Proposed Model of the Neurobiological Mechanisms Underlying Psychosocial Alcohol Interventions: The Example of Motivational Interviewing*

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ABSTRACT. Objective: Despite the prevalence and profound consequences of alcohol use disorders, psychosocial alcohol interventions have widely varying outcomes. The range of behavior following psychosocial alcohol treatment indicates the need to gain a better understanding of active ingredients and how they may operate. Although this is an area of great interest, at this time there is a limited understanding of how in-session behaviors may catalyze changes in the brain and subsequent alcohol use behavior. Thus, in this review, we aim to identify the neurobiological routes through which psychosocial alcohol interventions may lead to post-session behavior change as well as offer an approach to conceptualize and evaluate these translational relationships. **Method:** PubMed and PsycINFO searches identified studies that successfully integrated functional magnetic resonance imaging and psychosocial interventions. **Results:** Based on this research, we identified potential neurobiological substrates through which behavioral alcohol interventions may initiate and sustain behavior change. In addition, we proposed a testable model linking within-session active ingredients to outside-of-session behavior change. **Conclusions:** Through this review, we present a testable translational model. Additionally, we illustrate how the proposed model can help facilitate empirical evaluations of psychotherapeutic factors and their underlying neural mechanisms, both in the context of motivational interviewing and in the treatment of alcohol use disorders. (*J. Stud. Alcohol Drugs, 72,* 903–916, 2011)

IN THE UNITED STATES, APPROXIMATELY 17% of men and 8% of women meet alcohol dependence criteria at some point during their lives (Hasin et al., 2007). Problem drinking results in significant morbidity and mortality, with 3.8% of global deaths attributable to alcohol use (e.g., Rehm et al., 2009). Although many interventions exist, psychosocial treatments are the most frequently used (Substance Abuse and Mental Health Services Administration, 2009). Yet, psychosocial treatments have widely varying outcomes (e.g., 32%–96% days abstinent at 1-year follow-up; Anton et al., 2006; Project MATCH Research Group, 1998; UKATT Research Team, 2005). The range of treatment outcomes indicates the need to better understand how psychosocial alcohol interventions may operate.

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At this time, novel approaches are needed to elucidate what may be happening during effective and ineffective psychosocial interventions. Several researchers have advocated for translational efforts integrating basic biological approaches, such as neuroimaging, to the investigation of psychotherapy (Brewer et al., 2010; Etkin et al., 2005; Frewen et al., 2008; Goldstein et al., 2009; Hutchison, 2010). Integrative, or translational, efforts may help improve our understanding of psychosocial interventions because they offer an innovative tool to connect changes in clients' clinical symptoms (post-session drinking behavior) to basic biological (brain changes) that may underlie clients' post-session alcohol use.

Advancing a translational model with motivational interviewing

Although this is an area of great interest, only a handful of empirical studies link neurobiological mechanisms with psychosocial treatment outcomes. Moreover, few include theoretical or conceptual models to guide these investigations. Thus, in this review, we aim to contribute to the extant literature by presenting the neurobiological routes through which a psychosocial intervention may lead to post-session behavior change as well as by proposing a testable model to facilitate translational evaluations.

We chose motivational interviewing (MI; Miller and Rollnick, 2002) as the example psychosocial intervention in

this model for several reasons. First, the theoretical mediators of MI are well specified. MI seeks to promote positive post-session behavior change through eliciting client speech in favor of change, a construct that can be, and has been, objectively measured (i.e., change talk). Second, in MI, therapist behaviors have been found to successfully lead to clients' generation of change talk (Glynn and Moyers, 2010; Moyers and Martin, 2006; Moyers et al., 2009). Third, MI is one of the most widely studied and widely disseminated interventions for substance use disorders (SUDs; e.g., Hodgins, 2000; Marlatt and Witkiewitz, 2005), and research on the neurobiological mechanisms underlying the success of MI may have important clinical and research implications. Fourth, neural activation patterns associated with client language can be, and have been, empirically examined in MI (Feldstein Ewing et al., 2011).

Neurobiological correlates of psychosocial interventions

Although other approaches have been used to study neurobiological correlates (e.g., positron emission tomography; Brody et al., 2001; Goldapple et al., 2004), the majority have employed functional magnetic resonance imaging (fMRI), leading to this review's focus on fMRI. fMRI is an evaluation of blood oxygen level–dependent (BOLD) response, assumed to reflect changes in the activity of neurons in the brain. Although fMRI has numerous benefits, it also has several limitations (for a review, see Logothetis, 2008). As two examples, fMRI sessions have a restricted duration, thereby hampering the administration of psychosocial treatment sessions in the scanner (which would additionally introduce other variables into the scan session). fMRI also requires a certain number of trials (repetitions of the event of interest) to produce an observable and reliable effect.

Despite these considerations, several studies have successfully integrated evaluations of fMRI and psychosocial interventions to investigate a number of behavioral disorders. Specifically, across these studies, the selected tasks captured specific cognitive processing mechanisms in the behavioral treatment of depression (Dichter et al., 2010; Siegle et al., 2006), borderline personality disorder (Schnell and Herpertz, 2007), eating disorders (Vocks et al., 2010), obsessive–compulsive disorder (Nakao et al., 2005), posttraumatic stress disorder (Bryant et al., 2008; Felmingham et al., 2007), and specific phobias (Paquette et al., 2003). Collectively, changes in these processes, as indicated by behavior and specific brain activation during the task, predicted individual differences in pathology-related symptoms and treatment outcome. A detailed analysis of each of these paradigms is not possible within the context of this review; however, Table 1 provides a summary of the selected target behaviors, sample characteristics, study designs, and cognitive tasks from each evaluation.

Across the treatment of the various target behaviors (e.g., borderline personality disorder, anorexia nervosa, specific phobia, depression), BOLD activation in the insula, the parahippocampal gyrus (PHG), the anterior cingulate cortex (ACC), the posterior cingulate cortex (PCC)/precuneus areas, and the prefrontal cortex (PFC; specifically, the orbitofrontal cortex [OFC]) were related to successful treatment outcomes. These findings are compelling, as these areas are involved in memory encoding and retrieval (e.g., PHG; Milner et al., 1997; Stern et al., 1996), metacognition and self-regulation (e.g., PFC; Eslinger et al., 1992; Fleming et al., 2010; Steele and Lawrie, 2004), attention and emotional experience processing (e.g., insula; Naqvi and Bechara, 2010; Phan et al., 2002), monitoring of emotional salience (e.g., ACC; Bush et al., 2000; Mohanty et al., 2007; Vogt et al., 1992), stimuli and memory processing, consciousness, self-awareness, and episodic memory (e.g., PCC/precuneus areas; Andreasen et al., 1995; Fink et al., 1996; Kjaer et al., 2002; Pearson et al., 2011; Tomasi and Volkow, 2010; Viard et al., 2011).

In terms of SUDs, although many promising evaluations are under way, we found only five published studies assessing psychosocial treatment in the context of fMRI. Of these, three focused on amphetamine/cocaine dependence (e.g., Brewer et al., 2008; Kosten et al., 2006; Paulus et al., 2005) and two focused on alcohol use disorders (Feldstein Ewing et al., 2011; Schneider et al., 2001; see Table 1). In contrast to the other translational studies, many of the SUD studies used multimodal interventions (e.g., inclusion of urine screens, breath alcohol analysis, and/or pharmacological interventions in addition to the selected behavioral intervention) with designs that precluded an isolated evaluation of the psychosocial intervention or its active ingredients. In response to a variety of cognitive tasks (e.g., Stroop interference, alcohol cue exposure, two-choice prediction; Table 1), successful treatment response was associated with BOLD activation in the insula, PFC, and striatum (caudate/putamen), areas implicated in reward processing in SUD studies (e.g., Koob and Volkow, 2010).

The two alcohol studies examined the BOLD response to alcohol cues following psychosocial treatment (Feldstein Ewing et al., 2011; Schneider et al., 2001). Specifically, in the study by Schneider et al. (2001), 10 adults with alcohol dependence received a combined intervention including cognitive behavioral group therapy, doxepin (150 mg/day), and daily breath alcohol testing during a 3-week psychiatric day program. With an olfactory fMRI cue-exposure paradigm, the authors found that pre-intervention areas of activation (amygdala and cerebellum) were no longer evident at the post-intervention scan. The authors speculated that cue-elicited craving might involve a conditioned emotional reaction mediated by the amygdala and a learned memory association mediated by the cerebellum. Contrasting with patterns observed in prior studies (e.g., Filbey et al., 2008a;

TABLE 1. Psychosocial intervention studies using functional magnetic resonance imaging (fMRI) techniques

Study	Intervention target	Intervention approach	N[a]	fMRI task(s)	Brain areas of change[b]
Brewer et al. (2008)	Cocaine dependence	Individual plus group sessions (TAU), urine screens or TAU with computer-assisted CBT, urine screens, or CBT, medication (placebo or disulfiram), and/or contingency management	20	Event-related Stroop color-word interference	Putamen (R), posterior cingulate cortex, including superior parietal lobule (L), ventromedial prefrontal cortex (PFC), including medial frontal gyrus/ orbitofrontal cortex (OFC), ventral portion of the superior frontal gyrus, and ventral anterior cingulate cortex (ACC) (L), dorsolateral prefrontal cortex (dlPFC) (L)
Bryant et al. (2008)	Posttraumatic stress disorder	CBT (education, imaginal exposure, cognitive restructuring, relapse prevention) (+ antidepressant medication, $n = 6$)	14	Neutral and fearful faces	Dorsal ACC (bilateral), rostral/ventral ACC (bilateral), amygdala (bilateral)
Dichter et al. (2010)	Major depressive disorder	Brief behavioral activation therapy for depression	12	Forced-choice reaction time	Inferior frontal gyrus (R), precentral gyrus (L), paracingulate gyrus (R), OFC (R), frontal pole (R), precentral gyrus (bilateral), postcentral gyrus (bilateral), Heschl's gyrus (L), occipital pole (L), temporal gyrus (bilateral), supramarginal gyrus (R)
Feldstein Ewing et al. (2011)	Alcohol dependence	Motivational interviewing	10	Gustatory alcohol cue-exposure	Precentral gyrus (R), postcentral gyrus (L), superior temporal gyrus (R), OFC, nucleus accumbens, insula, caudate, putamen
Felmingham et al. (2007)	Posttraumatic stress disorder	CBT (imaginal exposure + cognitive restructuring) (+ SSRIs, $n = 2$)	8	Neutral and fearful faces	Rostral ACC (bilateral), middle temporal gyrus (L), inferior frontal gyrus (R), parietotemporal gyrus (L), hippocampus (R), postcentral gyrus (R), middle temporal gyrus (R), superior temporal gyrus (L), amygdala (bilateral)
Kosten et al. (2005)	Cocaine dependence	CBT, urine screening, sertraline (20 mg/daily)	33	Visual cocaine cue-exposure	Precentral gyrus (L), posterior cingulate (L), superior temporal gyrus (R), lingual gyrus (R), inferior occipital gyrus (R)
Nakao et al. (2005)	Obsessive–compulsive disorder	Behavior therapy + home practice vs. pharmacotherapy (50 mg fluvoxamine/daily)	10	Stroop task, symptom provocation task	dlPFC (R), frontal cortex (bilateral), putamen (bilateral), temporal cortex (bilateral), parietal cortex (bilateral), occipital cortex (L), cerebellum (bilateral), ACC (bilateral), thalamus (bilateral), hippocampus (R)

Continued

TABLE 1. *Continued*

Study	Intervention target	Intervention approach	N[a]	fMRI task(s)	Brain areas of change[b]
Paquette et al. (2003)	Specific phobia (spiders)	CBT (group-based exposure therapy with homework)	12	Visual spider cue-exposure	Middle occipital gyrus (bilateral), superior parietal lobule (bilateral), inferior occipital gyrus (L), fusiform gyrus (L), inferior frontal gyrus (R), dlPFC (R), parahippocampal gyrus (PHG) (R)
Paulus et al. (2005)	Amphetamine dependence	Inpatient alcohol and drug treatment, based on CBT model, including 12-step, daily group sessions, education, random drug and alcohol testing	40	Two-choice prediction	Insula (R), inferior parietal lobule (R), middle temporal gyrus (R), middle occipital gyrus (R), striatum (L), inferior/middle frontal gyrus (R), posterior cingulate (R), cingulate gyrus (L)
Schienle et al. (2007)	Specific phobia (spiders)	CBT (exposure group) vs. wait list	28	Spider, fear, disgust, and neutral scene presentation	Medial orbitofrontal cortex (R), insula (bilateral), PHG (L), amygdala (R)
Schneider et al. (2001)	Alcohol dependence	Inpatient day clinic, including CBT group therapy, breath-alcohol monitoring, doxepin (150 mg/daily)	10	Olfactory alcohol cue-exposure	Occipital cortex (R), insula (R), superior temporal sulcus (L), amygdala/ hippocampus (R), cerebellum (L)
Schnell and Herpertz (2007)	Borderline personality disorder	Dialetical behavioral therapy	6	Passive viewing paradigm using the Affective Picture System	ACG (bilateral), precentral gyrus (bilateral), paracentral lobule (R), middle frontal gyrus (R), insula (L), PHG (R), superior temporal gyrus (bilateral), middle temporal gyrus (bilateral), transverse temporal gyrus (R), posterior cingulate cortex (R), cuneus (bilateral), precuneus (R), putamen (R)
Siegel et al. (2006)	Major depressive disorder	CBT	14	Visual emotional word cue-exposure	Amygdala, subgenual cingulate cortex
Straube et al. (2003)	Specific phobia (spiders)	CBT (exposure therapy group) vs. wait list	28	Visual spider cue-exposure	Insula (bilateral), ACC (bilateral), thalamus (bilateral), precuneus (bilateral)
Vocks et al. (2010)	Anorexia nervosa	Body image therapy	5	Visual blocked photograph presentation	Middle temporal gyrus (R), precuneus (L), inferior frontal gyrus (R), superior frontal gyrus (R), posterior cingulate gyrus (L), inferior parietal lobule (bilateral), fusiform gyrus (L), PHG (R)

Notes: TAU = treatment as usual; CBT = cognitive–behavioral therapy; SSRI = selective serotonin reuptake inhibitor. [a]Because not all studies included controls, only the sample size for the treatment groups was included; [b]please note that the tasks and approach vary by study.

2008b; Naqvi et al., 2007), significant insula activation emerged during the post-intervention scan. With the insula's association with limbic systems (e.g., visceral functions, olfaction, taste, emotion), the authors posited that this activation might reflect cortical influence in alcohol-related cue processing. It is also possible that the observed insular activation might have reflected a basic interoceptive process (e.g., smelling something).

In the second alcohol study, the authors examined client language (change talk and counter change talk) with a gustatory fMRI cue-exposure paradigm (Feldstein Ewing et al., 2011). In this study, 10 adults with alcohol dependence completed one MI session and returned 1 week later to complete an fMRI scan. During the scan, participants were pseudorandomly presented with change talk and counter change talk statements derived from their MI session, immediately followed by pseudorandom presentations of alcohol or control taste cues. Following presentation of the statements in favor of sustaining their drinking (counter change talk), the pattern of brain response to the alcohol cues paralleled that of alcohol-dependent adults (Filbey et al., 2008a, 2008b) with significant reward activation (e.g., anterior insula, posterior insula, anterior cingulate gyrus [ACG], OFC, ventral striatum, dorsal striatum). Consonant with the work of Schneider and colleagues (2001), after presentation of the statements in favor of changing their drinking (change talk), reward area activation did not emerge in response to the alcohol cues. While the authors posited that change talk significantly dampened reward area activation, it is equally possible that taste cues simply did not activate this area following change talk.

Despite these significant advances in the field of translational research, a testable model to evaluate potential relationships between these important brain areas, their within-session function, and their role in post-session behavior remains absent.

What might effective psychosocial alcohol interventions "do" in the brain? The proposed model

As denoted by Moyers and colleagues (2009), effective psychotherapy is unlikely to be limited to within-session time. Rather, it is likely to contain both within-session and outside-of-session processes (see Figure 1). We therefore postulate that certain cognitive processes are necessary for within-session MI experiences to transpire into real-world (outside-of-session) behavior change. Based on the literature, we have consolidated these regions into networks for theoretical and empirical purposes. Yet, as demonstrated in the functional connectivity literature (e.g., executive net-

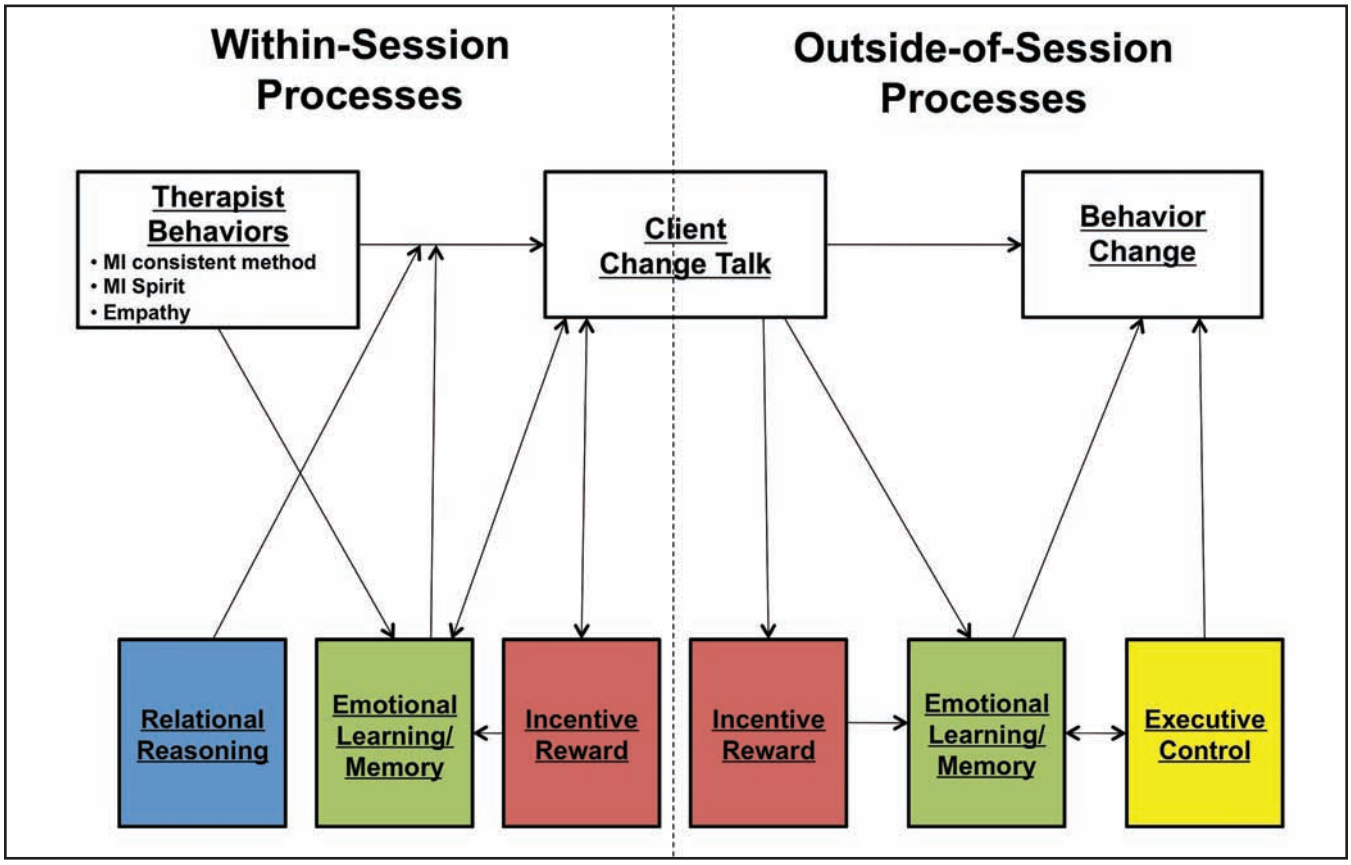

FIGURE 1. The proposed neurobehavioral model

work vs. default mode network; for a review, see Drevets et al., 2008; Seeley et al., 2007; Tomasi and Volkow, 2011), these areas are proximally located and clearly interconnected (Figure 2).

Within-session processes

Paralleling Miller and Rose's (2009) model, several cognitive, emotional, and motivational shifts are theorized to occur during an MI session. For example, it is postulated that interacting with open and non-judgmental therapists may reduce the clients' fear and anxiety responses (e.g., Tillfors et al., 2001), leaving the clients better able to contemplate their use of alcohol and its influence on their lives. Similarly, it has been suggested that with the freedom of a judgment-free atmosphere, clients may have a unique opportunity to consider their reasons for reducing and/or sustaining their alcohol use (Feldstein Ewing et al., in press), as well as to verbalize the discrepancy between their current alcohol use and longer-term life goals (e.g., Apodaca and Longabaugh, 2009).

In terms of candidates for within-session active ingredients, in contrast with other putative mechanisms (Apodaca and Longabaugh, 2009; Longabaugh and Wirtz, 2001), change talk (client statements in favor of change) has gained the most consistent support for its relationship with substance use outcomes across MI (Amrhein et al., 2003; Apodaca and Longabaugh, 2009; Baer et al., 2008; Bertholet et al., 2010; Daeppen et al., 2010; Gaume et al., 2008; Martin et al., 2011; Moyers et al., 2007, 2009; Strang and McCambridge, 2004; Vader et al., 2010; Walker et al., 2011), as well as across other psychosocial interventions (Aharonovich et al., 2008; Hodgins et al., 2009; Karno et al., 2010; Moyers et al., 2007). Together, these data suggest that change talk is the most relevant target for mechanism research in MI (Miller and Rose, 2009), and it therefore serves as the focus of this review.

Specifically, it is theorized that through repeatedly giving voice to reasons for change (i.e., change talk), clients have to think about, as well as hear themselves state, how alcohol use has been disruptive to their lives (Amrhein et al., 2003; Miller and Rollnick, 2002). Data indicate that when these statements are affirmed and, importantly, are reflected by an effective therapist, clients generate more change talk (Glynn and Moyers, 2010; Moyers et al., 2009). Consistent with clinical approaches (Miller and Rollnick, 2002) and empirical research (Amrhein et al., 2003), once the client has expressed substantial change talk, the therapist explores plans for changing, relying on the client's expertise for what may be possible in his or her world. Through relying on clients, autonomy and self-efficacy are supported, empowering the clients to feel like they can execute a change should they choose to do so (e.g., LaChance et al., 2009; Moyers et al., 2005; Schmiege et al., 2009).

We posit that three networks are important for the within-session success of psychosocial treatment: the relational reasoning network, the emotional learning/memory (ELM) network, and the incentive reward network. Although some research purports that the executive control network subsumes the cognition and behavior within the relational reasoning and ELM networks, we believe that the skills and cognitions in these two networks are important enough to the function of psychotherapy to warrant consideration in their own right.

1. The relational reasoning network (within session)

Across the MI theoretical literature, the importance of exploring ambivalence is emphasized; consequently, eliciting and amplifying ambivalence is one of the main clinical goals of MI interventionists (Miller and Rollnick, 2002). However, at the most basic level, people must be able to contemplate two situations simultaneously to discuss their ambivalence. Relational reasoning is one component of abstract reasoning that enables the simultaneous consideration of interrelated dimensions and situations (Christoff et al., 2001).

Specifically, for MI to be effective within session, we believe that the clients must be able to simultaneously consider at least two of the following: the rewarding aspects of their alcohol use, their longer-term goals, the relationship between their alcohol use and longer-term goals, the consequences of reducing their drinking (particularly in pro-use contexts), the situations that might pose the highest risk for use, and potential strategies to reduce alcohol use in those (or other) situations. Certain prefrontal cortical structures, such as the rostrolateral PFC (rlPFC) and dorsolateral prefrontal cortex (dlPFC; e.g., Christoff et al., 2001; Crone et al., 2009), are important in this type of high-level reasoning (Goldstein et al., 2009). We believe this high-level reasoning may moderate the relationship between skillful therapist behaviors and client change talk.

2. The emotional learning/memory network (within session)

We postulate that for MI to be effective within session, clients have to be able to access their stories. We consider the ELM network to be the brain-based representation of the client's story. This network encapsulates a person's consciousness, self-representation, episodic memory (memory for personally experienced events; Tulving, 1993, 2002), and their ability to access, retrieve, and communicate these thoughts. We believe that within-session changes in the ELM network may mediate the relationship between skillful therapist behaviors and client change talk.

As elucidated in the translational literature, key areas in the ELM network include the PHG and the PCC/precuneus areas. The PHG has been implicated in the contextual fear memory that drives pathological avoidance behaviors

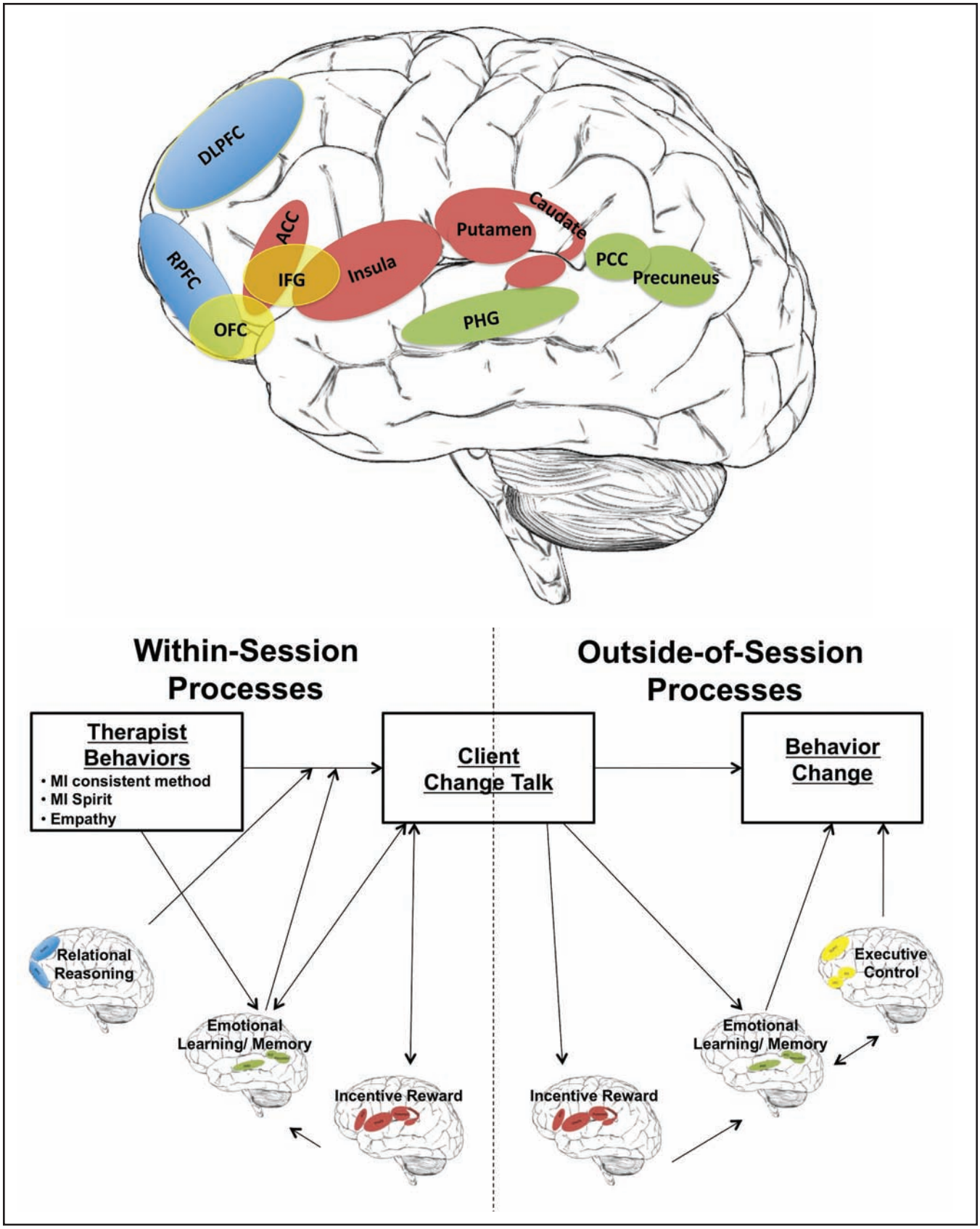

FIGURE 2. Neural circuitry associated with the proposed model; MI = motivational interviewing

(Paquette et al., 2003). Indicating its potential role in psychosocial treatment response, the PHG has demonstrated differential activation following various psychosocial interventions targeting various problem behaviors (Schienle et al., 2007; Schnell and Herpertz, 2007; Straube et al., 2006; Vocks et al., 2010), but it has been relatively absent from the SUD literature.

Similarly, the PCC/precuneus areas are likely to be important (Vocks et al., 2010). Anatomically connected, the PCC and precuneus are considered to be structural and functional hubs, connected to the PFC and striatum (Greicius et al., 2003), cuneus, calcarine cortex, paracentral lobule, cingulate, superior temporal sulcus, and inferior and superior parietal cortices (Dosenbach et al., 2010; Hagmann et al., 2008; Tomasi and Volkow, 2010). The PCC/precuneus areas are involved in human awareness, emotional and episodic memory, self-reference in memory retrieval, self-reflection, and consciousness (Legrand and Ruby, 2009; Northoff and Bermpohl, 2004).

3. The incentive reward network (within session)

Estimating the salience and potential effects of alcohol is theorized to influence a person's belief about the role, importance, and anticipated benefits of drinking as well as their communication about the benefits and consequences of their drinking (their change talk). We believe that incentive reward, which includes the expectation of the rewarding aspects of alcohol use, is likely to influence the within-session representation of a person's story (ELM network). Additionally, as supported by preliminary research regarding client language and reward network activation (Feldstein Ewing et al., 2011), we believe that within-session incentive reward functioning is likely to be correlated with change talk.

The key brain areas in the incentive reward network include the striatum (the putamen/caudate), ACC, globus pallidus, and insula (Hutchison, 2010; Koob and Volkow, 2010). Highly pertinent to SUD treatment is the striatum, as it appears to have a strong role in processing the salience of reward stimuli (Schnell and Herpertz, 2007; Straube et al., 2006; Zink et al., 2004).

The ACC also appears to play a role in processing high-valence emotional experiences (Nakao et al., 2005; Paulus et al., 2005; Schnell and Herpertz, 2007; Straube et al., 2006) and reward-based cognitive processes (Filbey et al., 2009). Translational studies have found changes in ACC/ACG activation in response to a variety of cognitive tasks following psychosocial treatment (e.g., Feldstein Ewing et al., 2011; Paulus et al., 2005; Straube et al., 2006; see Table 1).

Finally, the insula has been found to play a role in the perception of emotional experiences (Phan et al., 2002), particularly those related to substance-related cues (Nakao et al., 2005; Paulus et al., 2005; Schneider et al., 2001; Schnell and Herpertz, 2007; Straube et al., 2006). In fact, the insula has been implicated in substance-related decision making, but the debate continues as to how it influences SUDs (Naqvi and Bechara, 2010). Recent studies examining the role of emotional experience, awareness, insight (Goldstein et al., 2009; Naqvi and Bechara, 2010), and cognitive dissonance (van Veen et al., 2009) indicate that the insula might influence treatment response across intervention approaches.

Outside-of-session processes

Although empirical data have demonstrated that within-session change talk mediates the relationship between therapist behaviors and post-session substance use (Moyers et al., 2007, 2009), the neurocognitive factors that may influence this relationship outside of the therapist's office are less well understood. Following an MI session, clients return home. If they have significant use histories, their living and social contexts may be supportive of their alcohol use, meaning that clients may be presented with alcohol use opportunities regardless of their intentions to change. In the high-risk setting of being faced with alcohol and having to make a decision about drinking, several networks are likely to be activated. First, we posit that the incentive reward network prepotently identifies the anticipated reward of drinking. Second, following that appraisal, we suggest that the ELM network facilitates clients' ability to access and reflect on their drinking narrative—their reasons for (and for not) drinking. Finally, based on clients' ability to inhibit their impulses, we believe that these reflections may facilitate either their successful inhibition of the impulse to use or the unsuccessful navigation of this risk. We suggest that the following networks are integral to the relationship between within-session and outside-of-session behaviors: the incentive reward network, the ELM network, and the executive control network (Figure 1).

1. The incentive reward network (outside of session)

It is theorized that anticipating the benefits of drinking may modulate intervention efficacy (Goldstein et al., 2009). In terms of how this outside-of-session incentive reward might catalyze post-session behavior change, we suggest that change talk and the neurocognitive changes associated with change talk are likely to influence post-intervention incentive reward functioning (as measured immediately after the MI session), which may subsequently influence real-world behavior change. Specifically, after the session, it may be more difficult for people who experience alcohol use as highly positive to not want to drink. However, recollecting their discussion (their change talk) might make the prospect of drinking seem a little less rewarding. Moreover, this es-

timation might influence their own story/self-representation (as accessed by the ELM network), which might affect their decision to drink. As detailed above, the key brain areas in the incentive reward network include the striatum (the putamen/caudate), ACC, globus pallidus, and insula (Hutchison, 2010; Koob and Volkow, 2010).

2. The emotional learning/memory network (outside of session)

We believe that the most important network in the relationship between a client's within-session speech and post-session behavior is the outside-of-session ELM network (as measured following the MI session). As described above, this network encapsulates aspects of emotional, self-referential, episodic, and working memory. We suggest that the ELM network enables clients to successfully retrieve their stories (both memory about use experiences as well as the stories that emerged during therapy) and hold those thoughts in working memory (Vollstädt-Klein et al., 2010) as a decision about whether to drink is made. As one of many possible examples of how the ELM network might function, we believe that the ELM network may be activated when a client is handed a drink. In this scenario, successful activation of the ELM network would include accessing one's memory of drinking, reflecting on the reasons for and/or against drinking, and engaging the executive control network (described below) to successfully refuse an offered drink. As detailed above, two areas are key to this network: the PHG and the PCC/precuneus areas.

3. The executive control network (outside of session)

Prior studies have indicated the involvement of the executive control network in decision making (Nigg et al., 2006; Wiers et al., 2007). To this end, individuals with impaired response inhibition have been found to show greater alcohol-related problems, use a greater number of substances, and display greater comorbid substance use (Bechara, 2005; Goldstein and Volkow, 2002; Volkow and Fowler, 2000). In the high-risk situation of being presented with a drink, we believe that this network is the last crucial cognitive step taken when individuals make a decision about their use—to proceed and drink or to take actions against use.

The executive control network includes the OFC, the inferior frontal gyrus, and the dlPFC. These areas have been found to be important in reflection, control over impulsive decisions, and urge to use (Ernst et al., 2002; Ernst and Paulus, 2005). The OFC also plays a role in coding and analyzing information that carries motivational, emotive, evaluative, and survival significance (Dichter et al., 2010; Ernst and Paulus, 2005; Nakao et al., 2005; Volkow et al., 2002). Furthermore, studies have found significant changes in BOLD activation in the OFC in response to a variety of cognitive tasks following psychosocial interventions (e.g., Paulus et al., 2005; Schienle et al., 2007; Vocks et al., 2010; see Table 1).

Structurally connected with the OFC, the dlPFC is involved in top-down control, actively holding representations of emotional objects and other task-relevant information in awareness (e.g., Dosenbach et al., 2008; Naqvi and Bechara, 2010). Prior studies have suggested that effective psychosocial interventions may modulate dlPFC activation (Hutchison, 2010; Wiers et al., 2007).

Finally, despite good intentions, impulsivity can quickly compromise a person's ability to modify behavior in an emotionally charged context. The inferior frontal gyrus (IFG) plays a role in planfulness and impulsivity (Hampshire et al., 2010), which may be relevant to psychosocial treatment outcome (Hutchison, 2010).

Approaching empirical evaluation of the proposed translational relationships

To determine how the broader conceptual hypotheses presented within this review may connect to the specific component processes of treatment and change, we offer a few suggestions to guide the evaluation of the proposed translational model. Following Frewen and colleagues (2008), we recommend beginning with the following foundational steps: conducting resting-state analyses on all participants, using functional neuroimaging tasks with demonstrated support to assess the posited constructs and regions of interest, using empirically supported clinical measures, and randomizing participants to treatment conditions. Adherence to these criteria will form a solid framework from which to launch translational evaluations. Incorporating non-treatment control groups and/or wait-list control groups can further strengthen empirical designs. Finally, in terms of grounding research in methodology that has survived empirical scrutiny, a number of paradigms have been established to examine psychosocial interventions in the context of fMRI. Table 1 serves as an overview of target behaviors, fMRI tasks, design approaches, and relevant activation in specific brain areas.

With respect to the proposed model, to evaluate within-session behaviors (e.g., therapist MI-consistent behaviors, client change talk), we recommend using an empirically supported behavioral coding system, such as the Sequential Code for Observing Process Exchanges (SCOPE; Moyers and Martin, 2006; Moyers et al., 2009). For example, to evaluate the potential role of relational reasoning within session (Figure 1), participants could complete an fMRI-based relational reasoning task (e.g., Raven's Progressive Matrices; Christoff et al., 2001; Crone et al., 2009) immediately before receiving an MI session. With these data, researchers could evaluate whether the neurocognitive task results (Raven's Progressive Matrices data) moderate the relationship between therapist behavior and client change

talk (SCOPE scores). Similarly, to evaluate whether within-session ELM mediates the relationship between therapist behaviors and client change talk (Figure 1), an fMRI-based personal story task (e.g., past period task; Viard et al., 2011) could be implemented. As evaluating a mediator requires observing a change in a variable, the past period task would have to be administered twice (we recommend once before the session and once during the session—approximately midway through). These measurements would provide data for determining whether a change in ELM network functioning affects within-session client change talk, particularly during the important latter part of the session (Amrhein et al., 2003; Bertholet et al., 2010). Additionally, to evaluate the within-session relationships between incentive reward and ELM and/or change talk (Figure 1), an fMRI-based incentive task such as the monetary incentive delay task (Knutson et al., 2000) could be given during the same timeline as the ELM task (e.g., mid-MI session). Finally, to determine how the within-session change talk might influence outside-of-session behavior (Figure 1), participants could complete a scanning session immediately after the MI session. This session might include the monetary incentive delay task (Knutson et al., 2000) to evaluate the incentive reward network, the past period task (Viard et al., 2011) to access the ELM network, and any empirically supported Go/NoGo task to assess the executive control network. Participants could then return for a follow-up assessment of their alcohol use behavior (e.g., 1 month after the MI/post-MI scan session) to yield an empirical evaluation of their behavior change.

Relevance of the proposed integrative approach

Treatment outcome research. There are several advantages to integrating neurobiological variables into psychosocial treatment outcome research. This approach facilitates the study of novel, translational phenotypes that are proximal to underlying biological factors, which may be important to alcohol use disorder risk and psychosocial treatment success (Brewer et al., 2008; Hutchison, 2008). As such, this approach is consistent with the intermediate phenotype or endophenotype approach in neuropsychiatric research (Carrig et al., 2009; Etkin et al., 2005). In addition, this approach enables movement beyond self-report measures (Moyers et al., 2009), which can be far removed from biological mechanisms and may be susceptible to measurement error.

Implications for the treatment provider. Although theoretically and quantitatively compelling to the empirical researcher, models of how and why the brain responds can feel distant to the clinician. As clinical researchers, we believe that the proposed model is highly relevant for treatment providers. Gaining a better understanding of what might be happening *within the brain* during and after psychosocial interventions is crucial for creating and refining treatments so that they are more effective for our clients. For example, following the work of Goldstein et al. (2009) and Potenza and colleagues (2011), if relational reasoning and/or executive control are truly sticking points in psychosocial intervention efficacy (e.g., if people who have impairments in relational reasoning and/or executive control do not respond as well to psychosocial interventions like MI), then we will know three things. First, that it is important to assess people on these neurocognitive constructs before treatment (e.g., through brief neuropsychological screening). Second, that a different intervention approach may be required. For example, a person might need a more tailored treatment, such as a behavioral skills therapy, grounded in the rehearsal of critical skills. Third, this approach might contribute to the specificity in detecting cognitive processing deficits, which could guide the determination and implementation of innovative cognitive and behavioral remediation strategies to strengthen areas of neurocognitive functioning (e.g., memory and planning) and subsequent treatment outcome (e.g., Potenza et al., 2011). Similarly, data from this model may also specify whether change talk should indeed be the targeted active ingredient, or if other active ingredients (e.g., motivation, autonomy) may instead drive brain changes during psychosocial interventions. Ultimately, we aim for this model to offer a foundation to help researchers evaluate critical aspects of psychotherapy to yield clear, practical data to guide the refinement of psychosocial interventions.

Conclusions and future directions

Translational research is an area receiving great attention (Bechara, 2005; Frewen et al., 2008). The proposed model offers a working paradigm aimed at facilitating empirical evaluations of psychotherapeutic factors and their underlying neural mechanisms. Importantly, the psychosocial literature has only progressed so far in yielding an understanding of how and why psychosocial interventions like MI are effective (e.g., Miller and Rose, 2009). Translational research offers an innovative avenue for approaching and improving treatment mechanism research, through connecting therapist behaviors to proposed mechanisms of change, and these proposed mechanisms of change to client behavioral outcomes within the same sample. Like our foundational models (e.g., Hutchison, 2010; Miller and Rose, 2009), the proposed model is sufficiently complex that concomitant evaluation of all components might prove challenging at this time. However, the goal of this model is to organize a foundation to evaluate component relationships, from which resultant empirical data can guide further modification and refinement.

In this review, several considerations deserve attention. To begin, we were able to provide only a handful of examples of how the broader conceptual hypotheses may connect to the specific component processes of treatment and change (and attendant design implications); we encourage others to generate and evaluate additional examples and analytic

approaches. Furthermore, there are several limitations to fMRI-based approaches (e.g., a lack of specificity). However, collecting and comparing outcomes across neuroimaging studies yields areas of convergence and divergence, which is highly useful to informing our understanding of basic neurobiological processes. Additionally, although we referenced the anatomical and functional relationships that exist within this model, an examination of how these regions modulate one another would be a beneficial future step (e.g., Drevets et al., 2008; Seeley et al., 2007; Tomasi and Volkow, 2011). Furthermore, although we highlight some potential relationships between SUDs and behavior change, it is important to note that the neural mechanisms of behavior change may very well be independent from the neural mechanisms of substance abuse and dependence. We therefore encourage examination of all of the many routes toward behavior change. Moreover, one of the key active ingredients in the proposed model is change talk. Despite its promise as an active mechanism in MI research (Miller and Rose, 2009), within-session client speech accounts for a modest amount of variance in outcomes (Moyers et al., 2009). For this reason, empirical evaluations of what change talk is and how it may function is imperative. Ultimately, this could also help determine if change talk is indeed what we think it is, or rather, if it is an indicator reflecting some other mechanism (e.g., change in motivation). In addition, as there is not likely to be a single mechanism for change (Kazdin and Nock, 2003; Longabaugh, 2007), it is important to consider other pre-morbid (e.g., Stanton, 2010), brain-based (Brabant et al., 2010), individual factors (e.g., the role of self-talk; Zaki et al., 2009) and social factors that may influence the relationship between MI sessions and behavior outcomes. Finally, although the current review focuses on the role of MI in alcohol abuse and dependence, based on recent meta-analyses supporting commonalities across different psychosocial interventions (Imel et al., 2008; Wampold et al., 1997) and preliminary data regarding the role of client language across different psychosocial treatments (e.g., Aharonovich et al., 2008; Hodgins et al., 2009; Karno et al., 2010; Moyers et al., 2007; Russell, 1998), there is reason to believe that change talk may play a role across intervention approaches. Thus, an examination of this model across other behavioral treatments would be helpful (e.g., Brewer et al., 2010). Despite these caveats, the current review advances an important new perspective, as well as a testable translational model. Empirical evaluation of this translational model is critical to forming the foundation for a program of research that will help guide the improvement of MI and other psychosocial interventions.

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