On the Control of Social Approach–Avoidance Behavior: Neural and Endocrine Mechanisms

Reinoud Kaldewaij, Saskia B.J. Koch, Inge Volman, Ivan Toni and Karin Roelofs

Abstract The ability to control our automatic action tendencies is crucial for adequate social interactions. Emotional events trigger automatic approach and avoidance tendencies. Although these actions may be generally adaptive, the capacity to override these emotional reactions may be key to flexible behavior during social interaction. The present chapter provides a review of the neuroendocrine mechanisms underlying this ability and their relation to social psychopathologies. Aberrant social behavior, such as observed in social anxiety or psychopathy, is marked by abnormalities in approach–avoidance tendencies and the ability to control them. Key neural regions involved in the regulation of approach–avoidance behavior are the amygdala, widely implicated in automatic emotional processing, and the anterior prefrontal cortex, which exerts control over the amygdala. Hormones, especially testosterone and cortisol, have been shown to affect approach–avoidance behavior and the associated neural mechanisms. The present chapter also discusses ways to directly influence social approach and avoidance behavior and will end with a research agenda to further advance this important research field. Control over approach–avoidance tendencies may serve as an exemplar of emotional action regulation and might have a great value in understanding the underlying mechanisms of the development of affective disorders.

Keywords Approach-avoidance · Emotional action control · Social psychopathology · Anterior prefrontal cortex · Amygdala

R. Kaldewaij (✉) · S.B.J. Koch · I. Toni · K. Roelofs
Donders Institute for Brain, Cognition and Behaviour, Centre for Cognitive Neuroimaging, Radboud University Nijmegen, Nijmegen, The Netherlands
e-mail: r.kaldewaij@donders.ru.nl

I. Volman
Sobell Department of Motor Neuroscience and Movement Disorders, UCL Institute of Neurology, University College London, London, UK

K. Roelofs
Behavioural Science Institute (BSI), Radboud University Nijmegen, Nijmegen, The Netherlands

Curr Topics Behav Neurosci
DOI 10.1007/7854_2016_446

Contents

1 Introduction

The regulation of social–emotional behavior is crucial for social interactions. Events with a positive or negative valence, such as perceiving a happy or angry facial expression, trigger automatic emotional reactions. It has long been acknowledged that this automatic emotional (or affective) behavior is directed at either reducing or increasing the distance between the self and the object or person that triggered the emotional reaction: For example, people tend to walk away from things that scare them. In other words, positive or negative events or stimuli in the environment trigger automatic approach and avoidance tendencies. These tendencies can be crucial for survival, especially in situations of severe threat. However, in other situations, approach–avoidance tendencies can interfere with goal-directed (instrumental) behavior. In such situations, automatic approach–avoidance behavior needs to be controlled. Control over approach–avoidance tendencies is especially relevant to social interactions, during which overreacting to emotional cues can be at the core of aggression and social avoidance.

Here, we aim to give an overview of research on approach–avoidance behavior, focusing on the underlying neural and endocrine mechanisms, as well as how this behavior is altered in social psychiatric disorders, such as social anxiety and psychopathy. We will briefly discuss the theoretical background of approach–avoidance behavior and discuss how (control over) approach–avoidance tendencies can be experimentally measured and manipulated. Furthermore, we aim to integrate current findings on neural correlates of approach–avoidance behavior in a preliminary model and discuss future perspectives.

2 Theoretical Background

Theories on emotion have stressed the link between affective evaluation and action tendencies (Frijda 1986; Lang et al. 1990). These tendencies prepare for affective behavior (i.e., behavior influenced by emotional processing), which is organized in two motivational systems: approaching or appetitive behavior in response to positive, rewarding stimuli or events, and avoidant or aversive behavior in response to negative, threatening stimuli (Lang et al. 1990). This approach–avoidance distinction of behavior has been used for thousands of years: The ancient Greek philosopher Democritus (460–370 BCE) already described human action as "the pursuit of pleasure and avoidance of pain" (Elliot 2006). The fundamental role of approach–avoidance processes is illustrated by the fact that they are present across species, from single-cell organisms to humans (Elliot 2006). Moreover, they take place at different behavioral levels, from simple reflexes to advanced cognitive actions (Lang et al. 1990).

Gray (1990) described the two motivational systems as a behavioral approach (or activation) system (BAS), responding to stimuli that signal rewards or non-punishments, and a behavioral inhibition system (BIS), responding to signals of punishment and novelty. BAS activation causes an organism to approach a stimulus and has been associated with dopaminergic pathways (Carver et al. 2000). Engagement of the BIS system, in contrast, causes inhibition of ongoing behavior. Gray linked this system to the septo-hippocampal complex, brain stem, and frontal lobe. It has been argued that these systems also relate to the subjective experience of emotion: BAS is associated with positive feelings, such as happiness, whereas BIS is linked to negative feelings, such as fear, anxiety, and sadness (Carver et al. 2000).

3 Automatic Approach–Avoidance Behavior

Approach and avoidance tendencies have been mapped by different paradigms ranging from active approach–avoidance tasks using joysticks to decision paradigms. Using an emotional go-no-go task, Hare et al. (2005) found delayed go-responses for angry faces (versus neutral or happy) to be positively associated with amygdala activation. Berkman and Lieberman (2010) asked participants to imagine being part of a tribe that either liked or disliked certain food types, as appetitive and disgusting cues trigger approach and avoidance, respectively. They found increased left (compared to right) dorsal prefrontal cortex activation during approach (compared to avoidance) action decisions, measured with functional MRI. Experimental paradigms designed to directly tap into intrinsic action tendencies are so-called approach–avoidance tasks (AAT) (Chen and Bargh 1999; Rinck and Becker 2007; Rotteveel and Phaf 2004; Solarz 1960). In this type of task, participants are presented with valenced stimuli, e.g., positive or negative words, emotional faces, and pictures of positive or negative scenes. They are required to respond to these stimuli by flexing or extending of the arm to push a button or move an object, such as a lever or joystick. Flexing the arm is associated with approach behavior, whereas extending of the arm is associated with avoidance. The main outcome measure is reaction (or: initiation) time, i.e., the time that is required to initiate the movement after the presentation of the stimulus. Participants are generally faster at making approaching compared to avoiding movements to positive stimuli such as happy faces, reflecting an approach tendency toward positively evaluated stimuli. Similarly, participants are faster at making avoiding compared to approaching movements toward negative stimuli, such as angry faces, reflecting an avoidance tendency toward negatively evaluated stimuli (Chen and Bargh 1999; Rotteveel and Phaf 2004). These effects are typically found both when emotion evaluation is explicit (pull joystick when face is happy) and to a lesser extent when it is incidental (e.g., when faces are colored and participants push and pull using a color rule)—evidence for this latter category is mixed, and effect seems to depend on the specific task used (Phaf et al. 2014). Similar effects are found in symbolic approach–avoidance tasks where, for example, a manikin on a screen has to be moved toward or away from a negative or positive stimulus using button presses (De Houwer et al. 2001).

3.1 Individual Differences

There are individual differences in approach and avoidance action tendencies. Strong deviations from normal approach–avoidance behavior can be seen in social psychopathologies such as social anxiety, associated with relatively faster avoidance of emotional faces (Heuer et al. 2007; Roelofs et al. 2010), and psychopathy, associated with reduced avoidance of angry faces (Von Borries et al. 2012). Note that angry faces communicate a social challenge, usually eliciting avoidance tendencies in healthy individuals. The psychopathic patients showed no alterations in facial expression recognition, and the lack of avoidance in response to angry faces in psychopaths was associated with self-reported instrumental aggression levels (Von Borries et al. 2012). Together, this may suggest that it is not the face processing itself but the translation from affect to action that is altered in psychopathy (see also Ly et al. 2016). Usually, the altered approach–avoidance tendencies in social psychopathologies are found when angry faces are presented with direct gaze and not with averted gaze, indicating that the anger has to be directed toward the subject to elicit avoidance tendencies and indicating that the elicited avoidance is not simply the result of a stimulus–response compatibility effect (Roelofs et al. 2010; Von Borries et al. 2012). Indeed, using a manikin task and positive and negative words, Krieglmeyer and Deutsch (2010) showed that approach–avoidance tendencies reflect a specific, motivational link between perception of affect and behavior, rather than general stimulus–response compatibility.

4 Control Over Approach–Avoidance Behavior

Although evaluations of emotional situations often happen automatically and implicitly, the associated behavioral action tendency does not necessarily have to be implemented (Gross 2002). If the automatic tendency does not match the behavioral goal, it can be overridden; for example, objects or situations regarded as threatening or disgusting can be approached if one wants to. This ability to arbitrate between automatic affective action tendencies and instrumental goals is crucial for flexible behavior.

An example of affective influences on instrumental behavior is observed in pavlovian–instrumental transfer (PIT) paradigms. Participants first learn to associate specific stimuli (sounds or pictures) with reward (conditioned stimulus, CS+) and non-reward or punishment (CS−), a process which is known as Pavlovian conditioning. When subsequently engaging in a different task, for example, squeezing a handgrip to earn money, they respond more vigorously if the CS+ is presented in the background, even though this stimulus is not related to the monetary outcome at all (Talmi et al. 2008). Affective biasing of instrumental behavior is generally adaptive, and abnormalities in these processes have been associated with psychiatric disorders (Damasio 1997). For example, using a PIT-like paradigm, task-irrelevant happy and angry faces influenced approaching and avoiding whole-body movements to obtain a reward in healthy controls, but not in violent offenders with psychopathic tendencies (Ly et al. 2016, 2014)

The AAT tests the arbitration between automatic affective reactions and instrumental behavior. The task is subdivided into two conditions: an affect-congruent condition, in which participants are required to make approaching movements toward positive stimuli and avoiding movements toward negative stimuli, and an affect-incongruent condition, which requires the exact opposite, i.e., avoiding movements when a positive stimulus is presented and approaching movements when a negative stimulus is presented. The affect-incongruent condition requires control over automatic response tendencies and is therefore more effortful, which is reflected in longer reaction times for the affect-incongruent compared to the affect-congruent condition (Chen and Bargh 1999; Rinck and Becker 2007; Rotteveel and Phaf 2004). This is referred to as the congruency effect (Fig. 1).

4.1 Neural Mechanisms

In terms of brain activity, the anterior prefrontal cortex (aPFC) and the adjacent ventrolateral PFC have consistently been found to be more active during the affect-incongruent compared to the affect-congruent task conditions (Radke et al. 2015; Roelofs et al. 2009a, b; Volman et al. 2011a, b; Volman et al. 2013, 2016). The aPFC has structural connections to the amygdala via the uncinate fasciculus (Von Der Heide et al. 2013) and is highly connected to multiple functional

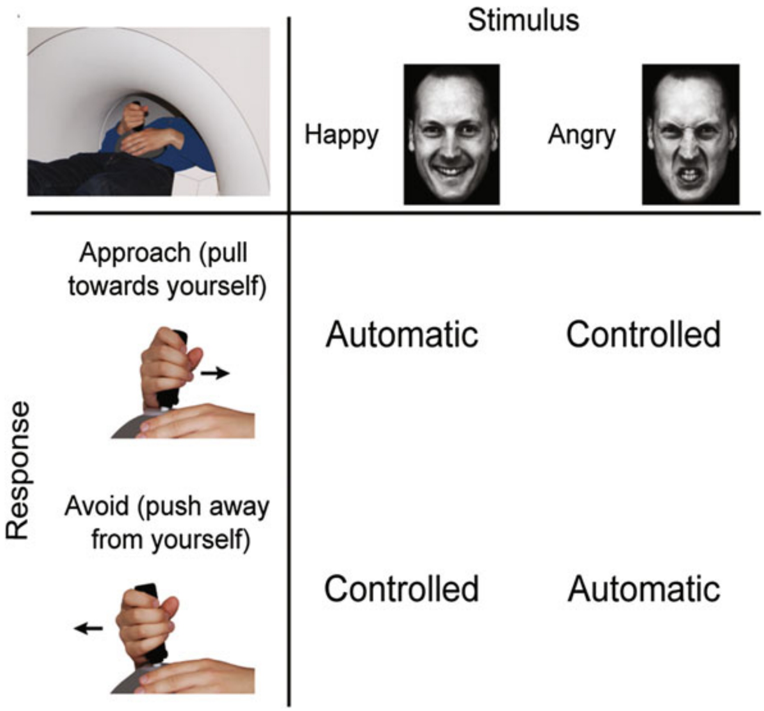

Fig. 1 Schematic overview of the approach–avoidance task (Joystick version). Participants are instructed to pull in response to happy faces or push in response to angry faces (affect-congruent) or vice versa (affect-incongruent). When the task is performed in a scanner, the joystick is placed on the abdomen of the participant. Outside the scanner, the joystick is placed on a table. (Figure from Volman et al. 2013)

networks, including the social–emotional network (see Box 1), cognitive processing network, and default mode network (Liu et al. 2013). It is implicated in the coordination of multiple cognitive processes (Ramnani and Owen 2004) and switching to alternative behaviors (Boorman et al. 2009). In the context of approach–avoidance behavior, the aPFC may coordinate automatic emotional processing with the implementation of a rule that depends on the automatic emotional processing. This coordination is implemented through modulatory effects on regions supporting those two constituent processes, namely the amygdala and the posterior parietal cortex (PPC), respectively (Volman et al. 2011a). Noteworthy, the areas involved in approach–avoidance behavior nicely fit with current models of the neural regions implicated in emotion processing (see Box 1). The dynamics of this network may be altered in individuals suffering from social psychopathologies. For example, psychopaths show less aPFC activation and less functional connectivity between the aPFC and amygdala during incongruent (control-related) trials, compared to healthy controls (Volman et al. 2016). This suggests a link between reduced prefrontal activation and reduced control during situations that provoke emotional reactions.

A study using continuous theta-burst stimulation (cTBS) to inhibit the left aPFC illustrates the central role of this structure in the emotional control over approach–avoidance tendencies. Compared to sham stimulation, active inhibition of this region shortly before the approach–avoidance task resulted in decreased task performance (i.e., more mistakes) during incongruent trials, but not during congruent trials. In addition, cTBS resulted in decreased cerebral blood flow in the bilateral aPFC, as well as increased blood flow in the amygdala. Taken together, these results support the notion that the aPFC is crucial for overriding automatic action tendencies, possibly via inhibition of the amygdala. In contrast, blood flow in the PPC decreased after aPFC inhibition, concordant with its role in rule selection (Volman et al. 2011a).

Box 1 Neural correlates of emotional processing

Over the past decades, there has been extensive research on the neural correlates of automatic emotional processes and control over emotion. The amygdala plays a key role in emotion processing, especially with respect to fear and arousal (LeDoux 2000) and salience processing in general. Salience processing refers to the identification of information relevant to survival (Seeley et al. 2007). The amygdala is connected to areas important for salience detection, such as the anterior insula and dorsal anterior cingulate cortex (Seeley et al. 2007) and responsible for the bodily fear response, such as the hypothalamus and periaqueductal gray (PAG) (Rodrigues et al. 2009). Emotional faces, among other salient stimuli, trigger automatic behavioral tendencies via the amygdala (Adolphs 2002). The prefrontal cortex has widely been implicated in emotion regulation by (inhibitory) control over the amygdala (Etkin et al. 2015), with different subregions serving specific types of regulation. The ventromedial prefrontal cortex (vmPFC) has inhibitory projections to the amygdala and is associated with the process of fear extinction (i.e., the reduction of the fear response toward a conditioned stimulus when the stimulus is no longer threatening) (Rodrigues et al. 2009). Another type of emotion regulation is cognitive reappraisal, which requires the reinterpretation of the meaning of the presented stimulus (Ochsner et al. 2002). Areas related to reappraisal include the dorsolateral prefrontal cortex (dlPFC), inferior frontal gyrus (IFG), and vmPFC (Ochsner et al. 2002). Control over emotional (approach–avoidance) actions implicates down-regulation of the amygdala by more anterior and ventrolateral parts of the prefrontal cortex (Volman et al. 2013).

An illustration of the network involved in control over approach–avoidance behavior is provided by Volman et al. (2013). Dynamic causal modeling (DCM) was used to define the neural circuit and the effective connectivity

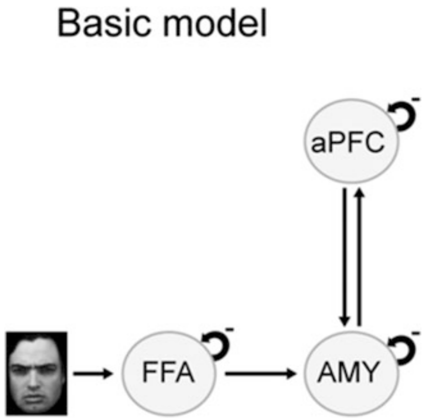

Fig. 2 DCM model as described by Volman et al. (2013). The figure shows a basic neural model of neural activity during the AAT. *aPFC* anterior prefrontal cortex, *FFA* fusiform face area, *AMY* amygdala. (Figure from Volman et al. 2013)

supporting AAT performance. The model focused on three fundamental nodes, namely the fusiform face area (FFA), necessary for processing the facial expressions used in the task (Kanwisher 1997); the amygdala, necessary for emotional processing of the stimulus (Adolphs 2002); and the aPFC, known to interact with the amygdala during AAT (Fig. 2; Volman et al. 2011a, b). Participants of the study performed the approach–avoidance task and showed the normal congruency effect, i.e., longer reaction times in the incongruent compared to congruent conditions, reflecting control over automatic responses during incongruent trials. DCM was used to estimate how the different structures interacted during task performance. Emotional control influenced aPFC activation via the feed-forward input from the amygdala and on the aPFC self-connection. Modulation of the amygdala occurred via the aPFC (Fig. 2). Interestingly, the inhibitory connection from the aPFC to the amygdala was weaker in carriers of a short allele (S-carriers) of the 5-HTTLPR gene compared to non-carriers. S-carriers are associated with reduced serotonin transporter availability and serotonin reuptake and are more likely to develop social psychopathologies after stressful events (Canli and Lesch 2007). Moreover, the amygdala response to threatening stimuli is increased in S-carriers (Hariri et al. 2002). The reduced inhibitory control of the aPFC over the amygdala in this group provides an explanation for the increased amygdala response and may be implicated in emotional vulnerability in general.

5 Manipulating Approach–Avoidance Behavior

5.1 Neuroendocrine Effects

Testosterone and cortisol are known to modulate emotional reactions. Neuroendocrine influences on approach–avoidance behavior have been investigated by determining effects of endogenous hormone levels and by drug administration studies. Noteworthy, effects of hormones have been shown to be especially relevant to approach–avoidance behavior in psychopathology related to social–emotional behavior.

5.1.1 Testosterone

Testosterone is released from the gonads as the end product of the hypothalamic–pituitary–gonadal (HPG) axis (Campbell et al. 2009) and is strongly associated with aggressive and approach-related behavior (Archer 2006; Bos et al. 2012). The hormone and its metabolites can influence neural activity via various neurochemical mechanisms. Baseline endogenous testosterone levels have shown to be positively correlated to activation of the amygdala and the orbitofrontal cortex, which is part of the prefrontal cortex (Mehta and Beer 2010; Van Wingen et al. 2011). Moreover, both the administration of testosterone and baseline testosterone levels are associated with decreased connectivity between the amygdala and prefrontal cortex (Peper et al. 2011)

Endogenous testosterone in male participants modulates the strength of the AAT congruency effect in the aPFC: Lower baseline (pretask) testosterone levels in saliva were associated with higher aPFC activity during incongruent (compared to congruent) trials. Moreover, functional connectivity between the aPFC and amygdala was modulated by endogenous baseline testosterone levels in this task. Lower baseline testosterone levels were associated with more negative functional connectivity between the aPFC and amygdala, suggesting a negative correlation between endogenous testosterone and prefrontal inhibitory control (Volman et al. 2011b). Psychopaths show a similar negative correlation between baseline testosterone levels and local activity in the aPFC as well as aPFC–amygdala connectivity (Volman et al. 2016). This underlines the impact of testosterone levels on control over emotional behavior. These findings are complemented by testosterone administration studies. Compared to placebo, sublingual testosterone administration in healthy female participants leads to reduced avoidance tendencies in response to angry faces, but not in response to happy faces (Enter et al. 2014). Neural effects of testosterone administration were specific to angry faces as well: In incongruent trials (approach-angry), testosterone administration resulted in increased amygdala activation (Radke et al. 2015). These testosterone administration studies indicate that testosterone biases behavior toward the approach of social threat, which may underlie mechanisms of social dominance and aggression. The approach-related effects of testosterone may be beneficial for individuals suffering from social anxiety disorder (SAD): A recent study by Enter et al. (2016) showed that SAD patients show increased approach tendencies toward angry faces after sublingual testosterone administration compared to placebo, indicating that testosterone reduces the social-avoidant tendencies in these patients.

5.1.2 Cortisol

The glucocorticoid cortisol is the end product of the hypothalamic–pituitary–adrenal (HPA) axis. The HPA axis plays an important role in responding to stressful events (De Kloet et al. 2005). Perception of a stressor leads to the activation of a cascade of hormones starting at the hypothalamus, ultimately leading to the release of cortisol by the adrenal glands. Cortisol increases activity of the sympathetic nervous system, which is important for fight and flight behavior. In the brain, cortisol binds to areas that contain glucocorticoid or mineralocorticoid receptors, such as the amygdala, hippocampus, and frontal areas (Lupien et al. 2007). As cortisol plays especially an important role in the context of responding to stress, studies have focused on cortisol levels in response to stress induction and cortisol administration rather than baseline cortisol levels. For example, cortisol administration has been shown to reduce amygdala activity in response to emotional expressions (Henckens et al. 2010).

Cortisol levels can be increased by stress induction, for example, by the Trier Social Stress Test (TSST), during which participants have to give a speech and do a mental arithmetic task in front of an audience (Kirschbaum et al. 1993). Stress-induced cortisol in male and female patients with SAD was associated with stronger avoidance in response to angry faces, compared to healthy controls (Roelofs et al. 2009). Also, cortisol administration enhances the behavioral congruency effect specifically for angry faces but only in highly avoidant healthy subjects: Male participants with a high score on the behavioral inhibition scale (BIS) were slower to approach an angry face after cortisol administration, compared to placebo (van Peer et al. 2007). This behavioral effect was accompanied by increased event-related potentials (ERPs), P150 and P3, in response to angry faces when an avoidant movement has to be made, suggesting increased processing of threat stimuli. Similar results were obtained in a cortisol administration study with male and female patients with SAD, in which an increased avoidance tendency was found in response to angry faces only. Additionally in SAD patients with high symptom severity, there was also an effect of cortisol on the P150 amplitude (i.e., increased visual processing) during avoidance, especially in response to angry faces (van Peer et al. 2009). Taken together, the effects of cortisol on threat avoidance seem to be specific for highly anxious individuals and might be an underlying factor in the maintenance of social avoidance in SAD.

5.1.3 Oxytocin

The neuropeptide oxytocin is synthesized in the hypothalamus and acts on various brain structures, such as the amygdala, hippocampus, and brainstem (Meyer-Lindenberg et al. 2011). Oxytocin has prosocial and anxiolytic properties (Koch et al. 2014; Meyer-Lindenberg et al. 2011) and has been implicated in social approach behavior (Heinrichs et al. 2009). After intranasal oxytocin administration, low socially anxious males showed increased approaching tendencies in response to specifically angry faces, while they showed the normal tendency to avoid angry faces in the placebo condition (Radke et al. 2013). This effect was absent in high socially anxious males. In addition, no effects of oxytocin on approach tendencies toward happy faces were found, which might have been expected given the prosocial effect of oxytocin. Therefore, the beneficial effects on approach behavior seem mainly to be due to the anxiolytic—and not the prosocial—effects of oxytocin (Radke et al. 2013).

5.2 *Training*

Approach–avoidance tendencies can be changed with behavioral training, in which an adapted version of the approach–avoidance task is used. The aim of the training could be to reduce an avoidance bias or to increase an approach bias. For instance, in the case of anxiety, participants are instructed to pull the stimulus that they would normally avoid (e.g., a spider in spider phobia) and to push away a neutral or positive control stimulus. The aim of the training could also be reducing an approach bias. For instance, in the case of addiction, exactly opposite instructions are used: Participants have to push away (abuse-related) stimuli that they would normally approach (e.g., a picture of an alcoholic drink in alcohol abuse).

Promising results have been obtained, for example, in the training of highly socially anxious individuals, who are inclined to avoid happy and angry faces. When highly socially anxious males and females are trained to approach happy male and female faces and avoid checkerboards, they approach female happy faces faster, compared to individuals who received the opposite training (i.e., avoid happy faces and approach checkerboards). Importantly, after training, they show less self-rated emotional vulnerability and anxiety in response to a social stress task (Rinck et al. 2013). Similar trainings have been shown to be beneficial for treatment outcome in alcohol-dependent inpatients. Alcohol-dependent/alcoholic patients who received a training using the AAT in which they have to avoid (i.e., push away) pictures of alcoholic drinks, showed an alcohol avoidance bias, instead of their pretraining alcohol approach bias. Moreover, after regular treatment, they showed less relapse after one-year follow-up. No effect on alcohol avoidance bias was found in the control groups of alcoholic patients receiving sham training or no training at all (Wiers et al. 2011). Approach–avoidance training has also been successfully applied in improving racial attitudes. Non–African American students were either trained to approach photographs of African American persons and avoid Caucasian persons, or approach Caucasian and avoid African American, or move the joystick sideways. Compared to the other conditions, participants in the approach-African American condition showed reduced implicit racial prejudice during an implicit association task and increased immediacy during interaction with a African American confederate (i.e., decrease in distance and increase in body orientation directed toward the confederate) (Kawakami et al. 2007).

6 Discussion and Future Horizons

Approach–avoidance tendencies result from the evaluation of positive and negative stimuli or events. Positive evaluations are associated with approaching behavior, whereas negative evaluations are related to avoidance. Behavior opposite to these automatic tendencies requires emotional control, reflected in slower action initiation. In the brain, the regulation of approach–avoidance behavior is marked by inhibition of the amygdala by the aPFC (see Fig. 3). The amygdala plays a central role in the network underlying emotional action processing, which also contains visual processing areas such as the FFA. The aPFC coordinates the implementation of task instructions, associated with PPC activation, and emotional action tendencies supported by the amygdala. Decoupling of functional connectivity between the aPFC and amygdala is associated with reduced control over emotional actions. The fact that control of approach–avoidance behavior requires involvement of these anterior regions of the PFC suggests that control over social approach and avoidance may involve coordination of multiple hierarchically organized processes (Koechlin and Summerfield 2007). Future studies should investigate the content and the format of the neural representations that are coordinated during emotional control. It is also important to understand whether those control circuits are used only when social approach–avoidance behavior needs to be controlled. The interplay of aPFC, PPC, and amygdala eventually leads to behavior via the motor system. The PMC is a likely candidate for this integration (Boorman et al. 2009). It is important to understand how motor synergies for approach/avoidance, computed in the PMC (Graziano 2006), are accessed by the aPFC during emotional

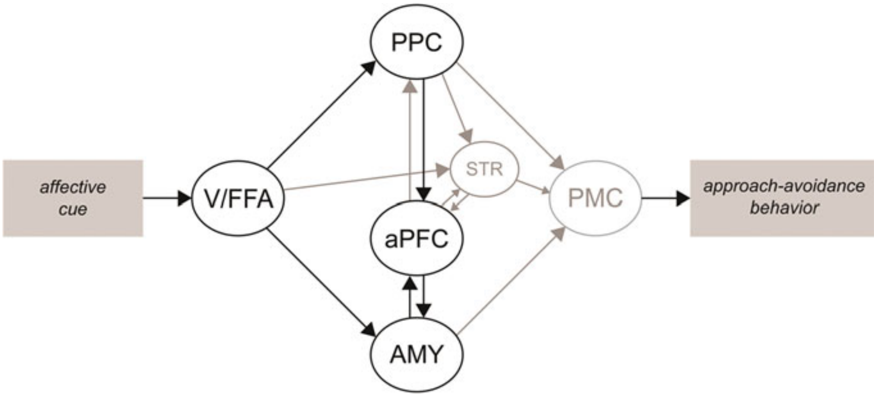

Fig. 3 Schematic model of brain regions involved in (control over) approach–avoidance behavior. Affective cues trigger emotional action tendencies via the amygdala. The aPFC arbitrates between these automatic tendencies and current behavioral goals, associated with posterior parietal cortex activation. Areas and connections in gray are hypothesized output regions. *PPC* posterior parietal cortex, *aPFC* anterior prefrontal cortex, *V/FFA* visual processing areas/fusiform face area, *AMY* amygdala, *PMC* premotor cortex, *STR* striatum

regulation. A likely route through which the aPFC could influence the PMC is provided by fronto-striatal loops (Haber and Knutson 2009). The striatum plays a central role in value-based action decisions (Rangel et al. 2008) and actions to obtain reward or avoid punishment in monetary and social incentive delay tasks (Spreckelmeyer et al. 2009). In AAT studies, it has also been found to be more active during affect-incongruent trials, in which the behavioral goal conflicts with the automatic tendency (Volman et al. 2016).

Social approach–avoidance behavior and the dynamics of the underlying neural network have been found to be altered in several (social–emotional) psychiatric disorders and to be influenced by (exogenous administration of) hormones such as testosterone and cortisol. Increased approach-related behavior toward angry faces has been found in patients with psychopathy, as well as in healthy female participants after testosterone administration. Similarly, reduced functional aPFC–amygdala connectivity and reduced aPFC activation during situations that require control (i.e., incongruent trials) were associated with both psychopathy and increased endogenous testosterone levels. In sum, testosterone is anxiolytic and promotes social approach behavior. Increased levels of cortisol, caused by stress induction or cortisol administration, enhance the tendency to avoid angry faces in anxious males and females. Moreover, cortisol led to higher amplitudes of ERPs related to visual processing, during the avoidance of angry faces. Taken together, cortisol seems to enhance threat processing and already existent avoidant behavior. Similar to testosterone, oxytocin has been shown to have anxiolytic effects, resulting in more approach to social threat, but only in low anxious individuals.

In this chapter, we did not go into detail about findings on lateralization of approach–avoidance tendencies. It has been proposed that the different motivational systems correlate with different sites of the prefrontal cortex: Approach motivation relates to left-sided activation of this brain area, whereas avoidance/withdrawal motivation is associated with right-sided activation (Davidson 2004). This notion of lateralized motivational systems is supported by electroencephalography (EEG) studies of baseline prefrontal activation asymmetry. For example, depressed patients show less left than right frontal activity compared to healthy controls (Davidson 1998). Moreover, behavioral approach sensitivity, measured on the BAS scale, relates to greater left than right frontal cortical activity (Harmon-Jones and Allen 1997). From functional MRI research, however, there is little evidence for lateralization of these motivational systems or affect in general (Wager et al. 2003), although one study found increased left (compared to right) dorsal prefrontal cortex activation during approach (compared to avoidance) action decisions (Berkman and Lieberman 2010). However, the paradigm used in that study is not likely to elicit automatic approach–avoidance action tendencies, because participants were required to imagine themselves being part of a tribe that made different approach or avoidance decisions than they would normally do.

6.1 Future Agenda

Research on the regulation of emotion has mainly focused on cognitive strategies related to the altering the affective evaluation of salient stimuli or events, such as emotion suppression, emotion reappraisal, and redirection of attention (Gross 2002). The control over emotional actions that follow such affective evaluations has remained a largely understudied aspect of emotion regulation. This is surprising, given the importance of these action tendencies in our understanding of emotional processing and social–emotional behavior. The control over automatic approach–avoidance tendencies, as operationalized in so-called approach–avoidance tasks, may serve as an exemplar of this type of emotional control. More research on the underlying neural correlates of controlling approach–avoidance and its relationship with other aspects of emotion regulation such as reappraisal and attention redirection will further our understanding on how individuals deal with emotional events they encounter. First hints that these processes may be related come from a study showing that neural medial and lateral PFC effects during appraisal are partly explained by regulating (avoidant) eye movements (van Reekum et al. 2007).

The studies discussed here indicate that endocrine influences on approach–avoidance behavior may play an important role in the development and maintenance of problems in social–emotional behavior. However, hormones can also have a beneficial effect on exaggerated approach–avoidance tendencies, as has been shown in the study by Enter and colleagues (2014, 2016): The approach-related effects of testosterone counteracted the avoidant tendencies toward angry faces in healthy subjects (Enter et al. 2014) and in SAD patients (Enter et al. 2016). This result shows the potential of hormones in the enhancement of existing therapies, such as cognitive–behavioral therapy. For example, it is worth investigating if testosterone might help patients during exposure to situations that are experienced as socially threatening.

Another way of improving maladaptive approach or avoidance tendencies is by behavioral training, which has been shown to be effective for alcohol addiction and social anxiety disorder (Rinck et al. 2013; Wiers et al. 2011). To date, little is known about the effects of such training on the underlying neural mechanisms. It would be insightful, for example, in case of social anxiety, to know whether reductions in avoiding social threat after training originate from increased top-down inhibitory control from the aPFC over the amygdala, or from reduced salience of the social threatening stimulus or event. The first explanation would indicate that approach–avoidance training increases emotional control over specific automatic tendencies, whereas the latter explanation would suggest that the affective evaluation of the stimulus itself has changed. A recent study on the effects of approach–avoidance training in alcoholism showed a reduction in amygdala activation in response to alcohol cues, suggesting devaluation of the stimulus (Wiers et al. 2014). More understanding about the underlying mechanism of approach–avoidance training could also be beneficial for the development of specific combination treatments. For example, administration of testosterone in SAD patients before approach–avoidance training of emotional faces might make the training even more effective.

Although it is clear that psychiatric disorders characterized by deficits in social–emotional functioning are associated with altered approach–avoidance behavior, little is known about the causal role of approach–avoidance tendencies and the (in) ability to control them. It would be valuable to know whether a lack of control over these tendencies can actually predict emotional vulnerability and/or the development of social psychopathology. Some evidence hints in that direction, for example, the study by Volman et al. (2013), showing reduced top-down control over approach–avoidance tendencies in carriers of a polymorphism associated with increased risk of social psychopathology, such as anxiety, depression, and aggression-related disorders, after stressful events. Longitudinal investigations could shed light on whether abnormal approach–avoidance tendencies relate pre-existing vulnerability for social psychopathology or that they are acquired abnormalities. Such a study could be performed in groups at risk of social psychopathologies or individuals who are likely to encounter stressful events, such as soldiers or policemen. More knowledge about the underlying mechanisms of the development and maintenance of social psychopathology is crucial for prevention of these disorders and the development of novel treatment approaches.

7 Conclusion

The study of the regulation of approach–avoidance tendencies has been shown to be instrumental for understanding affective behavior. Individual differences in (control over) approach–avoidance behavior are associated with levels of hormones such as testosterone and cortisol, and abnormal social interactions, as observed in social anxiety and psychopathy. The amygdala, triggering action tendencies in response to emotionally salient stimuli, and anterior PFC, inhibiting the amygdala when appropriate, play an important role in the neural network underlying the regulation of approach–avoidance tendencies. We have only just begun to explore the potential of the approach–avoidance paradigm in understanding the role of emotional action regulation in normal and affective behavior.

References

Adolphs R (2002) Recognizing emotion from facial expressions: Psychological and neurological mechanisms. Behav Cogn Neurosci Rev 1:21–62

Archer J (2006) Testosterone and human aggression: an evaluation of the challenge hypothesis. Neurosci Biobehav Rev 30(3):319–345. doi:10.1016/j.neubiorev.2004.12.007

Berkman ET, Lieberman MD (2010) Approaching the bad and avoiding the good: lateral prefrontal cortical asymmetry distinguishes between action and valence. J Cogn Neurosci 22 (9):1970–1979. doi:10.1162/jocn.2009.21317

Boorman ED, Behrens TEJ, Woolrich MW, Rushworth MFS (2009) How green is the grass on the other side? Frontopolar cortex and the evidence in favor of alternative courses of action. Neuron 62(5):733–743. doi:10.1016/j.neuron.2009.05.014

Bos PA, Hermans EJ, Ramsey NF, van Honk J (2012) The neural mechanisms by which testosterone acts on interpersonal trust. NeuroImage 61(3):730–737. doi:10.1016/j.neuroimage.2012.04.002

Campbell DW, Sareen J, Stein MB, Kravetsky LB, Paulus MP, Hassard ST, Reiss JP (2009) Happy but not so approachable: the social judgments of individuals with generalized social phobia. Depress Anxiety 26(5):419–424. doi:10.1002/da.20474

Canli T, Lesch K-P (2007) Long story short: the serotonin transporter in emotion regulation and social cognition. Nat Neurosci 10(9):1103–1109. doi:10.1038/nn1964

Carver CS, Sutton SK, Scheier MF (2000) Action, emotion, and personality. Pers Soc Psychol Bull. doi:10.1177/0146167200268008

Chen M, Bargh JA (1999) Consequences of automatic evaluation: immediate behavioral predispositions to approach or avoid the stimulus. Pers Soc Psychol Bull 25(2):215–224. doi:10.1177/0146167299025002007

Damasio A (1997) Neuropsychology. towards a neuropathology of emotion and mood. Nature 386 (6627):769–770. doi:10.1038/386769a0

Davidson RJ (1998) Affective style and affective disorders: perspectives from affective neuroscience. Cogn Emot 12(3):307–330. doi:10.1080/026999398379628

Davidson RJ (2004) What does the prefrontal cortex "do" in affect: perspectives on frontal EEG asymmetry research. Biol Psychol 67(1–2):219–234. doi:10.1016/j.biopsycho.2004.03.008

De Houwer J, Crombez G, Baeyens F, Hermans D (2001) On the generality of the affective Simon effect. Cogn Emotion 15:189–206. doi:10.1080/02699930125883

De Kloet ER, Joëls M, Holsboer F (2005) Stress and the brain: from adaptation to disease. Nat Rev Neurosci 6(6):463–475. doi:10.1038/nrn1683

Elliot AJ (2006) The hierarchical model of approach-avoidance motivation. Motiv Emotion 30 (2):111–116. doi:10.1007/s11031-006-9028-7

Enter D, Spinhoven P, Roelofs K (2014) Alleviating social avoidance: effects of single dose testosterone administration on approach-avoidance action. Horm Behav 65(4):351–354. doi:10.1016/j.yhbeh.2014.02.001

Enter D, Spinhoven P, Roelofs K (2016) Dare to approach single dose testosterone administration promotes threat approach in patients with social anxiety disorder. Clin Psychol Sci. doi:10.1177/2167702616631499

Etkin A, Büchel C, Gross JJ (2015) The neural bases of emotion regulation. Nat Rev Neurosci 16:693–700. doi:10.1038/nrn4044

Frijda NH (1986) The emotions. Cambridge University Press, London

Gray JA (1990) Brain systems that mediate both emotion and cognition. Cogn Emot 4(3):269–288. doi:10.1080/02699939008410799

Graziano M (2006) The organization of behavioral repertoire in motor cortex. Annu Rev Neurosci 29(1):105–134. doi:10.1146/annurev.neuro.29.051605.112924

Gross JJ (2002) Emotion regulation: affective, cognitive, and social consequences. Psychophysiology 39(3):281–291. doi:10.1017/S0048577201393198

Haber SN, Knutson B (2009) The reward circuit: linking primate anatomy and human imaging. Neuropsychopharmacol Official Publ Am Coll Neuropsychopharmacol 35(1):1–23. doi:10.1038/npp.2009.129

Hare TA, Tottenham N, Davidson MC, Glover GH, Casey BJ (2005) Contributions of amygdala and striatal activity in emotion regulation. Biol Psychiatry 57(6):624–632. doi:10.1016/j.biopsych.2004.12.038

Hariri AR, Mattay VS, Tessitore A, Kolachana B, Fera F, Goldman D, Weinberger DR (2002) Serotonin transporter genetic variation and the response of the human amygdala. Sci (New York, N.Y.) 297(5580):400–403. doi:10.1126/science.1071829

Harmon-Jones E, Allen JJ (1997) Behavioral activation sensitivity and resting frontal EEG asymmetry: covariation of putative indicators related to risk for mood disorders. J Abnorm Psychol 106(1):159–163. doi:10.1037/0021-843X.106.1.159

Heinrichs M, von Dawans B, Domes G (2009) Oxytocin, vasopressin, and human social behavior. Front Neuroendocrinol 30(4):548–557. doi:10.1016/j.yfrne.2009.05.005

Henckens MJAG, van Wingen GA, Joëls M, Fernández G (2010) Time-dependent effects of corticosteroids on human amygdala processing. J Neurosci 30(38):12725–12732. doi:10.1523/JNEUROSCI.3112-10.2010

Heuer K, Rinck M, Becker ES (2007) Avoidance of emotional facial expressions in social anxiety: the approach-avoidance task. Behav Res Ther 45(12):2990–3001. doi:10.1016/j.brat.2007.08.010

Kanwisher N (1997) The fusiform face area: a module in human extrastriate cortex specialized for face perception. J Neurosci 17(11):4302–4311

Kawakami K, Phills CE, Steele JR, Dovidio JF (2007) (Close) distance makes the heart grow fonder: improving implicit racial attitudes and interracial interactions through approach behaviors. J Pers Soc Psychol 92(6):957–971. doi:10.1037/0022-3514.92.6.957

Kirschbaum C, Pirke KM, Hellhammer DH (1993) The "trier social stress test"–a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobiology. doi:10.1159/000119004

Koch SBJ, van Zuiden M, Nawijn L, Frijling JL, Veltman DJ, Olff M (2014) Intranasal oxytocin as strategy for medication-enhanced psychotherapy of PTSD: salience processing and fear inhibition processes. Psychoneuroendocrinology 40:242–256. doi:10.1016/j.psyneuen.2013.11.018

Koechlin E, Summerfield C (2007) An information theoretical approach to prefrontal executive function. Trends Cogn Sci 11(6):229–235. doi:10.1016/j.tics.2007.04.005

Krieglmeyer R, Deutsch R (2010) Comparing measures of approach–avoidance behaviour: the manikin task vs. two versions of the joystick task. Cogn Emot 24(5):810–828. doi:10.1080/02699930903047298

Lang PJ, Bradley MM, Cuthbert BN (1990) Emotion, attention, and the startle reflex. Psychol Rev 97(3):377–395. doi:10.1037/0033-295X.97.3.377

LeDoux J (2000) Emotion circuits in the brain. Ann Rev Neurosci, 155–184

Liu H, Qin W, Li W, Fan L, Wang J, Jiang T, Yu C (2013) Connectivity-based parcellation of the human frontal pole with diffusion tensor imaging. J Neurosci Official J Soc Neurosci 33(16):6782–6790. doi:10.1523/JNEUROSCI.4882-12.2013

Lupien SJ, Maheu F, Tu M, Fiocco A, Schramek TE (2007) The effects of stress and stress hormones on human cognition: implications for the field of brain and cognition. Brain Cogn 65(3):209–237. doi:10.1016/j.bandc.2007.02.007

Ly V, Huys QJM, Stins JF, Roelofs K, Cools R (2014) Individual differences in bodily freezing predict emotional biases in decision making. Front Behav Neurosci 8(July):1–9. doi:10.3389/fnbeh.2014.00237

Ly V, Von Borries AKL, Brazil IA, Bulten HB, Cools R, Roelofs K (2016) Reduced transfer of affective value toinstrumental behavior in violent offenders. Submitted

Mehta PH, Beer J (2010) Neural mechanisms of the testosterone-aggression relation: the role of orbitofrontal cortex. J Cogn Neurosci 22(10):2357–2368. doi:10.1162/jocn.2009.21389

Meyer-Lindenberg A, Domes G, Kirsch P, Heinrichs M (2011) Oxytocin and vasopressin in the human brain: social neuropeptides for translational medicine. Nat Rev Neurosci 12(9):524–538. doi:10.1038/nrn3044

Ochsner KN, Bunge SA, Gross JJ, Gabrieli JDE (2002) Rethinking feelings: an FMRI study of the cognitive regulation of emotion. J Cog Neurosci 14(8):1215–29

Peper JS, van den Heuvel MP, Mandl RCW, Hulshoff Pol HE, van Honk J (2011) Sex steroids and connectivity in the human brain: a review of neuroimaging studies. Psychoneuroendocrinology 36(8):1101–1113. doi:10.1016/j.psyneuen.2011.05.004

Phaf RH, Mohr SE, Rotteveel M, Wicherts JM (2014) Approach, avoidance, and affect: a meta-analysis of approach-avoidance tendencies in manual reaction time tasks. Front Psychol 5 (MAY):1–16. doi:10.3389/fpsyg.2014.00378

Radke S, Roelofs K, de Bruijn ERA (2013) Acting on anger: social anxiety modulates approach-avoidance tendencies after oxytocin administration. Psychol Sci 24(8):1573–1578. doi:10.1177/0956797612472682

Radke S, Volman I, Mehta P, van Son V, Enter D, Sanfey A, Toni I, de Bruijn ERA, Roelofs K (2015) Testosterone biases the amygdala toward social threat approach. Sci Adv 1(5): e1400074

Ramnani N, Owen AM (2004) Anterior prefrontal cortex: insights into function from anatomy and neuroimaging. Nat Rev Neurosci 5(3):184–194. doi:10.1038/nrn1343

Rangel A, Camerer C, Montague PR (2008) A framework for studying the neurobiology of value-based decision making. Nat Rev Neurosci 9(7):545–556. doi:10.1038/nrn2357

Rinck M, Becker ES (2007) Approach and avoidance in fear of spiders. J Behav Ther Exp Psychiatry 38(2):105–120. doi:10.1016/j.jbtep.2006.10.001

Rinck M, Telli S, Kampmann IL, Woud ML, Kerstholt M, Te Velthuis S, Becker ES (2013) Training approach-avoidance of smiling faces affects emotional vulnerability in socially anxious individuals. Front Human Neurosci 7:481. doi:10.3389/fnhum.2013.00481

Rodrigues SM, LeDoux JE, Sapolsky RM (2009) The influence of stress hormones on fear circuitry. Annu Rev Neurosci 32:289–313. doi:10.1146/annurev.neuro.051508.135620

Roelofs K, Minelli A, Mars RB, van Peer J, Toni I (2009a) On the neural control of social emotional behavior. Soc Cog Affect Neurosci 4(1):50–58. doi:10.1093/scan/nsn036

Roelofs K, van Peer J, Berretty E, Jong P De, Spinhoven P, Elzinga BM (2009b) Hypothalamus-pituitary-adrenal axis hyperresponsiveness is associated with increased social avoidance behavior in social Phobia. Biol Psychiatry 65(4):336–343. doi:10.1016/j.biopsych.2008.08.022

Roelofs K, Putman P, Schouten S, Lange WG, Volman I, Rinck M (2010) Gaze direction differentially affects avoidance tendencies to happy and angry faces in socially anxious individuals. Behav Res Ther 48(4):290–294. doi:10.1016/j.brat.2009.11.008

Rotteveel M, Phaf RH (2004) Automatic affective evaluation does not automatically predispose for arm flexion and extension. Emotion (Washington, D.C.) 4(2):156–172. doi:10.1037/1528-3542.4.2.156

Seeley WW, Menon V, Schatzberg AF, Keller J, Glover GH, Kenna H, Greicius MD (2007) Dissociable intrinsic connectivity networks for salience processing and executive control. J Neurosci 27(9):2349–2356. doi:10.1523/JNEUROSCI.5587-06.2007

Solarz AK (1960) Latency of instrumental responses as a function of compatibility with the meaning of eliciting verbal signs. J Exp Psychol 59(4):239–245. doi:10.1037/h0047274

Spreckelmeyer KN, Krach S, Kohls G, Rademacher L, Irmak A, Konrad K, Grunder G (2009) Anticipation of monetary and social reward differently activates mesolimbic brain structures in men and women. Soc Cog Affect Neurosci 4(2):158–165. doi:10.1093/scan/nsn051

Talmi D, Seymour B, Dayan P, Dolan RJ (2008) Human Pavlovian instrumental transfer. J Neurosci 28(2):360–368. doi:10.1523/JNEUROSCI.4028-07.2008

van Peer JM, Roelofs K, Rotteveel M, van Dijk JG, Spinhoven P, Ridderinkhof KR (2007) The effects of cortisol administration on approach-avoidance behavior: an event-related potential study. Biol Psychol 76(3):135–146. doi:10.1016/j.biopsycho.2007.07.003

van Peer JM, Spinhoven P, van Dijk JG, Roelofs K (2009) Cortisol-induced enhancement of emotional face processing in social phobia depends on symptom severity and motivational context. Biol Psychol 81(2):123–130. doi:10.1016/j.biopsycho.2009.03.006

van Reekum CM, Johnstone T, Urry HL, Thurow ME, Schaefer HS, Alexander AL, Davidson RJ (2007) Gaze fixations predict brain activation during the voluntary regulation of picture-induced negative affect. NeuroImage 36(3):1041–1055. doi:10.1016/j.neuroimage.2007.03.052

Van Wingen GA, Ossewaarde L, Bäckström T, Hermans EJ, Fernández G (2011) Gonadal hormone regulation of the emotion circuitry in humans. Neuroscience 191:38–45. doi:10.1016/j.neuroscience.2011.04.042

Volman I, Roelofs K, Koch S, Verhagen L, Toni I (2011a) Anterior prefrontal cortex inhibition impairs control over social emotional actions. Curr Biol CB 21(20):1766–1770. doi:10.1016/j.cub.2011.08.050

Volman I, Toni I, Verhagen L, Roelofs K (2011b) Endogenous testosterone modulates prefrontal-amygdala connectivity during social emotional behavior. Cereb Cortex (New York, N.Y., 1991) 21(10):2282–90. doi:10.1093/cercor/bhr001

Volman I, Verhagen L, den Ouden HEM, Fernández G, Rijpkema M, Franke B, Roelofs K (2013) Reduced serotonin transporter availability decreases prefrontal control of the amygdala. J Neurosci Official J Soc Neurosci 33(21):8974–9. doi:10.1523/JNEUROSCI.5518-12.2013

Volman I, Louise K, von Borries A, Hendrik Bulten B, Jan Verkes R, Toni I, Roelofs K (2016) Testosterone modulates altered prefrontal control of emotional actions in psychopathic offenders. Eneuro. doi:10.1523/ENEURO.0107-15.2016

Von Borries AKL, Volman I, de Bruijn ERA, Bulten BH, Verkes RJ, Roelofs K (2012) Psychopaths lack the automatic avoidance of social threat: Relation to instrumental aggression. Psychiatry Res 200(2–3):761–766. doi:10.1016/j.psychres.2012.06.026

Von Der Heide RJ, Skipper LM, Klobusicky E, Olson IR (2013) Dissecting the uncinate fasciculus: disorders, controversies and a hypothesis. Brain 136(6):1692–1707. doi:10.1093/brain/awt094

Wager TD, Phan KL, Liberzon I, Taylor SF (2003) Valence, gender, and lateralization of functional brain anatomy in emotion: a meta-analysis of findings from neuroimaging. NeuroImage 19(3):513–531. doi:10.1016/S1053-8119(03)00078-8

Wiers RW, Eberl C, Rinck M, Becker ES, Lindenmeyer J (2011) Retraining automatic action tendencies changes alcoholic patients' approach bias for alcohol and improves treatment outcome. Psychol Sci 22(4):490–497. doi:10.1177/0956797611400615

Wiers CE, Stelzel C, Gladwin TE, Park SQ, Pawelczack S, Gawron CK, Bermpohl F (2014) Effects of cognitive bias modification training on neural alcohol cue reactivity in alcohol dependence. Am J Psychiatry. doi:10.1176/appi.ajp.2014.13111495