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Cognitive Bias Modification and Cognitive Control Training in Addiction and Related Psychopathology: Mechanisms, Clinical Perspectives, and Ways Forward

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Abstract

The past decade has witnessed a surge in research on training paradigms aimed at directly influencing cognitive processes in addiction and other psychopathology. Broadly, two avenues have been explored: In the first, the aim was to change maladaptive cognitive motivational biases (cognitive bias modification); in the second, the aim was to increase general control processes (e.g., working memory capacity). These approaches are consistent with a dual-process perspective in which psychopathology is related to a combination of disorder-specific impulsive processes and weak general abilities to control these impulses in view of reflective longer-term considerations. After reviewing the evidence for dual-process models in addiction, we discuss a number of critical issues, along with suggestions for further research. We argue that theoretical advancement, along with a better understanding of the underlying neurocognitive processes, is crucial for adequately responding to recent criticisms on dual-process models and for optimizing training paradigms for use in clinical practice.

Keywords

addiction, dual-process models, cognitive control, cognitive bias, intervention, theory, cognitive neuroscience

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The past two decades have witnessed a strong expansion of dual-process models in different branches of psychological science, including social, health, and clinical psychology. The basic idea underlying different varieties of dual-process models is that many of our behaviors are the outcome of two qualitatively different types of processes: relatively automatic, associative, or impulsive processes (from now on, "impulsive") and relatively controlled, symbolic, or reflective processes (from now on, "reflective"). We first briefly describe the general class of dual-process models, with some more specific instances related to clinical and health psychology with an emphasis on addictive behaviors. We then discuss two types of recent training interventions, both closely related to dual-process models. One type, *cognitive bias modification* (CBM), is aimed at changing disorder-specific maladaptive cognitive motivational biases; the other, *working memory training*, is aimed at training domain-general cognitive control functions. From a simple dual-process perspective, the first class of training interventions could be understood as influencing disorder-specific impulsive processes, whereas the second class influences general reflective processes. However, dual-process models have recently been criticized on theoretical grounds, and we argue that many of these problems are related to levels of description and should be addressed by considering the underlying neurocognitive processes. We address these issues and emphasize the dynamic interplay between cognitive and motivational processes. We argue that this change in perspective has important implications for the further development of training interventions in clinical psychological science, and we discuss critical next steps in this area of clinical research with great promise for applications.

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Dual-Process Models

The historical roots of dual-process models can be traced back to antiquity, often portrayed as a battle between "passion" and "reason" (Hofmann, Friese, & Strack, 2009) and to many philosophers predating the origin of psychology in the 19th century (see Schacter, 1987; Wilson, 2002). The two processes have also been described with a "horse and rider" metaphor, in which the horse represents the impulsive processes that can be constrained by the rider (reflective processes) if the rider is skilled and powerful (Friese, Hofmann, & Wiers, 2011). From this perspective, many problems in clinical and health psychology can be viewed as resulting from strong impulsive processes (geared toward either approach or avoidance) combined with suboptimal reflective processing and cognitive control. From this perspective, in interventions, either the "horse should be tamed" (CBM aimed at the cognitive motivational biases) or the "rider should be strengthened" (making long-term goals more salient and training cognitive control). Although this metaphor is useful as a heuristic, we will see that it has important limitations.

Many dual-process models have emphasized that the two processing modes rely on different operating principles: the impulsive system, relying on associative memory (slow learning, retrieval with minimal effort, difficult to change), and the reflective system, relying on symbolic processing with a limited capacity, related to working memory capacity (WMC), a fragile system with fast and flexible learning (Deutsch, Gawronski, & Strack, 2006; Evans, 2008; Gawronski & Bodenhausen, 2006; Smith & DeCoster, 2000; Strack & Deutsch, 2004). Emotional and motivational processes are important in the impulsive system, whereas knowledge of long-term consequences are important in the reflective system only (Slovic, Peters, Finucane, & Macgregor, 2005). Note that although the term "dual" suggests two independent systems, contemporary theorists emphasize that there are multiple processes involved both in the impulsive system and in the reflective system and that both systems interact (Deutsch & Strack, 2006).

These models have given rise to falsifiable predictions related to the different operating principles. A first prediction is that negation of a proposition requires symbolic processing (reflective system), and indeed, it has been demonstrated that negation swiftly changes propositional knowledge while leaving associations largely unaffected (Gawronski, Deutsch, Mbirkou, Seibt, & Strack, 2008). This has important implications for prevention, for which negation is often used (e.g., "drinking alcohol does not make you feel relaxed"), which can result in the paradoxical effect that this expectancy is increased by the intervention (Krank, Ames, Grenard, Schoenfeld, & Stacy, 2010). As this example indicates, dual-process models are not only of theoretical interest but also have implications for research and practice in addiction and related areas.

A second prediction from these models concerns individual differences: People can differ both with respect to their associations and with respect to their more reflective attitudes concerning a specific behavior. They also differ with respect to the (limited) capacity of their reflective system, which can be indexed, for example, by assessing WMC. It follows that in individuals with relatively limited WMC, indices of impulsive processes should better predict behavior, whereas in individuals with strong WMC (and motivation to control), reflective considerations should better predict the behavior of interest (Hofmann, Friese, & Wiers, 2008; Stacy, Ames, & Knowlton, 2004). Indeed, this prediction has been confirmed for a variety of behaviors involving self-control, including aggression, sexual interest, and candy eating in dieters (Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008), and the same logic has been tested for a variety of addictive behaviors and related behaviors (discussed later). In addition, the same prediction should apply not only for trait-related differences but also for state-related differences. Manipulations that influence the limited resources of the reflective system should shift the prediction of the behavior, with the relevant impulsive processes gaining more weight. Indeed, this effect has repeatedly been found (e.g., Hofmann & Friese, 2008; Hofmann, Rauch, & Gawronski, 2007), with studies in addiction and related psychopathology discussed later.

Dual-Process Models of Addiction and Related Problems

During the past years, more specific dual-process models have been developed to explain addictive behaviors (Bechara, 2005; Evans & Coventry, 2006; Wiers & Stacy, 2006). These models can be viewed as special cases of the more general dual-process models, but they also have some special features. These can be summarized as strong changes[1] as a result of substance use: strengthened impulsive reactions to cues signaling the drug of abuse and weakened reflective processes allowing control over these impulses.

Stronger impulsive processes as a result of substance use

First, psychoactive substances affect mechanisms that underlie impulsive processes. In the current neurobiological literature on addiction, at least three of these pharmacologically enhanced forms of learning (neuroadaptations) are described that occur in different stages of substance use and abuse: incentive sensitization, negative reinforcement, and habit formation (Everitt & Robbins, 2005; Koob & Volkow, 2010; Robinson & Berridge, 2003). We briefly describe these mechanisms here, noting that although the underlying mechanisms are different, they all result in stronger impulsive processes geared toward substance use.

In their incentive sensitization theory of addiction, Robinson and Berridge (1993, 2003) separate two processes underlying positive reinforcement: "liking" and "wanting" (quotation marks are used to distinguish the underlying neural processes from the subjective experience). "Liking" refers to a stimulus's hedonic impact, whereas "wanting" refers to the ability of a stimulus to evoke approach behavior. Whereas "liking" and "wanting" usually go hand in hand (for good evolutionary reasons; Nesse & Berridge, 1997), they dissociate as addiction develops (Berridge, Robinson, & Aldridge, 2009; Robinson & Berridge, 1993, 2003, 2008). As a result, individuals can respond with "wanting" to drug cues despite reduced "liking." The enhanced "wanting" response to drug-related cues is related to mesolimbic dopaminergic pathways, with a central role for the ventral striatum. Although most theorizing in this area is based on animal research, some attempts have been made to dissociate wanting from liking in humans using subjective (Ostafin, Marlatt, & Troop-Gordon, 2010), behavioral (Hobbs, Remington, & Glautier, 2005), and neurocognitive measures (Leyton, 2007; Vollstadt-Klein et al., 2012). For example, Hobbs and colleagues (2005) found that adding an aversive taste reduced consumption of fruit juice in both light and heavy drinkers. Whereas the same manipulation also decreased beer consumption in light drinkers, it did not decrease beer consumption in heavy drinkers, despite reduced subjective liking. From the present perspective, it is important that incentive sensitization has been related to a number of cognitive biases: an attentional bias (AB) for the substance (Field & Cox, 2008; Robinson & Berridge, 2003, 2008), an approach bias for the substance (Field, Kiernan, Eastwood, & Child, 2008; Robinson & Berridge, 2008; Wiers, Rinck, Dictus, & van den Wildenberg, 2009), memory associations with approach and arousal (Palfai & Ostafin, 2003; Wiers, van Woerden, Smulders, & de Jong, 2002), and subjective craving (Field, Munafo, & Franken, 2009; Robinson & Berridge, 2008).

In addition to "liking" and "wanting" (both positive reinforcement), there is a long history of negative reinforcement as an important motivational process in addiction, especially in relation to tolerance and withdrawal (Koob & Volkow, 2010; Siegel, 1999; Solomon & Corbit, 1974). Classically conditioned drug cues (e.g., a specific context) elicit opponent processes that counter the effects of the drug. As a result, the drug effect is moderated, resulting in increased tolerance. The opponent process is also assumed to elicit a withdrawal-like state with strong negative affect, which leads to a motivational state aimed at remedying this state. As a result of prolonged drug use, reward functions fail to return within the normal homeostatic range (a so-called allostatic state; Koob & Le Moal, 2008). At a subjective level this is experienced as "anhedonia," sometimes labeled "the dark side of addiction" (Koob & Le Moal, 2008). These changes are associated with neural circuits involving the extended amygdala (Koob & Volkow, 2010). Anhedonia is temporarily remedied through drug use, but in the long run this aggravates negative affect.

In addition to these motivational processes in addiction, habit formation has gained prominence in addiction research (Everitt & Robbins, 2005; Tiffany, 1990). Recent evidence has emphasized that in the etiology of addiction, this process is pharmacologically enhanced, with the result that after prolonged drug use, the addictive behavior can persist despite (lack of) reward or even punishment and can thus develop from an impulsive outcome-focused behavior to compulsive habitual behavior (Everitt et al., 2008; Everitt & Robbins, 2005; Vanderschuren & Everitt, 2004). This change from impulsive to compulsive drug use has been associated with a shift from ventral to more dorsal striatal processing in response to drug cues (Everitt & Robbins, 2005; Vollstadt-Klein et al., 2010). One interesting implication of the habit perspective on addiction is that it predicts that cognitive biases become smaller after long addiction, and there is some evidence supporting this shift in long-term addiction (Loeber et al., 2009).

Although there is much debate regarding the relative contributions of these different pharmacologically enhanced learning processes to different phases of addiction (Everitt et al., 2008; Koob & Le Moal, 2008; Robinson & Berridge, 2008), we emphasize that from the dual-process perspective, they all result in strengthened impulsive processes: Increased incentive salience results in cues related to the substance capturing attention and eliciting an approach tendency (Berridge et al., 2009; Robinson & Berridge, 1993, 2003, 2008); negative affect may trigger an urge to take new drugs through sometimes unconscious associative processes (Baker, Piper, McCarthy, Majeskie, & Fiore, 2004); and habitual drug-related responses become increasingly hard to control (de Wit & Dickinson, 2009; Everitt & Robbins, 2005). Note that this review is not exhaustive and that other neurocognitive mechanisms have been implied in the development of addiction, such as decreased self-insight (Goldstein et al., 2009). Furthermore, although neurobiological addiction research has emphasized the neuroadaptations underlying addiction as markers of addiction as a "brain disease" (Leshner, 1997), at least to some extent, similar cognitive biases have been reported for nonsubstance addictive behaviors, such as gambling (Brevers et al., 2011), and for excessive or deviant sexual behaviors (Gray, Brown, MacCulloch, Smith, & Snowden, 2005), highlighting the continuum between addictive and other motivated behaviors (Kopetz et al., in press). Although there is neurobiological evidence that neural changes as a consequence of addiction are long lasting, if not forever (Koob & Volkow, 2010; Robinson & Berridge, 2003), there are ample examples of heavily addicted individuals who successfully quit their addiction with or without intervention (Heyman, 2009; Miller, 1998). Hence, the "brain disease" perspective is important for developing a better understanding of addiction, but this should not leave the patient (or therapist!) with the idea that addicted patients are helpless "slaves of passion" (Wiers, Field, & Stacy, in press). In fact, some of the training processes described herein may help patients to increase control over their strong impulsive processes.

Weaker reflective processes as a result of substance use

There is evidence that heavy alcohol and drug use is associated with relatively weak reflective processing (Verdejo-Garcia, Lawrence, & Clark, 2008), defined in dual-process models as the combination of the ability to control impulses (cognitive control) and the motivation to control, related to long-term outcomes (Hofmann, Friese, & Wiers, 2008; Wiers et al., 2007). First, note that impulsivity[2] concerns a well-supported antecedent to early alcohol and drug use (H. de Wit, 2009; Verdejo-Garcia et al., 2008). Related, a relatively weak development of executive functions has been reported in children of alcoholics, related to externalizing problem behaviors and risk for addiction (Nigg et al., 2004; Sher, 1991). Impulsivity is also a risk factor for the escalation from substance use to compulsive drug use (Belin, Mar, Dalley, Robbins, & Everitt, 2008).

What is the evidence for substance-induced impairments of reflective processes? First, there is relatively strong experimental evidence from animal research that excessive use of alcohol and drugs (especially during adolescence) has strong effects on subsequent brain development involving cognitive and emotional regulatory processes (Crews & Boettiger, 2009; Nasrallah, Yang, & Bernstein, 2009). The difficulty with this line of evidence lies in the generalization to humans, wherein control over emotional processes develops longer. The second line of evidence comes from human studies demonstrating that adolescent binge drinking and heavy use of marijuana is associated with impaired executive functions (Tapert et al., 2004, 2007). However, these studies are predominantly cross sectional and can therefore not establish a causal effect of these substances on subsequent brain development, although dose-response relationships and the converging animal literature are suggestive of such a link. Scarce longitudinal human data using neuropsychological tests suggest that binge drinking (especially multiple detoxifications) results in brain damage (Duka et al., 2011; Loeber et al., 2009, 2010; Squeglia, Spadoni, Infante, Myers, & Tapert, 2009; Stephens & Duka, 2008) and suboptimal decision making (Duka et al., 2011; Goudriaan, Grekin, & Sher, 2007, 2011). A recent paper from the Dunedin study, in which neuropsychological testing was done before cannabis use (age 13) and again at age 38 (with several measurements of cannabis dependence in between), indicated a strong neurotoxic effect of persistent cannabis use when initiated at age 18 (Meier et al., 2012). Different drugs to some extent appear to differentially impair different executive functions, but the general picture is that substance abuse impairs reflective processing (Fernandez-Serrano, Perez-Garcia, & Verdejo-Garcia, 2011). From the dual-process perspective, these findings indicate that the control of cue-induced cognitive-motivational processes becomes increasingly hard in addiction, and some theorists have emphasized this lack of control as the defining feature in addiction (Jentsch & Taylor, 1999; Volkow, Fowler, & Wang, 2004).

Evidence Supporting Dual-Process Models in Addiction Research

There are three lines of behavioral research in humans that have tested aspects of dual-process models in addictive behaviors and related problems. The first concerns tests of the moderating role of reflective processes (as a trait variable) on impulsive behaviors. The second concerns state manipulations of the processes involved by priming impulsive or impairing reflective processes. The third concerns interventions aimed at directly modifying problematic impulsive processes or strengthening control in addiction.

Individual differences in associations and reflective processes

In many recent studies, impulsive cognitive motivational processes are assessed with implicit or indirect measures (De Houwer, Teige-Mocigemba, Spruyt, & Moors, 2009; Roefs et al., 2011). Different measures are used to this end: open-ended measures of first associations, derived from basic memory research (Stacy, Ames, & Grenard, 2006; Stacy & Wiers, 2010); various reaction time measures, including the most frequently used Implicit Association Test (IAT; Greenwald, McGhee, & Schwartz, 1998); priming measures (Fazio, 1990); and physiological measures, varying from eye movements (Friese, Bargas-Avila, Hofmann, & Wiers, 2010; Schoenmakers, Wiers, & Field, 2008) to measures of brain activation in response to subliminal stimuli (Childress et al., 2008; Oei, Rombouts, Soeter, van Gerven, & Both, 2012). Importantly, all measures need to be validated regarding their "implicit" properties (De Houwer et al., 2009). Note that there is evidence from mathematical modeling that frequently used measures such as the IAT should not be regarded as "process-pure" indicators of impulsive processes (Conrey, Sherman, Gawronski, Hugenberg, & Groom, 2005; Sherman et al., 2008). Despite these issues, the overall picture is that many studies have demonstrated that implicit and explicit measures predict unique variance in addictive behaviors, as two meta-analyses have shown (Reich, Below, & Goldman, 2010), with similar findings in other forms of psychopathology (Roefs et al., 2011).

A number of recent studies tested the hypothesis from dual-process models that the impact of relatively automatic processes on addictive behaviors is moderated by individual differences in reflective processes (Stacy et al., 2004; Wiers et al., 2007). These studies used different measures of impulsive processes—open-ended measures (Grenard et al., 2008), varieties of the IAT (Friese & Hofmann, 2009; Houben & Wiers, 2009; Thush et al., 2008; Wiers, Beckers, Houben, & Hofmann, 2009), and varieties of the Alcohol Approach Avoidance Test to assess automatically activated approach tendencies (Peeters et al., 2012; Peeters et al., in press; Sharbanee et al., in press). Individual differences in the relative strength of reflective processes were assessed with tests of WMC (Grenard et al., 2008; Sharbanee et al., in press; Thush et al., 2008); with other general tests of executive control (EC), such as the Classical Stroop Test (Houben & Wiers, 2009; Peeters et al., 2012; Peeters et al., in press; Wiers, Beckers, et al., 2009); and with a report measure of self-control (Friese & Hofmann, 2009). Participants were either high-risk adolescents (Grenard et al., 2008; Peeters et al., 2012; Peeters et al., in press; Thush et al., 2008) or undergraduate students (Friese & Hofmann, 2009; Houben & Wiers, 2009; Wiers, Beckers, et al., 2009). Outcome behaviors were alcohol use and problems (Friese & Hofmann, 2009; Grenard et al., 2008; Houben & Wiers, 2009; Peeters et al., 2012; Peeters et al., in press; Thush et al., 2008), smoking (Grenard et al., 2008), and aggression after alcohol (Wiers, Beckers et al., 2009). In all of these studies, the outcome behavior was more strongly predicted by impulsive processes in individuals with relatively weak EC than in individuals with relatively strong EC, in line with findings regarding other impulsive behaviors, such as candy eating in dieters (Hofmann, Friese, & Roefs, 2009; Hofmann, Gschwendner, et al., 2008). Note, however, that two studies did not find this pattern of results, and both used varieties of a more symbolic task to assess approach tendencies, the stimulus response compatibility (SRC) or manikin task (Christiansen, Cole, Goudie, & Field, 2012; van Hemel-Ruiter, de Jong, & Wiers, 2011), in which control processes play a major role (Cousijn et al., 2012). Some of these studies found that the measure of explicit attitudes or expectancies better predicted the outcome behavior in individuals with relatively strong EC (Friese & Hofmann, 2009; Thush et al., 2008), in line with findings in other domains (Hofmann, Gschwendner, et al., 2008). However, one recent study tested the latter hypothesis only (i.e., no implicit measures were assessed) and did not find that alcohol use was better predicted by alcohol expectancies in high versus low EC individuals (Littlefield, Verges, McCarthy, & Sher, 2011). Perhaps some explicit measures, such as simple positive expectancies, tap into both more impulsive and more reflective processes (Wiers & Stacy, 2010).

Hence, the overall pattern of results is consistent with the hypothesis that in individuals with low EC, measures of impulsive processes better predict the (addictive) behavior of interest, whereas in high EC individuals, measures of reflective processes have (often but not always) been found to be the better predictors. Note that the stronger prediction of addictive behaviors in low EC individuals holds after controlling for trait impulsivity and sensation seeking (Wiers, Ames, Hofmann, Krank, & Stacy, 2010).

Situational manipulation of associations and reflective processes

Some studies have manipulated self-control resources, sometimes referred to as "ego depletion" (Baumeister, 2003). Self-control and effortful control depend on a limited-capacity resource, sometimes compared with a muscle. After the muscle is strained ("ego depletion"), it becomes harder to override a subsequent dominant response tendency (Baumeister, Bratslavsky, Muraven, & Tice, 1998). To the extent that an individual's relatively automatic appetitive responses steer one's addictive behavior, unless inhibited by reflective processes, it is predicted that ego depletion will increase alcohol and drug use (Hofmann, Friese, & Strack, 2008; Muraven, Collins, & Nienhaus, 2002). Indeed, some evidence supports this claim (Friese, Hofmann, & Wanke, 2008; Muraven & Shmueli, 2006; Ostafin, Marlatt, & Greenwald, 2008). For example, emotion suppression, known to deplete cognitive resources (Wenzlaff & Wegner, 2000), has been found to increase consumption of alcohol in a subsequent taste test (Friese et al., 2008; Ostafin et al., 2008). In both studies, implicit alcohol associations better predicted alcohol consumption after ego depletion than in nondepleted control participants.

In addition, the use of alcohol (and most other drugs) can in itself be viewed as an ego-depletion manipulation. There is strong evidence of detrimental effects of acute alcohol on executive functions and performance monitoring (Field, Wiers, Christiansen, Fillmore, & Verster, 2010; Fillmore & Vogel-Sprott, 2006; Ridderinkhof et al., 2002). Some studies tested effects of alcohol on other behaviors in which self-control plays a role (Hofmann & Friese, 2008); for example, implicit attitudes better predicted candy consumption in dieters after alcohol condition than after a nonalcoholic drink. Alcohol also impairs goal-directed control of action selection, favoring habitual responding (Hogarth, Attwood, Bate, & Munafo, 2012).

Hence, manipulations of momentary reflective capacity—whether through exhaustion ("ego depletion"), through alcohol consumption (Field et al., 2010), or through other factors, such as stress (Field & Powell, 2007; Field & Quigley, 2009; Sinha et al., 2009) or sleep deprivation (Gohar et al., 2009)—will all lead to a momentary increase of the impact of impulsive processes on behavior, whether increased alcohol or drug use or other behaviors, such as eating despite restraint goals.

Training manipulations of associations and reflective processes

The third line of evidence comes from training studies. Note that the first studies that attempted to manipulate a cognitive bias were designed to experimentally test the causal status of the bias on behavior (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002). Once this had been established, CBM was tested in various clinical populations.

Attentional retraining. MacLeod and colleagues (2002) first developed a retraining procedure targeting an AB for threat-related stimuli in anxiety. Anxious people show an AB for threatening stimuli (Mathews & MacLeod, 2005), as do heavy drinkers for alcohol (Field & Cox, 2008). MacLeod and colleagues modified an assessment instrument (visual probe test) with the goal to manipulate the underlying process. In this test, two pictures appear simultaneously on the computer screen (one disorder related, one control), followed by a probe to which people react (e.g., an arrow pointing up or down). In an assessment variety of the test, the probe appears equally often in the location of the threat stimulus and the control stimulus.

AB is calculated by subtracting response times on threat trials from response times on nonthreat trials. In a modification version of the task, a contingency is introduced, with the probe appearing more often on the location of the threat stimulus (to increase AB) or the neutral stimulus (to reduce AB). Results indicated that the AB modification had been successful, at least for the longer presentation of stimuli (500 ms), in the absence of an effect on the very briefly presented stimuli (20 ms). Importantly, the change in AB was found for different stimuli in the same task, an example of close generalization (Hertel & Mathews, 2011). Further generalization was found in a subsequent stress-induction task, with participants in the attend-threat condition showing greater distress than participants in the attend-neutral condition. Subsequent research in this domain investigated clinical applications, typically with multiple training sessions, with recent successful studies in clinically anxious patient groups (Amir, Beard, Burns, & Bomyea, 2009; Schmidt, Richey, Buckner, & Timpano, 2009) and in targeted prevention (See, MacLeod, & Bridle, 2009). However, a recent meta-analysis indicated small to medium effects for attentional retraining in anxiety with indications of a publication bias (Hallion & Ruscio, 2011).

Researchers in addiction followed with a number of "proof of principle" studies, modeled after the seminal study by MacLeod and colleagues (2002). These studies involved a single session of CBM, assessing close generalization (different stimuli in same task) and further generalization (different tasks, craving, choice of drink). These studies showed a very similar pattern: An AB for alcohol (Field & Eastwood, 2005; Field et al., 2007; Schoenmakers, Wiers, Jones, Bruce, & Jansen, 2007) and smoking (Attwood, O'Sullivan, Leonards, Mackintosh, & Munafo, 2008; Field, Duka, Tyler, & Schoenmakers, 2009) could be modified in both directions. However, no evidence for generalization was found after a single session of retraining (Field et al., 2007; Field, Duka, et al., 2009; Schoenmakers et al., 2007).

More encouragingly, the first two studies using repeated attentional retraining in problem drinkers (Fadardi & Cox, 2009) and alcohol-dependent patients in treatment (Schoenmakers et al., 2010) both found generalized positive effects. Fadardi and Cox (2009) developed the Alcohol Attention-Control Training Program, an adaptive training procedure based on a pictorial alcohol Stroop task. This procedure resulted in a reduced AB for alcohol, which was accompanied by an increased motivation to change drinking and reduced drinking levels. However, interpretation is hindered by the lack of a control group. Schoenmakers and colleagues (2010) used a variation of the visual probe test in a first randomized clinical trial with alcohol dependent patients. Patients in the experimental condition received five sessions of attentional retraining, involving picture presentations at short (200 ms) and longer durations (500 ms). Results showed the expected effect of training on the AB at the 500-ms presentation, with patients in the experimental condition demonstrating an avoidance bias for alcohol at posttest and with participants in the control condition (who performed an unrelated task involving the same stimuli and motivating feedback) showing an increase in AB. This increase in AB could be the default development in patients in treatment and has been found to predict subsequent relapse (Cox, Hogan, Kristian, & Race, 2002). AB training resulted in a significantly longer time to relapse (Schoenmakers et al., 2010). No effects of training were found on the 200-ms presentation, which could be interpreted as evidence for a specific effect of CBM on the ability to disengage from alcohol-related stimuli in alcoholic patients while leaving the tendency to engage attention to alcohol-stimuli unaffected. Note that similar findings have been reported in depression (Hallion & Ruscio, 2011). This raises the question to what extent this training influences impulsive processes or, rather, control over impulses (discussed later).

Evaluative conditioning and counterconditioning. A second cognitive bias associated with addictive behaviors is an evaluative memory bias. Heavy drinkers have stronger positive and arousal associations with alcohol than light drinkers (Houben & Wiers, 2006; Rooke et al., 2008; Wiers et al., 2002). One way to change evaluative associations is through evaluative conditioning, as shown by many studies (Hofmann, De Houwer, Perugini, Baeyens, & Crombez, 2010). In this procedure, stimuli of a specific category (e.g., alcoholic drinks) are paired with an evaluative category (positive or negative). Though often used to create associations for a new product (advertising), the question here was whether existing (positive) associations for a relevant category (e.g., alcohol) could be changed. Two recent studies indicate that this is indeed possible (Houben, Havermans, & Wiers, 2010; Houben, Schoenmakers, & Wiers, 2010). Pairing alcohol to negative pictures resulted in more negative evaluations of alcohol (in the first study also on implicit attitudes) and reduced drinking compared with a control condition in which alcohol pictures were paired with neutral pictures. In both experiments there was no evidence of contingency awareness, but more rigorous testing of the role of awareness in other domains has indicated that contingency awareness does play a role in evaluative conditioning (Hofmann, De Houwer, Perugini, Baeyens, & Crombez, 2010; Pleyers, Corneille, Luminet, & Yzerbyt, 2007). Note that recent studies have also found changes in implicit alcohol associations as a result of a content-specific inhibition training (Houben, Nederkoorn, Wiers, & Jansen, 2011), discussed later.

A related intervention concerns counterconditioning (Van Gucht, Vansteenwegen, Van den Bergh, & Beckers, 2008). In this procedure, a classically conditioned incentive cue is systematically coupled to a strong negative outcome (e.g., a very bad-tasting liquid). This procedure is conceptually related to aversive conditioning, which produced promising results but was plagued by poor research methods (Wiers, Houben, Smulders, Conrod, & Jones, 2006). Initial positive findings have been reported for counterconditioning, which contrasts with largely negative findings with extinction (Van Gucht et al., 2010; Van Gucht, Vansteenwegen, Beckers, & Van den Bergh, 2008) and cue exposure in addiction (Conklin & Tiffany, 2002; Marissen, Franken, Blanken, van den Brink, & Hendriks, 2007).[3]

A related CBM training used frequently in anxiety and depression concerns interpretation bias training, with large effect sizes in anxiety (Hallion & Ruscio, 2011). This training manipulates the bias to interpret ambiguous information in a negative way. To the best of our knowledge, this training has not been applied to addiction yet, although there is evidence for an interpretation bias in addiction (Stacy et al., 2006; Woud, Fitzgerald, Wiers, Rinck, & Becker, 2012). The latter study used a similar format as adopted in interpretation bias retraining studies in anxiety, which opens up new possibilities for interpretation bias training in addiction. Note that in this paradigm, participants read ambiguous stories and are trained in a specific interpretation in the training variety, a procedure that most likely also involves both impulsive and reflective processes.

Approach bias retraining. A third cognitive bias found in addictive behaviors is a bias in the automatically activated action tendency to approach addiction-related stimuli. An approach bias can be detected using different tasks. In one task, the SRC or manikin task, participants are instructed to move a manikin toward a substance-related picture in one block (and away from other pictures) and in another block, away from the substance (and toward other pictures). With this task, an approach bias has been found for cigarette cues in smokers (Mogg, Bradley, Field, & De Houwer, 2003), for marijuana cues in marijuana users (Field, Eastwood, Bradley, & Mogg, 2006), and for alcohol in heavy drinkers (Field et al., 2008). Relatively strong associations between alcohol and approach have also been found using an approach-avoid variety of the IAT (Ostafin & Palfai, 2006; Palfai & Ostafin, 2003). Recently, the alcohol Approach Avoidance Task (AAT) has been developed (Wiers, Rinck, et al., 2009), which can also be adapted to retrain this bias. The AAT is a joystick task in which participants react by pushing or pulling a joystick, depending on a feature of the stimulus unrelated to the contents (e.g., picture format, landscape, or portrait).[4] The AAT contains a "zoom feature": Upon a pull movement, the picture size on the computer screen increases, and upon a push movement, it decreases, which generates a strong sense of approach and avoidance, respectively (Neumann & Strack, 2000) and disambiguates the task (Rinck & Becker, 2007). Note that the AAT is a more indirect task than the SRC and IAT, which both require participants to categorize the contents of stimuli to make a response, which is not the case in the AAT. With the alcohol AAT, heavy drinkers (Wiers, Rinck, et al., 2009) and alcoholic patients (Wiers, Eberl, Rinck, Becker, & Lindenmeyer, 2011) demonstrated an approach bias for alcohol (defined as a stronger tendency to pull than to push in response to alcohol pictures; note that in some cases, the approach bias for soft drinks was larger than the approach bias for alcohol). The alcohol bias was moderated by the G allele of the *OPRM1* gene: Carriers of a G allele demonstrated a particularly strong approach bias for alcohol, as well as for other appetitive stimuli (Wiers, Rinck, et al., 2009). An AAT approach bias for cannabis was the best predictor of escalation of cannabis use in young cannabis abusers (Cousijn, Goudriaan, & Wiers, 2011).

Based on the logic of attentional retraining, the alcohol AAT was turned into a modification task by changing the contingencies of the percentage of alcohol-related or control pictures that were presented in the format to be pulled or pushed. In a first study, a split design was used, with students being trained in one session to either approach alcohol (90% of the alcohol pictures were pulled) or avoid it (Wiers, Rinck, Kordts, Houben, & Strack, 2010). In this study, generalized effects were found both in the same task (novel pictures, close generalization) and in a different task (a verbal approach-avoid alcohol IAT). In those participants who demonstrated the change in approach bias in the expected direction, an effect on subsequent alcohol use during a taste test was found (further generalization). These generalized effects of a single session of approach bias retraining are remarkable in light of the consistent failure to find generalized effects after a single session of attentional retraining in addictive behaviors.

In a first clinical application of this approach bias retraining paradigm (Wiers et al., 2011), 214 alcohol-dependent patients were randomly assigned to one of two experimental conditions, in which they were trained to make avoidance movements (pushing a joystick) in response to alcohol pictures,[5] or to one of two control conditions, in which they received either no training or sham training. Four sessions of approach bias retraining preceded regular inpatient treatment, primarily cognitive-behavioral therapy (CBT). In the experimental conditions, patients' approach bias changed into an avoidance bias for alcohol. This effect generalized to untrained pictures in the task used (close generalization) and to the verbal approach-avoid IAT (further generalization). Patients in the experimental conditions showed better treatment outcomes a year later (13% less relapse). It should be noted that no mediation was found. In a recent large replication study ($N = 509$), the clinical effect replicated; 10% reduced relapse rates were found a year later in trained patients compared to control patients (Eberl et al., in press). Both mediation and moderation were found: The effect on relapse was mediated by a change in alcohol approach bias, and patients with a strong alcohol approach bias profited most from the training. Finally, in the domain of anxiety, first attempts to modify an avoidance bias have been made, with socially anxious participants being trained to approach social stimuli (Taylor & Amir, 2012).

Training general abilities. From the perspective of dual-process models, one could train self-control or WMC independent of the problem domain. There is a rapidly growing literature indicating that WMC can be trained successfully, especially in groups with relatively weak WMC, such as children with attention-deficit/hyperactivity disorder (Klingberg, 2010; Klingberg et al., 2005) and children with poor WMC (Holmes, Gathercole, & Dunning, 2009; Jaeggi, Buschkuehl, Jonides, & Shah, 2011), and in healthy elderly (Buitenweg, Murre, & Ridderinkhof, 2012). However, evidence for generalized training effects on cognitive abilities is weaker (Shipstead, Redick, & Engle, 2012).

One recent study tested the effects of WMC training in problem drinkers and found that WMC increased more strongly in the experimental condition than in the control condition. This increase was associated with reduced drinking in those problem drinkers who had strong automatic positive associations with alcohol, a case of moderated mediation (Houben, Wiers, & Jansen, 2011). A second recent study (Bickel, Yi, Landes, Hill, & Baxter, 2011) found that stimulant-abusing patients who received WMC training compared to control training showed reduced delay discounting, but no generalized effects were found on other tasks, and no effects on behavior were reported. There is also some evidence that practicing self-control can have generalized effects on health behaviors (Gailliot, Plant, Butz, & Baumeister, 2007; Muraven, Baumeister, & Tice, 1999; Oaten & Cheng, 2006). For example, Muraven (2010) found that daily practice of self-control for 2 weeks prior to smoking cessation improved the chance of remaining abstinent, in comparison to participants in a control condition.

Another recently developed intervention concerns training of inhibition in response to a specific category of stimuli (which makes it, in terms of dual-process models, more a combination of training of impulsive and reflective processes). This can be done using an adapted go/no-go task, in which one category is consistently followed by a no-go cue (Veling, Holland, & van Knippenberg, 2008) or with a stop task (Verbruggen & Logan, 2009). Houben and colleagues applied the first method to alcohol in heavy drinkers (Houben, Nederkoorn, et al., 2011) and found that selective inhibition of alcohol led to stronger negative alcohol associations and to reduced alcohol intake, compared with the control condition. A recent replication study found that the change in drinking was mediated by a reduction in implicit valence of the alcohol stimuli and not by a change in general inhibition capacity, as measured with the stop task (Houben, Havermans, Nederkoorn, & Jansen, 2012). Hence, although inhibition is trained (in relation to a specific category), this training appears to change impulsive processes (automatic attitude toward alcohol). In addition to specific category-related inhibition manipulations, recent evidence also indicates that priming a general cautious state by emphasizing accuracy in a stop task spills over to other behaviors, including beer consumption (Jones et al., 2011).

In summary, dual-process models of addiction and related problems have stimulated research on novel ways to influence the relative balance between impulsive and reflective processes.[6] These findings are promising but also raise questions concerning underlying mechanisms and their consistency with dual-process models.

Criticisms and Next Steps in Theory Development

Recently, general dual-process models have been criticized, and these criticisms are also relevant for more specific dual-process models of addiction and related disorders. We briefly summarize these criticisms and argue that the way forward is to better define and understand dual-process models in terms of dynamic interactions among underlying component processes. This changed theoretical perspective also has implications for next steps in research on CBM and control training.

Addressing theoretical criticism of dual-process models

A first criticism is that if human cognition can be divided into two types of processes defined by a coherent set of mutually exclusive characteristics, then these characteristics should covary consistently for a given process. This does not appear to be the case—for instance, automatic processes may require attentional resources or be efficient but still dependent on intentions (Keren & Schul, 2009; Kruglanski & Gigerenzer, 2011). Such results suggest that a single impulsive-reflective or automatic-controlled dimension may not be tenable (Moors & De Houwer, 2006). It can be argued, however, that this is by no means fatal to dual-process models—it has long been pointed out that all meaningful behavior is likely to involve a mixture of automatic and controlled processes (De Houwer et al., 2009; Moors & De Houwer, 2006).

Second, even if a true fundamental division between two types of processes is accepted, the relationship between dual processes and the implementation of these processes in cognitive or neural systems raises questions. In a critical review (Keren & Schul, 2009), it was argued that much of the evidence used to support the existence of such dissociable systems is problematic. We briefly note that some theorists have described the relation between dual-process concepts and the brain by tentatively mapping specific brain regions to either the impulsive ("reflexive") or reflective system. In these models, typically emotional and motivational systems provide the drive and frontal cortices the control (Heatherton & Wagner, 2011; Satpute & Lieberman, 2006). Our metaphorical horse has now become a motivational brain circuit, and the rider, a control circuit. Criticisms on dual-system models apply to these models. However, it should be noted that in the broader neurocognitive literature, control is commonly defined as the top-down biasing of ongoing subordinate processes rather than as a separate systems (Cohen, Braver, & O'Reilly, 1996; O'Reilly, Noelle, Braver, & Cohen, 2002; Ridderinkhof, Forstmann, Wylie, Burle, & van den Wildenberg, 2011). Therefore, a meaningful distinction between controlled and automatic processes does not depend on the separability of systems.

Third, dual-process models aimed primarily at distinguishing types of processing do not naturally provide an explanation of why reflective control is exerted, at what moments, and of what kind. This is not to say that motivation plays no part in dual-process models. In some recent dual-process models of addiction, motivation is explicitly mentioned, in terms of both a reflective component, "motivation to control" (following Fazio, 1990), and in an impulsive component, "appetitive motivation," suggesting that the two kinds of motivation should be considered as separate "boxes" from each other and from EC (e.g., Wiers & Stacy, 2006). Such descriptive models provide a necessary first step in structuring conceptual elements relevant to addiction. The next question is how the processes involved in reflective processing are themselves reinforced (Gladwin, Figner, Crone, & Wiers, 2011), a topic undergoing a much-needed revival of interest (Ridderinkhof, Cohen, & Forstmann, 2012). Hence, the question is not "Why is the reflective system motivated to control?" but rather "When the reflective system exerts control, why does it work toward motivationally significant ends?" There is emerging evidence that this "motivational homunculus problem" can be solved by modeling the interplay between the development of motivation and control (Frank & Badre, 2012; Hazy, Frank, & O'Reilly, 2006, 2007). Hence, we argue that the two central issues that have the potential to be fatal flaws of dual-process models—defining impulsive and reflective processes and the relationship between control and motivation—are in fact closely related. Indeed, contemporary cognitive neuroscience suggests that the integration of motivation and control is essential to understand what control is and how control works (Harsay et al., 2011; Hazy et al., 2006, 2007; Kouneiher, Charron, & Koechlin, 2009; Ridderinkhof et al., 2012).

Our goal here is not to present a complete model but to point out that reflective and impulsive "processes" can be redefined in terms of distinguishable states in a system of overlapping functional components rather than qualitatively different processes in separable systems (Gladwin et al., 2011). These states can be defined in terms of iterative reprocessing, as proposed in research on evaluation (Cunningham & Zelazo, 2007):

> Stimuli (e.g. people, objects and abstract concepts) initiate an iterative sequence of evaluative processes (the evaluative cycle) through which the stimuli are interpreted and reinterpreted in light of an increasingly rich set of contextually meaningful representations. Whereas evaluations that are based on few iterations of the evaluative cycle are relatively automatic, in that they are obligatory and might occur without conscious monitoring, evaluations based on additional iterations and computations are relatively reflective. (p. 97)

We suggest that the mechanism of iterative reprocessing also involves reflective versus impulsive response selection (Gladwin et al., 2011). With continued reprocessing, the outcome becomes more "reflective." This view of reflective processing is closely related to the cognitive neuroscience literature and theories of conscious processing, adaptation, and control that use processing cycles and reentry as their organizing principle (Dehaene & Changeux, 2011; Edelman, 2001; Fuster, 2004). Importantly, "reinforcement" processes (Bunge, Burrows, & Wagner, 2004; Seger, 2008) form the foundations for subsequent "reprocessing." In this way, rather than a reflective system of a set of processes acting as a homunculus exerting control to achieve some distal goal, a reflective state can be defined that changes how previously reinforced associations affect response selection. From this perspective, addictive substances affect the availability of information concerning immediate versus long-term outcomes of reflective versus impulsive responses, which affects response selection.

This argument is not intended to entail a full-fledged model but primarily serves as a proof of principle regarding important theoretical criticisms. However, the preliminary model (termed the reinforcement/reprocessing model of reflectivity, or R3 model; Gladwin et al., 2011) may be of use in generating hypotheses and providing a theoretically strong framework for interpreting results. This perspective implies that the timing of events plays an essential role in relatively reflective versus impulsive processing. In line with this prediction, it was recently found that more delayed automatic affective reactions to tempting food stimuli were correlated more strongly with conscious food cravings than immediate automatic affective reactions (Hofmann, van Koningsbruggen, Stroebe, Ramanathan, & Aarts, 2010). Presumably, extending the interstimulus interval in the task used allowed for the iterative reprocessing of tempting stimuli until a conscious craving response was generated (in line with the elaborated intrusion theory of craving; Kavanagh, Andrade, & May, 2005). Further evidence for a role of time-dependent processes was found in AB research. In alcohol-dependent patients, an approach bias is found at cue presentation, which later reverses into an avoid bias (Noel et al., 2006; Vollstadt-Klein et al., 2010), similar to the vigilance-avoidance pattern found in anxiety (Mathews & MacLeod, 2005). Time dependence has also been found for the effects of alcohol-related distracters (Gladwin & Wiers, 2012).

Next Steps in Clinical Research and Applications

We contend that a grounding of dual-process models in contemporary cognitive neuroscience emphasizing the dynamic interplay between motivation and control will help to optimize training in a clinical context. What follows are a number of next steps regarding the optimalization of training and the combinations with other interventions.

What are we training?

As anticipated, the horse-rider metaphor has been helpful in generating novel interventions, but some of the outcomes were hard to reconcile with the metaphor and may be better understood from the iterative reprocessing alternative. For example, the finding that attentional retraining in alcoholic patients successfully changed the relatively slow AB, while leaving the AB for short presentations unaffected (Schoenmakers et al., 2010), may be understood as CBM influencing reprocessing once triggered by the initial appraisal of motivationally relevant processes, without changing the initial appraisal (Frijda, 1986). The category-specific inhibition training (Houben, Nederkoorn, et al., 2011) appears to teach participants a category (e.g., alcoholic drinks) as a stop signal, and as a result, this category is evaluated more negatively even in an implicit task (suggesting a change in relatively early processing). From the present perspective, all of these interventions may help to overcome the dominant response tendency to approach alcohol-related stimuli. As a patient in the first clinical study of approach bias CBM explained: "When I see the beer section in a supermarket now, I immediately turn away from it while remembering the joystick training." The training may provide the patient with a longer time window for decision making (i.e., iterative reprocessing) or may "buy the patient time" from the tendency to react impulsively (cf., Lewis, 2011). One crucial aspect of CBM training is that the alternative response is triggered when needed, in a bottom-up fashion, by relevant stimuli. In fact, that may be the added value of CBM above CBT and motivational interventions, for which alternative goals are discussed but no specific alternative responses are trained in such a concentrated way.

From this perspective, one may wonder how general WMC training may have reduced problem drinking (Houben, Wiers, & Jansen, 2011). Findings indicated that WMC was improved by the training, but how was it triggered in high-risk situations? One possible explanation concerns incidental learning: Participants were aware that the goal of the training was to help them to cut down their drinking, and in many sessions, alcohol use and problems were also assessed. Perhaps this context already created enough associations to make the increased control capacity available for participants who lacked control when facing a drink, owing to their relatively strong automatically activated associations. Clearly, this requires further study.

More broadly, one area in need of further research is to what extent it is more efficient to train domain-general capacities (such as attentional control or WMC) or control in relation to a specific domain (triggered by domain-specific stimuli, as in CBM). One interesting suggestion would be to test what would happen in a CBM training of an irrelevant domain. If the active ingredient in training is domain general, one might train alcoholic patients with fear pictures and anxious patients with alcohol pictures. We would predict that it would make a difference because an important aspect of training is that control processes are triggered in time by stimuli related to the problem domain. Hence, automatic activation of control processes appears to be crucial (cf. Bijleveld, Custers, & Aarts, 2009). Preliminary evidence in line with this suggestion comes from a study in anxiety showing that training attention toward and away from threat attenuated social anxiety, whereas in the control condition it did not (Klumpp & Amir, 2010).

A related question is to what extent effects of one type of CBM generalize to another bias (e.g., if we do attentional retraining, does this also affect an approach bias for a substance?). Initial work demonstrates that effects of one type of CBM may generalize to other biases in anxiety (Amir, Bomyea, & Beard, 2010) and depression (Everaert, Koster, & Derakshan, 2012). We are presently investigating this issue in addiction. It may also be wise to consider older cognitive literature on optimizing generalization of training effects (Hertel & Mathews, 2011).

Studying changes in underlying processes. How do we proceed with studying which underlying neurocognitive processes are affected by training? One way to study this is by mathematical modeling (Conrey et al., 2005; Sherman et al., 2008). Future modeling should also try to incorporate the different neural processes involved in addiction (incentive sensitization, habit, negative reinforcement, reduced control), for which the relevant weight may differ for different addictions (Badiani, Belin, Epstein, Calu, & Shaham, 2011). Different underlying processes may require different training techniques, which could imply that different addictions require different types of training.

A second way to study mediating processes is to more directly study the effects of training on brain functioning, as has been done for working memory training (Olesen, Westerberg, & Klingberg, 2004), and initial attempts have been made regarding CBM in anxiety (Browning, Holmes, Murphy, Goodwin, & Harmer, 2010; Eldar & Bar-Haim, 2010). CBM might change white matter connectivity profiles, associated with habitual versus goal-directed action (S. de Wit et al., 2012). Clearly, this type of research could shed more light on the effects of training in addiction too.

Optimizing training by integrating motivation and control

From the present perspective, CBM most likely works by extending the time window within which decision making takes place—in other words, by training relatively more reflective decision making. In this narrow context, it may be helpful to train an alternative behavioral option. For example, in the case of alcohol, often nonalcoholic drinks have been chosen as a contrast category, which is made more salient in the experimental condition. The reasoning behind this was that in many social situations for which one is at risk to drink alcohol despite long-term motivation to abstain, the logical choice will be between an alcoholic and nonalcoholic drink (Ostafin & Palfai, 2006; Wiers et al., 2002). This narrow response window training will probably profit from a context in which more broadly defined alternative goals are explored (in more conventional CBT and motivational interviewing).

Up to now, CBM in addiction has typically been delivered as an add-on to "treatment as usual" (usually CBT with motivational interviewing elements).[7] Hence, all patients receive regular treatment with a training module added: for half, the true training; for the other half, a placebo version.[8] This is a good design to establish additional effects in a clinical context, but it does not help to integrate the CBM and CBT. There are examples of training programs that integrate patients' personal alternative goals into the training (Alfonso, Caracuel, Delgado-Pastor, & Verdejo-Garcia, 2011). This may help to motivate patients for the training. In addition, elements of CBT may be fine-tuned to integrate training into the total program, which would also help to motivate patients but at the same time make controlled research more difficult. This could be tackled by employing different research designs, such as multiple case series (Rozenman, Weersing, & Amir, 2012; Teachman, Marker, & Smith-Janik, 2008).

A related issue concerns the acceptability of the training for the patients. This appears to be a concern, especially for attentional retraining, both in the domain of anxiety (Beard, Weisberg, & Primack, 2011) and in addiction (Schoenmakers et al., 2010). In the latter study, participants were asked to guess whether they had received the real or placebo training variety, and they almost all guessed they received placebo training. Though positive from an experimental perspective (making placebo effects unlikely), this is less desirable from a clinical perspective: Apparently, no patients could imagine how the training could ever help them with their addiction. In anxiety, a similar conclusion was reached on the basis of qualitative interviews (Beard et al., 2011). Somewhat more positive attitudes were reached for interpretation bias retraining in anxiety (Beard et al., 2011) and approach bias retraining in addiction (Wiers et al., 2011). In the latter case, patients even protested against closing the study. These preliminary findings suggest that implementing interpretation bias and approach bias retraining may be easier in clinical practice than attentional retraining, but at the same time they also make these interventions more vulnerable for placebo effects. One way to improve acceptability of training may be to introduce motivating feedback (Fadardi & Cox, 2009). A next step could be to further introduce gamelike elements, such as gaining points that are helpful in a shell game surrounding the training, an approach that has been successful in children with attention-deficit/hyperactivity disorder (Dovis, Van der Oord, Wiers, & Prins, 2012) and might be helpful in young substance abusers with little motivation to change.

A related topic concerns the optimal delivery method. Because almost all training methods are computerized, they may be delivered over the Web. However, as noted earlier, successful training in clinical groups, at least in addiction, has always been combined with some other form of treatment. This does not necessarily mean that CBM can work only when added to traditional face-to-face CBT, because some of the elements of traditional treatment may also be given in a computerized fashion, with positive results in addictive behaviors (Riper et al., 2008; Riper et al., 2011). The combination of CBM and a brief computerized cognitive-motivational intervention has shown promising results in anxiety (Amir & Taylor, 2012), whereas Internet-delivered CBM alone has not (Carlbring et al., 2012). An additional interesting possibility is to start a training in a clinical context (with appropriate motivational context) and let patients continue the training at home over the Internet, as we are presently testing. This may help the transfer from the clinic to more difficult situations in everyday life. In addition, integration into daily life may be promoted by CBM applications for smartphones, although efficacy remains to be proven (Enock, Hofmann, & McNally, 2012).

Finally, regarding optimizing training, it should be emphasized that we are at the beginning of a journey, rather than at the end, with many practical questions that need systematic investigation. First, we do not know the optimal duration and timing of training; all we can conclude from the present literature is that more than one session appears to be needed. Second, we do not know which training or combination of training methods works best for a specific problem.

Enhanced training

One interesting emerging possibility is to enhance training by electrical stimulation or by pharmacological means. For instance, there is emerging evidence that direct low-voltage electrical stimulation (transcranial direct current stimulation; tDCS) of the dorsolateral prefrontal cortex can temporarily enhance WMC (Fregni et al., 2005). Recent studies have attempted to further specify the nature of this enhancement, suggesting that tDCS affects component processes of WMC rather than control as a whole (Gladwin, den Uyl, Fregni, & Wiers, 2012), consistent with the present perspective. However, stimulation may also make behaviorally relevant information more accessible, in which case stimulation effects are not self-evident and may depend on the task context (Gladwin, den Uyl, & Wiers, 2012). Interestingly, tDCS also temporarily reduced craving for alcohol (Boggio et al., 2008) and cigarettes (Boggio et al., 2009). How could this be the case? Prefrontal regions support top-down biasing: an internal, cognitive response that may be required to inhibit craving-related processes. Anodal prefrontal stimulation would be expected to facilitate the activation of such biasing processes. Because tDCS also influences neuronal plasticity (Nitsche et al., 2003; Paulus, 2003), a potentially important application is the combination of tDCS with the novel training interventions described earlier. Whereas the immediate effects of tDCS are temporary, its effects on concurrent training could be more persistent, either directly via plasticity or by aiding the subject in performing the training task at a higher level. However, because tDCS does not appear to increase control as a whole but rather context-specific component processes, effects on cognitive biases can be surprising (Gladwin, den Uyl, & Wiers, 2012); therefore, the effects of tDCS-enhanced CBM should first be critically tested before it can be applied to clinical populations. Some medication (e.g., modafinil) may serve a similar goal, with indications that baseline levels of impulsivity may be crucial (Schmaal et al., in press; Zack & Poulos, 2009). In addition, there are initial positive findings regarding neurofeedback in addiction (Sokhadze, Cannon, & Trudeau, 2008), which may also be viewed as “training” but is beyond the scope of the present review.

Tailored training?

It would seem important to select participants for a specific type of CBM or training. For example, patients with a strong AB would most likely gain most by attentional retraining. One important prerequisite for this type of treatment matching is that the matching variable can be assessed in a reliable way. For AB, that is very difficult, with modest reliabilities being reported for tests of AB (Ataya et al., 2012). However, two studies found that a stronger bias at pretest predicted stronger CBM effects in anxiety (Amir, Taylor, & Donohue, 2011; Salemink & Wiers, 2011). In the first randomized clinical trial of attentional retraining in addiction (Schoenmakers et al., 2010), the pattern of the data suggested that the training effect on AB occurred only in those patients in the experimental condition with a strong AB at pretest, but the corresponding interaction was not significant, probably because of the poor reliability of the measure and low power. In the recent large replication study of approach bias retraining, a strong approach bias before training was found to moderate the training effect (Eberl et al., in press). Hence, there is some promise to the idea to select participants for CBM who show a strong bias, but the challenge is to assess this bias in a reliable-enough way to justify individual assignment to a condition. An interesting paradox appears to emerge here: Tasks that are most indirect are most easily adjusted for retraining (visual probe, AAT) because participants react to a different feature of the stimulus and because contingencies of the stimuli can be manipulated without changing the instructions. At the same time, these measures appear to be suboptimal for assessment, owing to suboptimal reliability (De Houwer & De Bruycker, 2007; Field, Caren, Fernie, & De Houwer, 2011), and therefore for determining whether an individual patient would benefit from this training. One alternative could be to use another measure for the latter purpose (e.g., SRC or IAT), but the correlations between these measures is typically low. A recent study using the relevant-feature SRC found that alcoholic patients with relatively strong alcohol avoidance tendencies had a relatively large chance to relapse (Spruyt et al., in press), a finding apparently at odds with training results in alcoholic patients, which showed that training to avoid alcohol reduces relapse (Eberl et al., in press; Wiers et al., 2011). Hence, although the SRC is more reliable than the AAT, selecting participants for approach bias retraining with the SRC seems inadequate.

Another alternative could be to assess a correlated variable that can be assessed reliably, such as the presence of a G allele in the *OPRM1* gene for a strong appetitive approach bias (Wiers, Rinck, et al., 2009), but this hypothesis remains to be tested. Encouragingly, initial evidence regarding genetic moderation of AB retraining in anxiety has been found (Fox, Zougkou, Ridgewell, & Garner, 2011). One possibility is that training effects are dependent on a number of genes that moderate plasticity and learning (Belsky et al., 2009). In support of the latter view, plasticity genes have recently been found to be cumulative with respect to their moderating role on the relationship between parenting and adolescent self-regulation (Belsky & Beaver, 2011).

Other moderators, such as EC, are of interest too, as shown in interpretation bias retraining in anxiety in adolescents (Salemink & Wiers, 2012). Given the moderating role of EC in addictive behaviors, this variable is likely to be relevant in the domain of addiction as well. In the recent replication study of the clinical approach bias retraining, it was found that age moderated the effect of training and was negatively correlated with EC capacity in these alcoholic patients (Eberl et al., in press), as would be expected by the detrimental effects of alcohol and detoxifications on EC capacity (Crews & Boettiger, 2009; Duka et al., 2011).

Conclusion

Dual-process models have generated significant progress in the understanding of addictive behaviors and other psychopathology. As predicted by these models, impulsive predictors better predict problem behaviors when control is relatively weak, either as a trait variable or as a state variable. In addition, these models stimulated the development of novel interventions to either reduce impulsive tendencies or increase control over impulses. However, dual-process models have been criticized. We argued that the way forward is to better define and understand dual-process models in terms of dynamic interactions between underlying component processes grounded in reinforcement learning. Our alternative iterative reprocessing perspective implies that the timing of events plays an essential role in relatively reflective versus impulsive processing. We argue that this perspective will help to better understand the effects of current training interventions—for example, why CBM appears to primarily influence later stages of processing rather than the initial appraisal. Our perspective may also be helpful in research aimed at a better understanding of the neurocognitive effects of training interventions. In addition, the present perspective points in new directions regarding training interventions, for which enhancing control over impulses and motivation to control should go together. Improved understanding of underlying processes may help to improve training interventions, either by themselves or under “enhanced conditions”—for example, by supplementing training with electrical stimulation (tDCS) or medication. From a clinical perspective, a better integration of training interventions with "treatment as usual" is desired, and this will also have implications for clinical research designs. Though this is admittedly a platitude, it is clear that more research is needed in this area: At present, we do not know which cognitive biases are best tackled in which addictions or other problems, which methods work best to change these biases, whether each bias should be retrained separately, or to what extent training of more general control mechanisms may work as well. We argued from our general perspective that effective training should probably contain elements that automatically trigger control when needed. For clinical applications, an important research question remains how to tailor training for a specific individual, with paradigms that are easily adjusted for training producing unreliable prediction at the individual level. In conclusion, we hope that the present perspective will be helpful in improving research on training interventions in clinical practice.

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Notes

1. Although it can be argued that behavior may also change the relative strength between impulsive and reflective processes in the prediction of specific behaviors, these changes appear to be qualitatively more profound due to the relatively strong neuroadaptations evoked by psychoactive substances. However, this does not imply that findings from the psychology of motivated behaviors do not apply to addictions (cf. Kopetz, Lejuez, Wiers, & Kruglanski, in press).
2. From the dual-process perspective, impulsivity can be defined as a general tendency to react impulsively rather than reflectively (Wiers, Ames, Hofmann, Krank, & Stacy, 2010).
3. Note that there are more positive evaluations regarding the usefulness of cue exposure in alcoholism (e.g., Havermans & Jansen, 2003; Monti & MacKillop, 2007).
4. The original AAT (Rinck & Becker, 2007, Study 1) uses a block format, in which participants approach the category of interest (spiders) in one block and avoid it in another block (relevant feature instructions, similar to the stimulus response compatibility). The alcohol AAT uses a more indirect assessment strategy, in which participants react to another feature (picture format) and the tendency to approach or avoid alcohol is derived from the difference in reaction times as a function of pulling versus pushing.
5. The difference between the two experimental conditions was that in one experimental condition explicit instruction was given to respond with a push movement to alcohol pictures, whereas in the other experimental condition, patients responded to the format of the picture, which made them push in response to alcohol pictures and pull in response to nonalcohol pictures (indirect instruction). There were no significant differences between these two experimental groups in any of the outcomes.
6. Note that traditional interventions could also influence the interplay between impulsive and reflective processes, with some work in anxiety (Teachman, Cody, & Clerkin, 2010; Teachman, Marker, & Smith-Janik, 2008). The few studies in addiction show mixed findings: A brief cognitive intervention ("expectancy challenge") found little effect on impulsive processes as compared with reflective processes (Wiers, van de Luitgaarden, van den Wildenberg, & Smulders, 2005). Another study showed no effects on impulsive processes of a brief motivational intervention in adolescents (Thush et al., 2009). More promising, a recent study reported effects of mindfulness meditation on automatic associations and drinking behavior: In the mindfulness condition, automatic associations no longer predicted heavy drinking as they continued to do in the control condition (Ostafin, Bauer, & Myxter, 2012). There are also indications that entirely different interventions, such as physical exercise, may reduce an attentional bias for smoking (Van Rensburg, Taylor, & Hodgson, 2009).
7. A recent coverage of CBM in the *Economist* had the title "Therapist-Free Therapy: Cognitive-Bias Modification May Put the Psychiatrist's Couch out of Business" (2011), which is clearly not appropriate for the present state of affairs in addiction research, for which all positive findings of CBM have been found in addition to "treatment as usual."
8. In clinical studies, patients and staff usually do not like the idea that only half of patients get the real training. When more training varieties are tested in a within-subjects design, the percentage of patients who receive at least one version of a training of which positive effects are expected can be increased (two training modalities with a 50% chance of receiving placebo reduce "overall placebo" chance to 25%, three to 12.5%).

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