190)	625	(203)	616	(182)
	Incongruent	668	(281)	678	(287)	639	(263)
Aggregate		638	(217)	643	(232)	634	(202)

RT=Reaction Times; Condition: Congruent=Approach Happy/Avoid Disgust; Incongruent=Approach Disgust/Avoid Happy