

PHARMACOGENOMIC DECISION SUPPORT FOR MODULATORS OF THE NMDA, GLYCINE, AND AMPA RECEPTORS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to and the benefit of the filing date of (1) provisional U.S. Application Serial No. 62/795,705, filed on January 23, 2019, entitled “Methods and Systems to Reconstruct Drug Spatial Networks from Pharmacogenomic Regulatory Interactions and Uses Thereof,” and (2) provisional U.S. Application Serial No. 62/795,710, filed on January 23, 2019, entitled “Companion Diagnostic Assays for N-methyl-D-Aspartate Receptor Modulators,” the entire disclosures of each of which is hereby expressly incorporated by reference herein.

FIELD OF THE INVENTION

[0002] The techniques described herein pertain to pharmacogenomic clinical decision support assays useful for the selection of N-methyl-D-aspartate (NMDA) receptor, glycine receptor, and α -amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid (AMPA) receptor-based therapies for depression (especially treatment-resistant or refractory depression) and other clinical indications including anesthesia and analgesia/pain disorders, neuropsychiatric disorders, and neurological disorders using ketamine and its enantiomers as examples. More specifically, the techniques relate to specific biomarkers, including genetic markers, clinical values, and disease phenotypes derived from a patient to optimize selection of medications that impact these receptor networks and doses for an individual patient.

BACKGROUND

[0003] Existing antidepressant medications are not effective for many patients. A new class of antidepressant drugs are being developed that target glutamate receptors in human forebrain. Ketamine (*RS*-2-chlorophenyl-2-methylamino-cyclohexanone), a glutamate N-methyl-d-aspartate receptor (NMDAR) noncompetitive antagonist, approved by the U.S. Food & Drug Administration (FDA) as an anesthetic, has shown promise as an antidepressant in patients with treatment-resistant depression (TRD). Although the racemic formula may have potent and undesirable psychotomimetic and other side effects depending upon several variables, chemical analogs of ketamine exhibit diminished adverse events. Intravenous and oral formulations have

demonstrated efficacy and tolerability in controlled trials and open-label studies across patient populations known to often achieve little to no response from traditional antidepressants that target the serotonin transporter (SLC6A4, also called 5HTT or SERT1), including serotonin-norepinephrine reuptake inhibitors (SNRIs). Evidence suggests that ketamine, its enantiomers, and ketamine analogs exert their mechanism of action primarily through modulation of the NMDA receptor (NMDAR) and downstream receptors in this network in the human brain.

[0004] The pharmacodynamic (PD) target for ketamine-like drugs is an NMDAR that consists of GRIN1 and GRIN2 subunits, which binds glutamate and N-methyl-D-aspartate, a binding site for glycine and D-serine encoded by *GLRB*, as well as sites that bind polyamines, histamine and cations. Antagonists, partial antagonists and receptor modulators such as ketamine and its and other NMDAR and glycine modulators, including phencyclidine, amantadine, dextromethorphan, tiletamine, riluzole, methoxetamine, methoxphenidine and memantine, block inward Ca^{+2} influx, preventing postsynaptic depolarization. Neuroimaging studies have demonstrated that intravenous infusion of ketamine causes a transient surge in glutamate levels observed in prefrontal cortex in concert with a rapid antidepressant effect. It has been shown that following NMDAR blockade, glutamate preferentially binds to the GRIA1, GRIA2 and GRIA4 subunits of the α -amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid (AMPA) receptor. Several NMDAR antagonists and partial antagonists, GLRB modulators and AMPAR agonists are in development for therapy of refractory depression, but exhibit dissociative effects in patients. In addition, NMDAR antagonists, GLRB antagonists and AMPAR modulators, partial antagonists and receptor modulators that act in the same network as this class of drugs that have failed in clinical trials based on safety concerns might be repurposed using the methods of this disclosure to improve their chances of success in clinical trials.

[0005] The three dimensional (3D) architecture of the human regulatory epigenome plays a major role in determining human phenotype. It is now acknowledged that the majority of significant single nucleotide polymorphisms (SNPs) associated with disease risk, drug response, and other human traits found in genome-wide association studies (GWAS) are located within enhancers, promoters and other non-coding regulatory elements. Coupled with recent insights into the organization of the functional 4D Nucleome, an abundance of biomedical “big data” has become accessible in open source and proprietary resources, enabling the reconstruction of drug regulatory pathways in the human genome. New methods are being applied for the mining of

regulatory variants from genomewide association studies (GWAS), phenome-wide association studies (PheWAS), and results from mining electronic health record data and clinical trial data. It is now standard practice in the art that single nucleotide polymorphism (SNP) trait-associations from these data sources are re-evaluated in the context of pathway analysis, and have been found to be significant because they resolve to the same or related biological networks. Combining an abundance of biomedical data coupled with innovative methods for mining biological networks has provided a foundation for the detection of gene variants that may impact variability in drug response, including adverse drug events. This approach promises tremendous advances in specialties such as psychiatry, in which a lack of drug efficacy and an abundance of adverse drug events have proven especially problematic in patient care.

[0006] Over half of all Americans will exhibit the symptoms of a psychiatric disorder during their lifetime. The most prevalent lifetime psychiatric disorders are stress and anxiety disorders, mood disorders, including major depressive disorder and bipolar disorder, impulse-control disorders, substance use disorders and schizoaffective disorders. The lifetime prevalence of any psychiatric disorder in the U.S. is 53%, while 28% have two or more lifetime disorders and 18% have three or more, showing that comorbidity of psychiatric disorders is a significant medical challenge. Although some psychiatric disorders, such as bipolar 1 disorder are inherited in families at approximately an 80% penetration rate, others exhibit no obvious heritability. For major depressive disorder (MDD), genetic factors play important roles in the etiology of the disease, as indicated by family, twin, and adoption studies. Twin studies suggest a heritability of 50%, and family studies indicate a twofold to threefold increase in lifetime risk of developing MDD among first-degree relatives. Several socio-demographic variables are significantly related to lifetime risk of psychiatric disorders in studies that controlled for cohort. For example, females (biological sex) have a significantly higher risk than men of anxiety and major depressive disorder, and males (biological sex) have a significantly higher risk than females of impulse-control and substance abuse disorders. Non-Hispanic blacks and Hispanics have a significantly lower risk than non-Hispanic whites of anxiety, mood, and substance abuse disorders, and low education is associated with a high risk of substance abuse disorders. The data shows that many factors, ranging from environmental and sociological factors, biological sex, ethnicity and familial genetics, all contribute to the etiology of psychiatric disease. In addition, the complexity of phenotype within an individual patient or cohort of patients,

including comorbidities with other psychiatric disorders and stress-related diseases, necessitates a range of distinct algorithmic classification solutions, including machine learning, as well as multiple statistical analyses, including linear regression, to accurately specify precision therapy beyond what is currently available.

[0007] Psychiatric illness has a greater impact on human health than any other disease. For example, major depressive disorder (MDD) causes a greater burden of disability worldwide than any other medical condition including cancer, heart disease, stroke, chronic obstructive pulmonary disease, and HIV/AIDS, yet it remains the most undiagnosed, misdiagnosed and untreated or poorly treated disease known to humankind. In 2013, the U.S. National Institutes of Health (NIH) provided 13 times more funding for research in oncology than for depression - ~\$5.3 billion versus \$415 million. In the U.S. from 2009-2011, adverse events related to prescribed antidepressants amounted to over 25,000 visits to the emergency room on an annual basis, resulting in 30% of all prescription drug-related hospitalizations each year. Patients with major depressive disorder and comorbid medical conditions experience more severe symptoms of depression and lower rates of response and remission with antidepressant treatment compared with patients with no comorbid conditions. Treatment-resistant depression (TRD) constitutes 30-40% of all patients diagnosed with MDD and is defined as “failure to achieve remission after two well-established antidepressant courses known to have been of evidence-based acceptable dose and duration.”

[0008] Contemporary antidepressant medications are not effective in many patients, and in patients that do respond or remit, weeks to months of pharmacotherapy are required before the alleviation of symptoms is achieved. Consequently, newer and more effective antidepressant medications are being developed. For example, both the racemic mixture of ketamine and the *S*-enantiomer of ketamine are examples of N-methyl-D-aspartate receptor (NMDAR) partial antagonists that have been approved by the U.S. Food and Drug Administration (FDA) for treatment of TRD. Ketamine elicits a rapid antidepressant response and concomitant elevated levels of glutamate in cortex for approximately 50% of TRD patients as measured by the Montgomery-Åsberg Depression Rating Scale (MADRS) total score. Although *R*, *S*-ketamine has been used for clinical indications such as chronic pain, peri-operative analgesia and sedation since 1970, adverse drug events (AEs) are common following ketamine treatment, and diversion is limited by restricting use to inpatient and outpatient treatment settings. For example, in the

phase III clinical trial of Esketamine for TRD prior to submission to the FDA, almost a quarter of the TRD patients experienced severe dissociative effects, 2 deaths were reported, and an additional 6.9% of TRD patients in the treatment arm experienced severe psychotomimetic effects including delirium, delusion and suicidal ideation, as well as suicide attempts.

[0009] One of the challenges in psychiatry is precise matching of pharmacotherapy to accurately address the complex symptomatology of the individual patient. Psychiatric patients exhibit extensive comorbid disorders, and there are few objective biomarkers that can be used as diagnostic criteria to accurately tailor antidepressant, antipsychotic and anti-manic therapy to the patient. Although diagnostic rating scales such as the Hamilton Scale for Depression (HAM-D) exhibit good inter-rater reliability, psychiatric disorders such as depression present as various distinct phenotypes. Non-pharmacological therapies may exhibit improved efficacy in patients with TRD or recurrent depression. For example, repetitive transcranial magnetic stimulation (rTMS) shows promise as a non-medication therapeutic alternative for patients suffering from TRD; however, the best outcomes in TRD occur when rTMS is used as an adjunct to traditional antidepressant pharmacotherapy, as is the case for the antidepressant class of medications that include an NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist, which can only be provided in a clinical setting to a patient who is already taking another antidepressant medication.

[0010] rTMS therapy requires dozens of clinical visits, remission is highly variable among patients with TRD, and rTMS is effective in only about 20-40% of cases, in which remission from depression lasts for as long as 1-2 years. Recent results from rTMS combined with neuroimaging demonstrate specific clustering of depressed patients into 4 distinct phenotypes along axes of anhedonia and anxiety based on differential rTMS array placement. These results provide substantive evidence that it is possible to stratify psychiatric patients by phenotype based on activation of different brain connectivity pathways, networks which exhibit considerable inter-individual variability among patients, and greatly improves the opportunity for precise matching of optimal therapy to the individual patient.

[0011] Although rTMS offers promise for patients with TRD, its mechanism of action remained elusive until independent research studies demonstrated that TMS first acts in the

subgenual anterior cingulate cortex and significantly increases glutamate levels along with biomarkers of N-methyl-d-aspartate receptor (NMDAR) modulation.

[0012] These are remarkable findings, as they demonstrate that the mechanism of rTMS brain activation is virtually indistinguishable from that of ketamine's pharmacotherapeutic mechanism of action. Thus, rTMS and ketamine exhibit similar mechanisms of action to relieve TRD, although about half of all TRD patients do not remit after treatment using either therapeutic option. In addition, both rTMS and ketamine exhibit transient but serious AEs, including dissociation (the presumptive basis of ketamine's analgesic efficacy), psychotomimesis, and neurocognitive impairment. This suggests that it is critically important to match individual patients to one of these therapies or to other antidepressant medications if we can choose which patient will benefit from these treatments and which patient will suffer unnecessarily from serious AEs without adequate antidepressant efficacy.

[0013] Recent research combining transcranial magnetic stimulation (TMS) to alleviate depression followed by neuroimaging demonstrated that TRD patients can be unambiguously stratified into 4 subtypes based on their response to placement of the TMS device, with 4 different intrinsic neuroanatomical pathways activated concomitant with distinctly different symptom clusters. These 4 subtypes can now be determined independently, as demonstrated by this disclosure, using a combination of clinical and molecular data, thereby providing an exemplar for other psychiatric disorders and stress-related disorders, in which improved pharmacophenomic decision support will deliver better therapeutic options to the patient. Similarly, NMDAR antagonist therapy may be used as an adjunct to age-related degenerative medical conditions.

SUMMARY

[0014] Different methods may be used to accurately determine the precise therapeutic requirements for an individual patient phenotype or cohort of phenotypes. This disclosure describes methods for the configuration of a pharmacophenomic assay for clinical decision support, or a companion diagnostic for a psychotropic medication, which optimizes the fit of a therapeutic intervention to an individual patient or cohort of patients diagnosed with a psychiatric or related disorder, such as treatment-resistant depression, chronic pain, migraine, fibromyalgia, inflammatory disorders and other conditions in which ketamine or one its analogs

comprise an effective therapeutic. In the context of this disclosure, the patient's drug response and adverse event phenotype is comprised of multiple sets of variables as described herein, ranging from a patient's intrinsic configuration of a drug's pharmacogenomic network including its mutational profile configuration, to behavioral phenotypes that may be obtained from clinical data.

[0015] The methods used for patient stratification in this disclosure use disparate data sources, some of which may be incomplete, require data cleansing and/or curation, or may be non-existent. The different methods as described herein range from those that may accommodate different combinations of limited data to more extensive computational solutions, or which may bridge missing data elements using probabilistic methods.

[0016] This disclosure comprises a range of concatenated and distinct methods to provide accurate pharmacophenomic decision support for a patient diagnosed with a psychiatric disorder. Outputs provide quantitative scores for ranking therapeutic interventions including recommendations such as medication selection and dose, transcranial magnetic stimulation, electroconvulsive therapy and behavioral intervention. This disclosure comprises pharmacophenomic methods to classify patients diagnosed with a psychiatric disorder into subtypes for optimization of therapeutic intervention. These methods can be used to configure a diagnostic to recommend the best therapeutic match to an individual patient. In another embodiment, these methods may be used to enhance the selection of patients based on pharmacophenomic stratification prior to a clinical trial. In another embodiment, these methods may be used to configure a companion diagnostic for a psychotropic medication to ensure patient safety during the development, marketing and post-marketing of a pharmaceutical.

[0017] In another embodiment, clinical values are obtained from an EHR or similar source, and SNPs in PD and PK genes are obtained from the genotype of a patient, and these are entered as quantitative values in a regression equation (nomogram) for determination of medication dose for a drug such as ketamine for that individual patient. In this embodiment, the therapeutic dose optimum is developed in a step-wise regression model equation containing genetic and clinical values, and the regression model is re-tested and validated using a population of patients to ensure the accuracy of the regression equation's output, as might be judged by a receiver-operator (ROC) curve as area under the curve (AUC).

[0018] In another embodiment, clinical values are obtained from an EHR or similar source, and SNPs in PD and PK genes are combined with disease risk SNPs obtained from genomewide association studies (GWAS) to differentially annotate adverse event and efficacy-specific sub-networks of a drug pharmacogenomic network, such as that of ketamine, to predict whether the patient would benefit from the drug or not, and if so, be determinative of a patient-appropriate dosage.

[0019] In another embodiment, clinical values are obtained from an EHR or similar source, and SNPs in PD and PK genes are combined with disease risk SNPs obtained from GWAS and PheWAS to differentially annotate adverse event and efficacy-specific sub-networks of a drug pharmacogenomic network, such as that of ketamine, to predict whether the patient would benefit from the drug or not, and if so, be determinative of a patient-appropriate dosage. In this embodiment, therapeutic drug monitoring through pharmacometabolomics is used to gather more accurate data on pre-existing prescribed and non-prescribed drugs and their metabolites used by the patient, through analysis of a biological sample (blood, cheek swab, urine or other bodily fluid) obtained from a patient or from a cohort of patients.

[0020] In yet another embodiment, clinical values are obtained from an EHR or similar source, and SNPs in PD and PK genes are combined with disease risk SNPs obtained from GWAS and PheWAS to differentially annotate adverse event and efficacy-specific sub-networks of a drug pharmacogenomic network, such as that of ketamine, and these data are matched with 1 of 4 phenotypes, which may or may not be derived from rTMS and neuroimaging data), determined using scoring from the Hamilton Depression Rating Scale (HAMD) in the context of an antidepressant drug such as ketamine.

[0021] In another embodiment, pharmacophenomic decision support is determined using inputs from a model that includes: (1) molecular profiling of drug-induced sub-networks in a patient or cohort of patients, (2) clinical variables as derived from an electronic health record or equivalent measurements made by a clinician, (3) patient subtyping based on clinical variables and neuroimaging studies, and (4) PD and PK SNPs that stratify patients by drug response. In addition, drug-drug and drug-gene interactions objectively measured using a pharmacometabolomic method can be used to minimize adverse drug events for the individual patient or a cohort of patients.

[0022] Another embodiment of this system is configuration of a companion diagnostic that can be used for patient selection for a clinical trial, and during the marketing and post-marketing phases of a drug, such as an antidepressant medication that acts as a NMDAR antagonist, partial antagonist, GLRB modulator and AMPAR agonist.

[0023] Another embodiment of this system is to determine and select a therapeutic medication addition to a NMDAR modulator to improve outcome. Another embodiment of the methods and system described herein could be used for the re-evaluation of drugs for clinical trials and for drug re-purposing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] Figure 1A illustrates a block diagram of a computer network and system on which an exemplary companion diagnostic system may operate in accordance with the presently described embodiments;

[0025] Figure 1B is a block diagram of an exemplary drug and dose decision server that can operate in the system of Figure 1A in accordance with the presently described embodiments;

[0026] Figure 1C is a block diagram of an exemplary client device that can operate in the system of Figure 1A in accordance with the presently described embodiments;

[0027] Figure 1D illustrates a flow diagram representing an exemplary method for determining a drug and dosage to administer to a patient suffering from depression or other neuropsychiatric illness based on comparing data from the patient's biological sample to a reference drug-specific pharmacogenomic network and the constituent sub-networks for the drug of interest;

[0028] Figure 2 illustrates example measurements collected from a patient's biological sample using chromosome conformation capture, bioinformatics analysis, and/or similar measures;

[0029] Figure 3 shows a simple example of how a SNP located within an enhancer in the network might disrupt the enhancer's contact with one of its target gene promoters in the TAD, leading to adverse drug events in a patient within a drug response cohort. Figure 3A illustrates how different laboratory methods may be used to obtain measures from the chromatin spatial interactome in three dimensions and analyze the data as 2 dimensional plots of enhancer-gene

promoter interactions. Figure 3B depicts how a SNP may disrupt a chromatin loop between an enhancer and one of two gene promoters that it regulates within a TAD. This disruption removes the spatial connection between the enhancer and gene promoter 1 resulting in dysregulation of gene 1, resulting in an adverse event in this patient and its cohort in response to administration of the particular drug of interest;

[0030] Figure 4 illustrates a flow diagram and scoring system representing an exemplary method for determining a the proper drug and dosage while avoiding adverse events (AEs) to administer to a patient suffering from depression or other neuropsychiatric illness based on comparing data from the patient's biological sample to a reference drug-specific pharmacogenomic network and the constituent sub-networks for the drug of interest;

[0031] Figure 5 illustrates a flow diagram representing an exemplary method for using efficacy and adverse event sub-networks derived from an individual patient's pharmacogenomic network to prescribe a given drug at a given dose safely, proceed with caution, or to stop recommendation to prescribe using molecular phenotype quantitative assays generated from the drug's sub-networks;

[0032] Figure 6 illustrates 2 different methods based on the *post hoc* bioinformatics analysis and annotation of disease risk SNPs from GWAS to determine that the patient of a specific ancestry should receive ketamine based on disease gene risk variant analysis and the presence of disease risk SNPs associated with ketamine's adverse event sub-network 3 and efficacy sub-network 2;

[0033] Figure 7 illustrates how fine-tuning of a range of sub-network types spanning the range of human drug response phenotypes is accomplished using machine learning against a model created from a highly heterogenous set of hierarchal biomedical and biological data types and elements as a compared with that of the patient input sample data after a particular drug is chosen from a database of reference set of drug pharmacogenomic networks and their constituent sub-networks;

[0034] Figure 8 illustrates a flow diagram of an exemplary method for using similarity scores to match a patient's drug pharmacodynamic efficacy and adverse events to that of a reference drug pharmacogenomic network for novel pharmacodynamic target discovery using TAD matrix mapping and deep learning based on computer vision algorithms to allow for TAD patterns to be

used to investigate drug similarity and/or use TAD matching methods in clinical trial investigating drug TAD profiles;

[0035] Figure 9A illustrates an exemplary model for how the system integrates heterogeneous hierarchal biomedical and biological data and processes these multi-scale data using machine learning and deep learning for pharmacogenomic network topology and sub-network reconstruction. This strategy for mapping drug networks provides insight into the *mechanistic* on- and off-target effects. Using the discovered pharmacogenomic network topologies provides the basis for advanced pharmacogenomics decision support, laying a foundation for subsequent preclinical and clinical studies to refine this capability, which can also be used for drug mechanism discovery and drug repurposing prediction;

[0036] Figure 9B illustrates a flow diagram representing a method for generating a reconstructed drug pharmacogenomic network and corresponding sub-networks for a drug of interest, including the human pharmacogenomic SNP input filter, the drug spatial network reconstruction engine, and the iterative gene set optimization engine. Reference sets of these drug pharmacogenomic networks, drug efficacy, and drug adverse event information can also be created;

[0037] Figure 10 illustrates a flow diagram representing an exemplary method for integrative drug-gene set optimization to construct a pharmacogenomic network and to determine into its sub-networks;

[0038] Figure 11 illustrates a flow diagram for *post hoc* validation of a reconstructed drug pharmacogenomic network and sets of such networks using bioinformatics data/software and integrative pharmacoinformatics pipelines;

[0039] Figure 12 illustrates an example of a comparison of the results of significance testing of the SNP rs12967143-G, an intragenic enhancer located in the *TCF4* gene, versus other GWAS SNPs as described using the numerical output from six different machine learning algorithms used in the analysis and among various neural and non-neural cell types;

[0040] Figure 13 illustrates characteristics of the 2 different ketamine pharmacogenomic sub-networks as determined from a *post hoc* validation of the ketamine pharmacogenomic network in the human brain. Figure 13A is gene enrichment for the ketamine pharmacogenomic sub-

network in the human brain that mediates efficacy and neuroplasticity. Figure 13B is gene enrichment for the ketamine pharmacogenomic sub-network in the human brain that mediates glutamate receptor signaling and adverse events in the human brain;

[0041] Figure 14A illustrates graphical depictions of the ketamine pharmacogenomic sub-network in the human brain that mediates efficacy and neuroplasticity, and the diseases and conditions that are associated with efficacy and neuroplasticity;

[0042] Figure 14B illustrates graphical depictions of the ketamine pharmacogenomic sub-network in the human brain that mediates glutamate receptor signaling and adverse events in the human brain, and the diseases and conditions that are associated with this signaling and these adverse events;

[0043] Figure 15 lists the genes and regulatory RNAs located in the ketamine efficacy and neuroplasticity sub-network;

[0044] Figure 16 lists the genes located in the ketamine glutamate receptor signaling and adverse event sub-network;

[0045] Figure 17 lists the genes located in the ketamine pharmacokinetics and hormonal regulation sub-network;

[0046] Figures 18A-18B illustrate example values of a linear regression analysis for ketamine dose determination and the accuracy of the ketamine dosing in a validation cohort;

[0047] Figure 19 illustrates definitions of four treatment-resistant depression (TRD) patient subtypes as determined by transcranial magnetic stimulation (TMS) coupled with neuroimaging of resting connectivity networks in human brain;

[0048] Figure 20 illustrates example neuromaps for the four different subtypes of TRD depressed patients;

[0049] Figure 21 illustrates example drug prescribe/do not prescribe recommendations and alternative medication options for each of the four different subtypes of TRD depressed patients;

[0050] Figure 22 illustrates an example of beneficial combinatorial mechanisms and therapeutics mediated by synergistic histone modifications discovered using the methods

described herein using valproic acid and ketamine in H3K9 acetylation and deacetylation respectively, leading to neurogenesis and neuro-differentiation, in combination;

[0051] Figure 23 illustrates the complementary pharmacogenomic network of valproic acid, Figure 23A, and the pharmacogenomic network of ketamine, Figure 23B, showing neurogenesis and neuro-differentiation, respectively; and

[0052] Figure 24 illustrates the combinatorial and biologically synergistic actions of valproic acid and ketamine pharmacogenomic networks in neurogenesis, neuronal proliferation and terminal neuronal differentiation.

DETAILED DESCRIPTION

[0053] Although the following text sets forth a detailed description of numerous different embodiments, it should be understood that the legal scope of the description is defined by the words of the claims set forth at the end of this disclosure. The detailed description is to be construed as exemplary only and does not describe every possible embodiment since describing every possible embodiment would be impractical, if not impossible. Numerous alternative embodiments could be implemented, using either current technology or technology developed after the filing date of this patent, which would still fall within the scope of the claims.

[0054] It should also be understood that, unless a term is expressly defined in this patent using the sentence “As used herein, the term ‘_____’ is hereby defined to mean...” or a similar sentence, there is no intent to limit the meaning of that term, either expressly or by implication, beyond its plain or ordinary meaning, and such term should not be interpreted to be limited in scope based on any statement made in any section of this patent (other than the language of the claims). To the extent that any term recited in the claims at the end of this patent is referred to in this patent in a manner consistent with a single meaning, that is done for sake of clarity only so as to not confuse the reader, and it is not intended that such claim term be limited, by implication or otherwise, to that single meaning. Finally, unless a claim element is defined by reciting the word “means” and a function without the recital of any structure, it is not intended that the scope of any claim element be interpreted based on the application of 35 U.S.C. § 112, sixth paragraph.

[0055] This disclosure comprises a system and methods for stratification of patients or cohort of patients diagnosed with a psychiatric disorder or requiring these drugs for other clinical indications for accurate medication selection and dose of a NMDAR antagonist. Ketamine is used as an exemplar, but these methods can be used for NMDAR antagonists or α -amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid (AMPA) receptor modulators that are in clinical trials for a clinical indication of refractory depression. Ketamine and its enantiomers are novel antidepressants that exhibit greater efficacy and reduced side effects compared to other antidepressants for a patient or specific subset of patients diagnosed with TRD. The pharmacogenomic decision support system can determine which patients diagnosed with TRD should receive ketamine or one its enantiomers as an antidepressant medication, and if so, what the appropriate dosage should be for an individual patient or cohort of patients to maximize efficacy, minimize adverse drug events and drug-drug interactions, and reduce the harmful effects of drug-gene and drug-drug interactions. The adverse psychotropic side effects, including psychotomimetic and neurocognitive effects of glutamate receptor targeted medications for alleviation of depression, coupled with the heterogeneity of the patient population who may exhibit treatment-resistant depression (TRD) is based on multiple variables, including demographic and sociological variables, trauma history, genotype and clinical variables.

[0056] The system includes several methods that can be used for configuration of a clinical decision support diagnostic for selection and dosing of ketamine or one its enantiomers as an antidepressant in refractory depression and may be generalized to other psychotropic medications. One embodiment includes an integrated multi-scale measurement system that comprises the components shown in Figure 1D, where patient biosamples can be extensively analyzed as shown in Figure 2 and other relevant clinical data may also be obtained.

[0057] In some embodiments, the system is configured to analyze the minimal amount of results from the biosample required to match a stored cohort sub-network reference set. In this case, patient data is compared with a reference set of drug sub-networks that span the entire range of human drug response cohorts using a learning machine which has been pre-trained on the cohort response range for a particular drug, and the match to a reference set prompts a clinical decision recommendation. For example, the reference set of drug sub-networks may include a set of reference drug pharmacodynamic efficacy sub-networks, reference drug

pharmacodynamic adverse event sub-networks, reference chromatin remodeling sub-networks, and reference pharmacokinetic enzymes and hormones sub-networks for the particular drug.

[0058] An electronic encryption broker is first used to protect health information through de-identification and to prevent patient identification. Biological sample(s) (e.g., blood, cheek swab, saliva, urine or other bodily fluid) are obtained from a patient or cohort of patients with accompanying clinical data from a medical record, such as an electronic health record (EHR) or other source. Initial pharmacometabolomic analysis on small blood samples, or plasma components thereof, collected from a patient or cohort of patients is performed for determination of potential drug-drug and drug-gene interactions that might alter subsequent pharmacogenomic decision support. These objective measurements augment self-reported, clinician-reported or other data contained in an EHR or another patient record.

[0059] Generally speaking, techniques for determining whether to administer a drug to a patient, such as a glutamate NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist, and/or determining the appropriate dosage of the drug to administer to the patient may be implemented in one or several client devices, one or several network servers, or a system that includes a combination of these devices. However, for clarity, the examples below focus primarily on an embodiment in which a health care professional obtains a patient's biological sample and provides the biological sample to an assay laboratory for analysis.

[0060] The biological sample may include the subject's skin, blood, urine, sweat, lymph fluid, bone marrow, cheek cells, saliva, cell lines, tissues, etc. Cells are then extracted from the biological sample and reprogrammed into stem cells, such as induced pluripotent stem cells (iPSCs). Then the iPSCs are differentiated into various tissues, such as neurons, cardiomyocytes, etc., and assayed to obtain genomic data, chromosomal data, metabolomic data, etc. for the patient. In some embodiments, the iPSCs may be assayed for loci associated with or causatively associated a phenotypic response to the drug of interest. iPSCs comprise part of the reference set used to derive variables for assessing individual patients.

[0061] The drug and dose decision server relies on the drug and dose decision support engine. This engine receives a numerical score representing the overlap between an input patient sample as shown in Figure 2 with the relevant drug-specific reference pharmacogenomic network stored in a database of such references 154. The system uses a learning machine trained on the entire

range of human drug response cohorts, which consists of the pharmacogenomic network reference set for a particular drug, encompassing the range of human drug response variation to a particular drug that comprises the reference set to match to the input patient sample.

[0062] The drug and dose decision server analyzes the laboratory results to determine a sub-network representation for the patient for a drug gene set for an NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist such as ketamine. Additionally, the drug and dose decision server retrieves a reference pharmacogenomic network and constituent reference sub-networks for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for example, from a reference drug pharmacogenomic network database. Then the drug and dose decision server compares the drug sub-network representation for the patient to the reference pharmacogenomic network and constituent reference sub-networks for the drug to determine whether to administer the drug to the patient. For example, the drug and dose decision server may compare an efficacy drug-specific (e.g., ketamine) sub-network for the patient to a reference efficacy drug-specific (e.g., ketamine) sub-network and may compare an adverse event drug-specific (e.g., ketamine) sub-network for the patient to a reference adverse event drug-specific (e.g., ketamine) sub-network. The drug and dose decision server may then determine that the patient should be administered the drug if the similarity between the efficacy drug-specific sub-network for the patient and the reference efficacy drug-specific sub-network is greater than a threshold (indicating the drug is likely to be effective on the patient). The drug and dose decision server may also determine that the patient should be administered the drug if the similarity between the adverse event drug-specific sub-network for the patient and reference adverse event drug-specific sub-network is below a threshold (indicating the patient is unlikely to experience adverse events), or based on some combination of the two.

[0063] Accordingly, the drug and dose decision server may provide a recommendation to a health care professional's client device indicating that the patient should receive the drug, thereby causing the health care professional to administer the drug to the patient. As a result, the health care professional may administer the drug to the patient. In some embodiments, the drug and dose decision server may determine a dosage of the drug to administer to the patient according to a dosing algorithm. The dosing algorithm may be determined using machine learning techniques such as linear regression and may be based on demographic data for the patient, clinical data for the patient, biological data for the patient, etc.

[0064] The drug and dose decision server may determine the dosage of the drug to administer to the patient and perform other methods described herein using various machine learning techniques, including, but not limited to regression algorithms (*e.g.*, ordinary least squares regression, linear regression, logistic regression, stepwise regression, multivariate adaptive regression splines, locally estimated scatterplot smoothing, etc.), instance-based algorithms (*e.g.*, k-nearest neighbors, learning vector quantization, self-organizing map, locally weighted learning, etc.), regularization algorithms (*e.g.*, Ridge regression, least absolute shrinkage and selection operator, elastic net, least-angle regression, etc.), decision tree algorithms (*e.g.*, classification and regression tree, iterative dichotomizer 3, C4.5, C5, chi-squared automatic interaction detection, decision stump, M5, conditional decision trees, etc.), clustering algorithms (*e.g.*, k-means, k-medians, expectation maximization, hierarchical clustering, spectral clustering, mean-shift, density-based pharmacogenomic clustering of applications with noise, ordering points to identify the clustering structure, etc.), association rule learning algorithms (*e.g.*, a priori algorithm, Eclat algorithm, etc.), Bayesian algorithms (*e.g.*, naïve Bayes, Gaussian naïve Bayes, multinomial naïve Bayes, averaged one-dependence estimators, Bayesian belief network, Bayesian network, etc.), artificial neural networks (*e.g.*, perceptron, Hopfield network, radial basis function network, etc.), deep learning algorithms (*e.g.*, multilayer perceptron, deep Boltzmann machine, deep belief network, convolutional neural network, stacked autoencoder, generative adversarial network, etc.), dimensionality reduction algorithms (*e.g.*, principal component analysis, principal component regression, partial least squares regression, Sammon mapping, multidimensional scaling, projection pursuit, linear discriminant analysis, mixture discriminant analysis, quadratic discriminant analysis, flexible discriminant analysis, factor analysis, independent component analysis, non-negative matrix factorization, t-distributed stochastic neighbor embedding, etc.), ensemble algorithms (*e.g.*, boosting, bootstrapped aggregation, AdaBoost, stacked generalization, gradient boosting machines, gradient boosted regression trees, random decision forests, etc.), reinforcement learning (*e.g.*, temporal difference learning, Q-learning, learning automata, State-Action-Reward-State-Action, etc.), support vector machines, mixture models, evolutionary algorithms, probabilistic graphical models, etc.

[0065] Referring to Figure 1A, an example pharmacogenomic decision support system 100 determines whether to administer a psychotropic drug to a patient suffering from depression such as a patient with TRD, and the appropriate dosage for the psychotropic drug. The

pharmacogenomic decision support system 100 includes a drug and dose decision server 102 and a plurality of client devices 106-116 which may be communicatively connected through a network 130, as described below. In an embodiment, the drug and dose decision server 102 and the client devices 106-116 may communicate via wireless signals 120 over a communication network 130, which can be any suitable local or wide area network(s) including a WiFi network, a Bluetooth network, a cellular network such as 3G, 4G, Long-Term Evolution (LTE), 5G, the Internet, etc. In some instances, the client devices 106-116 may communicate with the communication network 130 via an intervening wireless or wired device 118, which may be a wireless router, a wireless repeater, a base transceiver station of a mobile telephony provider, etc. The client devices 106-116 may include, by way of example, a tablet computer 106, a smart watch 107, a network-enabled cell phone 108, a wearable computing device such as Google Glass™ or a Fitbit® 109, a personal digital assistant (PDA) 110, a mobile device smart-phone 112 also referred to herein as a “mobile device,” a laptop computer 114, a desktop computer 116, wearable biosensors, a portable media player (not shown), a phablet, any device configured for wired or wireless RF (Radio Frequency) communication, etc. Moreover, any other suitable client device that record clinical data for patients may also communicate with the drug and dose decision server 102.

[0066] Each of the client devices 106-116 may interact with the drug and dose decision server 102 to receive a recommendation on whether to administer the psychotropic drug to the patient and the dosage for the psychotropic drug. The client device 106-116 may present the recommendation via a user interface for display to a health care professional.

[0067] In an example implementation, the drug and dose decision server 102 may be a cloud based server, an application server, a web server, etc., and includes a memory 150, one or more processors (CPU) 142 such as a microprocessor coupled to the memory 150, a network interface unit 144, and an I/O module 148 which may be a keyboard or a touchscreen, for example.

[0068] The drug and dose decision server 102 may also be communicatively connected to a database 154 of reference drug pharmacogenomic networks and constituent sub-networks such as efficacy and adverse-event sub-networks for the drug.

[0069] The memory 150 may be tangible, non-transitory memory and may include any types of suitable memory modules, including random access memory (RAM), read only memory

(ROM), flash memory, other types of persistent memory, etc. The memory 150 may store, for example instructions executable of the processors 142 for an operating system (OS) 152 which may be any type of suitable operating system such as modern smartphone operating systems, for example. The memory 150 may also store, for example instructions executable on the processors 142 for a drug and dose decision support engine 146. The drug and dose decision server 102 is described in more detail below with reference to Figure 1B. In some embodiments, the drug and dose decision support engine 146 may be a part of one or more of the client devices 106-116, the drug and dose decision server 102, or a combination of the drug and dose decision server 102 and the client devices 106-116.

[0070] In any event, the drug and dose decision support engine 146 may obtain laboratory results from the patient biosample only as is necessary to match one of the set of pharmacogenomic networks and their constituent sub-networks that define human drug response variation for the particular drug. These include molecular data that includes variation in the genome defined by SNPs in PD and PK genes, pharmacogenomic interactions between regulatory elements, genes in a patient's genome that can be defined using chromosome conformation data such as Hi-C, and/or direct topologically associating domain (TAD)-specific measures, including differential gene expression determined using RNA sequencing (RNA-Seq) or expression microarray profiling and patient-specific TAD contactome measures in relevant or surrogate cell types using chromosome conformation capture (e.g., 3C, 4C, 5C, Hi-C, ChIA-PET and GAM). The molecular data may be assayed for loci associated with or causatively associated a phenotypic response to the drug of interest. Additionally, the drug and dose decision support engine 146 may obtain a reference pharmacogenomic network and constituent reference sub-networks for the psychotropic drug of interest (e.g., ketamine) from a reference drug pharmacogenomic network database 154.

[0071] Then the drug and dose decision support engine 146 may analyze the laboratory results for the patient to determine a sub-network representation for the psychotropic drug of interest, such as an efficacy sub-network and an adverse event sub-network. The drug and dose decision support engine 146 may compare the efficacy sub-network and an adverse event sub-network for the patient to reference efficacy and adverse event sub-networks to determine whether to administer the psychotropic drug of interest to the patient. If the similarity between the efficacy drug-specific sub-network for the patient and the reference efficacy drug-specific sub-network is

greater than a threshold and/or the similarity between the adverse event drug-specific sub-network for the patient and reference adverse event drug-specific sub-network is below a threshold, the drug and dose decision support engine 146 may determine that the patient should be administered the psychotropic drug of interest. The drug and dose decision support engine 146 may then provide a recommendation to a health care professional's client device 106-116 indicating that the patient should receive the psychotropic drug of interest. Otherwise, the drug and dose decision support engine 146 may provide a recommendation of another drug to administer to the patient to treat depression. Furthermore, the drug and dose decision support engine 146 may determine a dosage of the psychotropic drug of interest to administer to the patient according to a dosing algorithm. The drug and dose decision support engine 146 may also provide a recommended dosage for the psychotropic drug of interest to the health care professional's client device 106-116.

[0072] The drug and dose decision server 102 may communicate with the client devices 106-116 via the network 130. The digital network 130 may be a proprietary network, a secure public Internet, a virtual private network and/or some other type of network, such as dedicated access lines, plain ordinary telephone lines, satellite links, combinations of these, etc. Where the digital network 130 comprises the Internet, data communication may take place over the digital network 130 via an Internet communication protocol.

[0073] Turning now to Figure 1B, the drug and dose decision server 102 may include a controller 224. The controller 224 may include a program memory 226, a microcontroller or a microprocessor (MP) 228, a random-access memory (RAM) 230, and/or an input/output (I/O) circuit 234, all of which may be interconnected via an address/data bus 232. In some embodiments, the controller 224 may also include, or otherwise be communicatively connected to, a database 239 or other data storage mechanism (*e.g.*, one or more hard disk drives, optical storage drives, solid state storage devices, etc.). The database 239 may include data such as drug pharmacogenomic network reference data, drug recommendation display templates, web page templates and/or web pages, and other data necessary to interact with users through the network 130. The database 239 may include similar data as the database 154 described above with reference to Figure 1A.

[0074] It should be appreciated that although Figure 1B depicts only one microprocessor 228, the controller 224 may include multiple microprocessors 228. Similarly, the memory of the controller 224 may include multiple RAMs 230 and/or multiple program memories 226. Although Figure 1B depicts the I/O circuit 234 as a single block, the I/O circuit 234 may include a number of different types of I/O circuits. The controller 224 may implement, for example, the RAM(s) 230 and/or the program memories 226 as semiconductor memories, magnetically readable memories, and/or optically readable memories.

[0075] As shown in Figure 1B, the program memory 226 and/or the RAM 230 may store various applications for execution by the microprocessor 228. For example, a user-interface application 236 may provide a user interface to the drug and dose decision server 102, which user interface may, for example, allow a system administrator to configure, troubleshoot, or test various aspects of the server's operation. A server application 238 may operate to receive molecular data for a patient, analyze the molecular data to determine sub-networks for the patient related to a particular drug of interest, compare the sub-networks for the patient to reference sub-networks for the particular drug of interest, determine to administer the particular drug of interest to the patient based on the comparison, and transmit a recommendation to administer the particular drug of interest to the patient to a client device 106-116. The server application 238 may be a single module 238 such as the drug and dose decision support engine 146 or a plurality of modules 238A, 238B.

[0076] While the server application 238 is depicted in Figure 1B as including two modules, 238A and 238B, the server application 238 may include any number of modules accomplishing tasks related to implementation of the drug and dose decision server 102. Moreover, it will be appreciated that although only one drug and dose decision server 102 is depicted in Figure 1B, multiple drug and dose decision servers 102 may be provided for the purpose of distributing server load, serving different web pages, etc. These multiple drug and dose decision servers 102 may include a web server, an entity-specific server (e.g. an Apple® server, etc.), a server that is disposed in a retail or proprietary network, etc.

[0077] Referring now to Figure 1C, the laptop computer 114 (or any of the client devices 106-116) may include a display 240, a communication unit 258, a user-input device (not shown), and, like the drug and dose decision server 102, a controller 242. Similar to the controller 224, the

controller 242 may include a program memory 246, a microcontroller or a microprocessor (MP) 248, a random-access memory (RAM) 250, and/or an input/output (I/O) circuit 254, all of which may be interconnected via an address/data bus 252. The program memory 246 may include an operating system 260, a data storage 262, a plurality of software applications 264, and/or a plurality of software routines 268. The operating system 260, for example, may include Microsoft Windows®, OS X®, Linux®, Unix®, etc. The data storage 262 may include data such as application data for the plurality of applications 264, routine data for the plurality of routines 268, and/or other data necessary to interact with the drug and dose decision server 102 through the digital network 130. In some embodiments, the controller 242 may also include, or otherwise be communicatively connected to, other data storage mechanisms (*e.g.*, one or more hard disk drives, optical storage drives, solid state storage devices, etc.) that reside within the laptop computer 114.

[0078] The communication unit 258 may communicate with the drug and dose decision server 102 via any suitable wireless communication protocol network, such as a wireless telephony network (*e.g.*, GSM, CDMA, LTE, etc.), a Wi-Fi network (802.11 standards), a WiMAX network, a Bluetooth network, etc. The user-input device (not shown) may include a “soft” keyboard that is displayed on the display 240 of the laptop computer 114, an external hardware keyboard communicating via a wired or a wireless connection (*e.g.*, a Bluetooth keyboard), an external mouse, a microphone for receiving voice input or any other suitable user-input device. As discussed with reference to the controller 224, it should be appreciated that although Figure 1C depicts only one microprocessor 248, the controller 242 may include multiple microprocessors 248. Similarly, the memory of the controller 242 may include multiple RAMs 250 and/or multiple program memories 246. Although the Figure 1C depicts the I/O circuit 254 as a single block, the I/O circuit 254 may include a number of different types of I/O circuits. The controller 242 may implement the RAM(s) 250 and/or the program memories 246 as semiconductor memories, magnetically readable memories, and/or optically readable memories, for example.

[0079] The one or more processors 248 may be adapted and configured to execute any one or more of the plurality of software applications 264 and/or any one or more of the plurality of software routines 268 residing in the program memory 246, in addition to other software applications. One of the plurality of applications 264 may be a client application 266 that may

be implemented as a series of machine-readable instructions for performing the various tasks associated with receiving information at, displaying information on, and/or transmitting information from the laptop computer 114.

[0080] One of the plurality of applications 264 may be a native application and/or web browser 270, such as Apple's Safari®, Google Chrome™, Microsoft Internet Explorer®, and Mozilla Firefox® that may be implemented as a series of machine-readable instructions for receiving, interpreting, and/or displaying web page information from the drug and dose decision server 102 while also receiving inputs from a user such as a health care professional or researcher. Another application of the plurality of applications may include an embedded web browser 276 that may be implemented as a series of machine-readable instructions for receiving, interpreting, and/or displaying web page information from the drug and dose decision server 102.

[0081] One of the plurality of routines may include a drug recommendation display routine 272 which presents a recommendation of whether to administer a psychotropic drug of interest to a patient and/or a recommended dosage on the display 240.

[0082] Preferably, a user may launch the client application 266 from a client device, such as one of the client devices 106-116 to communicate with the drug and dose decision server 102 to implement the companion diagnostic system 100. Additionally, the user may also launch or instantiate any other suitable user interface application (*e.g.*, the native application or web browser 270, or any other one of the plurality of software applications 264) to access the drug and dose decision server 102 to realize the companion diagnostic system 100.

[0083] Figure 1D illustrates a flow diagram representing an exemplary method 160 for determining a drug and dosage to administer to a patient suffering from depression based on comparing data from a patient's biological sample to a reference pharmacogenomic network and constituent sub-networks for the drug of interest. The method 160 may be executed by the drug and dose decision server 102.

[0084] In some embodiments, patient bio-samples are analyzed as shown in Figure 1D for personalized therapy to quantify the relative activation of the different pathways that mediate ketamine's mechanisms of action in the human CNS determined using the methods described herein. Patient or patient cohort biosamples may be analyzed using pharmacometabolomic assays for determination of drug or metabolites in samples that may cause unwanted drug-drug-

interactions, impacting the efficacy, adverse events and dosing of the medication. Biosample measurement includes: (1) genotyping of pharmacokinetic SNPs, in the exemplar of ketamine consisting of mutations in the *CYP2B6* gene that have been shown to be determinative of metabolizer status (poor, subnormal, normal or ultra-rapid subtypes), (2) pharmacodynamic SNP targeting as inputs into pharmacogenomic network and sub-network profiling, which is deterministic of both efficacy and adverse events as analyzed using the pharmacogenomic genome classifier and pharmacodynamic sub-network profiling systems, (3) direct topologically associating domain (TAD)-specific measures including differential gene expression determined using RNA sequencing (RNA-Seq) or expression microarray profiling, and patient-specific TAD contactome measures in relevant or surrogate cell types using chromosome conformation capture (e.g., 3C, 4C, 5C, Hi-C, ChIA-PET and GAM), and (4) pharmacometabolomic analysis.

[0085] The data processing pipeline shown in Figure 1D comprises parallel routes for analysis of the biosample using multiple methods, and analysis of available clinical data for the same patient as might be collected from an electronic health record (EHR). This example illustrates the analytics used to determine whether a specific patient should be administered an *N*-methyl-D-aspartate receptor (NMDAR) modulator. The adverse events associated with NMDAR modulators such as ketamine may be severe, including severe dissociation, hallucinations and nightmares. Thus, the first decision to be made from these parallelized analytics is to ensure that the patient does not receive NMDAR modulators such as ketamine if the system predicts that the individual will experience moderate to serious adverse events.

[0086] The data processing pipeline shown in Figure 1D may determine a “no-go” decision on administration of NMDAR modulators such as ketamine based on the molecular network representation in the patient, certain disease risk SNPs that the patient may harbor as shown in Figure 23, the treatment-resistant depression phenotype of the patient as shown in Figure 20 and Figure 22, as well as a dose adjustment based on the pharmacometabolic profile of the patient. If the system decides that the patient may receive an NMDAR modulator such as ketamine, a dose determination algorithm is then initiated.

[0087] The method 160 is utilized as a clinical decision support diagnostic to determine whether the patient should be prescribed an NMDAR modular as an antidepressant (block 162) and the optimal dosage for the patient. In some embodiments, patient bio-samples are analyzed

(block 164a) for personalized therapy to quantify the relative activation of the different pathways that mediate ketamine's mechanisms of action in the human CNS determined using the methods described herein. Patient or patient cohort biosamples may be analyzed using pharmacometabolic assays for determination of drug or metabolites in samples that may cause unwanted drug-drug-interactions, impacting the efficacy, adverse events and dosing of the medication. At block 166, biosample measurements include: (1) genotyping of pharmacokinetic SNPs, in the exemplar of ketamine consisting of mutations in the *CYP2B6* gene that have been shown to be determinative of metabolizer status (poor, subnormal, normal or ultra-rapid subtypes), (2) pharmacodynamic SNP targeting as inputs into pharmacogenomic network and sub-network profiling, which is deterministic of both efficacy and adverse events as analyzed using the pharmacogenomic genome classifier and pharmacodynamic sub-network profiling systems, (3) direct topologically associating domain (TAD)-specific measures including differential gene expression determined using RNA sequencing (RNA-Seq) or expression microarray profiling and patient-specific TAD contactome measures in relevant or surrogate cell types using chromosome conformation capture (e.g., 3C, 4C, 5C, Hi-C, ChIA-PET and GAM), and (4) pharmacometabolomic analysis (block 164c).

[0088] As described above, biosample measurements include pharmacodynamic SNP targeting as inputs into pharmacogenomic network and sub-network profiling (blocks 168, 170b), which is deterministic of both efficacy and adverse events as analyzed using the pharmacogenomic genome classifier and pharmacodynamic sub-network profiling systems. At block 170a, a reference pharmacogenomic network and sub-networks for the drug of interest are retrieved from a reference database. The patient's sub-networks for the particular drug of interest, which include efficacy and adverse event sub-networks, are then compared to the reference pharmacogenomic network and sub-networks for the drug of interest (block 172). For determination of similarity to the reference set, the two different pairs of reference-patient metrics include an accurate measurement of similarity and outputs similarity scores for each of the efficacy and adverse events sub-networks. At block 172, the similarity scores for the efficacy and adverse event sub-networks for the drug of interest may be used to determine whether to administer the drug of interest to the patient. For example, if the similarity score for the efficacy sub-network is above a threshold similarity score, the method 160 may determine

that the drug of interest should be administered to the patient (block 176). Otherwise, the method 160 determines to select a different medication (block 174).

[0089] In addition to comparing the patient's sub-networks for the drug of interest to reference sub-networks for the drug of interest, at block 164b clinical data is collected and analyzed for the patient to determine whether to administer the drug to the patient and/or the dosage for the drug. More specifically, the patient's HAMD score and/or patient symptoms may be analyzed to categorize the patient into one of four TRD patient subtypes (block 180). The TRD patient subtypes are described in more detail below with reference to Figures 15-17. If the patient is categorized as TRD subtype 3 (block 182), the method 160 determines to select a different medication (block 184). Other clinical data may also be analyzed such as the patient's drug-drug interactions, age, weight, biological sex, body mass index, ethnicity, family history, patient history of substance abuse, diagnostic codes, hospitalization history, drug-gene interactions, mental illness history, whether the patient smokes or uses nicotine, etc. (block 186).

[0090] Then a dosage of the drug of interest is determined to administer to the patient (block 178). The dosage may be determined based on a dosing algorithm having predetermined constants to apply to each of several patient characteristics, such as biological characteristics, demographic characteristics, clinical characteristics, etc. In other embodiments, the dosing algorithm may be generated using machine learning techniques. The patient characteristics utilized in the dosing algorithm may include biological data, such as SNPs that have been reported to stratify response to ketamine in humans. The patient characteristics may also include demographic data for the patient, such as the patient's sex, height and weight, age, and ethnicity. Furthermore, the patient characteristics may include clinical data, such as family history, drug-drug interactions, mental illness history, whether the patient smokes or uses nicotine, and Hamilton Scale for Depression (HAM-D) score.

[0091] Figure 2 shows various measures that may be undertaken from the patient's biosample. In one embodiment, blood and buccal swab samples are obtained and processed. For ketamine and other medications that undergo first pass metabolism by the protein encoded by the hyper-inducible and hyper-variable *CYP2B6* gene, targeted SNP genotyping is performed using a 4-SNP panel, but most importantly, examination of the splicing variant SNP rs3745274 is prioritized, because it is relatively common (>10% frequency) among human populations, and

carriers of this SNP comprise ultra-poor metabolizers of any drug which is primarily metabolized by this enzyme, and it is very likely to experience adverse drug events from an NMDAR modulator such as ketamine.

[0092] In the method illustrated in Figure 1D and in the measurements collected Figure 2, a pharmacometabolomic analysis of the patient's blood is recommended to rule out any possibility of negative drug-drug or drug-gene interactions.

[0093] Figure 2 illustrates the analytics that may be performed on the patient's biosample to obtain the minimal information necessary to permit a machine or deep learning algorithm to match the drug-specific pattern of the reference set of comprehensive sub-networks that comprise activation of the topologically associating domains (TADs) contained in a database 154. These methods may include measurements of TAD-specific changes in gene expression using RNA-seq or expression microarrays, pharmacogenomic contacts between genes using chromosome conformation capture analysis such as Hi-C, and/or targeted genotyping following induction of geometric alterations in the pharmacogenomic genome by the drug, either after administration of the particular drug to the patient, or proactively, through analysis of a buccal swab obtained from the patient prior to deciding whether the drug should be administered or not.

[0094] The biosample measurements in Figure 2 include genotyping of targeted pharmacokinetic and pharmacodynamic SNPs (block 292), direct TAD-specific measures including differential gene expression and pharmacogenomic contacts (block 294), and pharmacometabolomics (block 296). Genotyping of targeted pharmacokinetic and pharmacodynamic SNPs includes identifying mutations in the *CYP2B6* gene that have been shown to be determinative of metabolizer status (block 282), and classifying the strength of efficacy and adverse events sub-networks according to pharmacogenomic network and sub-network profiling (block 284). The direct chromatin contact-specific measures include differential gene expression determined using circumscribed RNA sequencing (RNA-Seq) (block 286), and circumscribed chromosome conformation capture analysis to identify pharmacogenomic contacts (block 288). Moreover, the pharmacometabolomic analysis is used to identify pre-existing drugs and metabolites in the patient's biosample to assess potential drug-drug interactions, for example (block 290), and can be used to periodically monitor patient drug-drug interactions and drug adherence.

[0095] Figure 3 shows a simple example of how a SNP located within an enhancer or superenhancer in the network might disrupt the enhancer's contact with one of its target gene promoters in the TAD, leading to adverse drug events in a patient within a drug response cohort. Figure 3A illustrates how different laboratory methods may be used to obtain measures from the chromatin pharmacogenomic interactome in three dimensions and analyze the data as 2 dimensional plots of enhancer-gene promoter interactions. Figure 3B depicts how a SNP may disrupt a chromatin loop between an enhancer and one of two gene promoters that it regulates within a TAD. This disruption removes the pharmacogenomic connection between the enhancer and gene promoter 1 resulting in dysregulation of gene 1, resulting in an adverse event in this patient and its cohort in response to administration of the particular drug of interest.

[0096] Figure 4 illustrates the first of several embodiments for matching reference data to a patient input for clinical decision support. In this example, the pharmacogenomic drug sub-network reference set for a particular drug may be combined with a biosample input of sparse results from a patient and using a combinatorial co-training method be used to derive a drug efficacy score for decision-making.

[0097] For example, as shown in Figure 5, the drug and dose decision server 102 compares the patient's efficacy and adverse event sub-networks for a psychotropic drug of interest to reference efficacy and adverse event sub-networks for the psychotropic drug of interest. In this example, reference sub-network 1 (ref. no. 502) and reference sub-network 2 (ref. no. 504) are adverse event sub-networks, while reference sub-network 3 (ref. no. 506) is an efficacy sub-network. Patient X's sub-networks 510 are dissimilar from the adverse event sub-networks (reference sub-networks 1 and 2 (ref. nos. 502, 504)) and similar to the efficacy sub-network (reference sub-network 3 (ref. no. 506)). Accordingly, the drug and dose decision server 102 determines that the psychotropic drug of interest should be administered to the patient 520. Patient Y's sub-networks 512 are dissimilar from one of the adverse event sub-networks (reference sub-network 1 (ref. no. 502)) and similar to the other adverse event sub-network and the efficacy sub-network (reference sub-networks 2 and 3 (ref. nos. 504, 506)). Due to the adverse events in sub-network 2 (ref. no. 504), the drug and dose decision server 102 determines that the psychotropic drug of interest should be administered to the patient but with a reduced dosage 522. Patient Z's sub-networks 514 are similar to both adverse event sub-networks (reference sub-networks 1 and 2 (ref. nos. 502, 504)) and dissimilar from the efficacy sub-network (reference sub-network 3 (ref.

no. 506)), and thus, the drug and dose decision server 102 determines not to administer the psychotropic drug of interest to the patient 524.

[0098] Figure 5 provides examples of how bioinformatics analytics can be used in matching a drug's reference set of antidepressant efficacy versus adverse event signatures from the gene set optimizer with those of an input patient biosample. In Figure 5, patient X can be administered ketamine based on the match of antidepressant efficacy from sub-network 2 of the reference pharmacogenomic network and reduced match to sub-network 3 of adverse events to antidepressant efficacy from the pharmacogenomic network that will be experienced by the individual. However, in patient Z, since this individual harbors some of the disease risk SNPs from GWAS found in sub-networks of the pharmacogenomic network, patient Z's ketamine dose should be adjusted.

[0099] Figure 6 illustrates how two different methods may be derived from and based on the post hoc bioinformatics analysis or annotation of disease risk SNPs from GWAS to determine that the patient should not receive ketamine based on disease gene risk variant analysis and the presence of disease risk SNPs associated with ketamine's adverse event sub-network and efficacy sub-network of the pharmacogenomic drug network for ketamine. These simple and preliminary methods may be used to initially screen a patient as to potential negative consequences of ketamine administration.

[0100] Biosamples 2002, 2004 are collected from patient A and patient B. Patient A's biosample 2002 is analyzed to perform pharmacodynamic SNPs targeting as inputs into pharmacogenomic network and sub-network profiling to determine efficacy and adverse event sub-networks for Patient A (block 2006). Patient B's biosample 2004 is analyzed to identify pharmacokinetic SNPs associated with ketamine response (block 2008). Patient A's efficacy and adverse event sub-networks are then compared to a reference pharmacogenomic network and reference efficacy and adverse event sub-networks for ketamine (block 2010). Patient B's SNPs are compared to SNPs included in reference pharmacogenomic network and reference efficacy and adverse event sub-networks for ketamine (block 2012). In Figure 6, patient A dose must be adjusted prior to administration of ketamine based on the matching of ketamine sub-network mediating adverse events to that of antidepressant efficacy from the pharmacogenomic network that will be experienced by the individual and the reduced match of antidepressant efficacy sub-

network of the reference pharmacogenomic network (block 2014). Also, in patient B, since this individual harbors many of the disease risk SNPs from GWAS found in sub-networks of the pharmacogenomic network, the dose of ketamine administered to patient B should be adjusted (block 2016).

[0101] Figure 7 illustrates a comprehensive strategy in which a library spanning human drug response cohort phenotypes stored in a reference database are used to make an initial “go or no-go” decision about whether ketamine should be administered or not for a specific patient, and how other clinical data from a particular patient may be fine-tuned to make an informed clinical decision.

[0102] Figure 8 illustrates a flow diagram that uses well known pattern matching algorithms from deep learning in computer vision to use similarity scores to match a patient’s drug efficacy and adverse events to that of a reference drug pharmacogenomic network. Figure 8 also illustrates how this strategy may be used for the discovery of novel, similar drugs.

[0103] Figure 9A illustrates an overview of the integrative, multiscale data analysis used in the system. Figure 9B illustrates a flow diagram representing an exemplary method for generating a reconstructed drug pharmacogenomic network and corresponding sub-networks for a drug of interest, including the human pharmacogenomic SNP input filter, the drug pharmacogenomic network reconstruction engine, and the iterative gene set optimization engine.

[0104] As described above, biosample measurement includes pharmacodynamic SNP targeting as inputs into pharmacogenomic network and sub-network profiling, which is deterministic of both efficacy and adverse events as analyzed using the pharmacogenomic genome classifier and pharmacodynamic sub-network profiling systems. The patient’s sub-networks for a particular drug of interest are then compared to a reference pharmacogenomic network and its constituent sub-networks for the drug of interest. Figure 9B illustrates a method 300 for identifying a reference pharmacogenomic network and constituent sub-networks for a particular drug of interest, such as ketamine. In some embodiments, the drug and dose decision server 102 executes the method 300 to identify the pharmacogenomic network and constituent sub-networks for a particular drug of interest and stores the pharmacogenomic network and constituent sub-networks in the reference pharmacogenomic network database 154. In other embodiments, the method 300 is executed by another computing device and the output of the

method is provided to the drug and dose decision server 102 and stored in the reference pharmacogenomic network database 154.

Selection of SNPs

[0105] In any event, at block 302, SNPs are obtained from human clinical studies that have demonstrated significant association with response and adverse events to the drug of interest. Since the location of a SNP associated with the trait under study has been, in most cases, inaccurately assigned to the nearest gene or nearby candidate gene in the published literature and GWAS per the linear sequence of the reference human genome assembly, accurate localization using imputation and annotation techniques are used to determine the actual location of the reported SNP.

[0106] New research has several important implications for drug pharmacogenomic network identification. First, new drug target mechanisms can be identified by collecting pharmacogenomic network outputs in a training set through the use of computer vision-based TAD matching using deep learning (machine learning) and validation using correspondence to known drug-induced genomewide TAD matrices. Second, the clustering of new drug target mechanisms in previously defined but incompletely informed biological pathways will increase the probability of success. Third, insight gained using three dimensional (3D) genome architecture to determine drug targets from pharmacogenomic GWAS will lead to a next generation of drug candidates and greatly enhance the accuracy of pharmacogenomic clinical decision support diagnostics.

[0107] At block 304, pharmacodynamics, pharmacokinetic, and other SNPs are evaluated using a pharmacogenomics informatics pipeline. The pharmacogenomics informatics pipeline uses lead SNPs reported from GWAS and candidate gene studies to find genetically linked permissive candidate SNPs using TAD boundary instead of measures of linkage disequilibrium. These SNPs are evaluated with two separate workflows: the enhancer regulatory workflow for regulatory SNPs and the coding SNP workflow. The enhancer regulatory SNP workflow evaluates the permissive candidate SNPs in disease-relevant tissues for DNA methylation, transcription factor binding, histone marks, DNase I hypersensitivity, chromatin state, quantitative trait loci (QTLs) and transcription factor binding site disruption using tissue-specific omics datasets. The coding SNP workflow finds common nonsynonymous coding SNPs within the pool of permissive candidate

SNPs, which are then examined for histone modifications ruling out exon-containing enhancer SNPs. Both sets of SNPs are mapped back to their TADs and host genes and screened for expression in relevant tissues. The final output SNPs are then evaluated using open source machine learning algorithms to determine if the SNP is causal or not (block 306), and the causal variants are kept for further analysis in the workflow (block 308). Exon SNPs are also evaluated as splice donors or splice acceptors using the Altrans algorithm. If they are found to be involved in alternative splicing, they are stored as such.

Use of casual enhancer SNPs for interrogation

[0108] At block 310, enhancer SNPs are used as probes to determine target genes within the same TAD as the enhancer is located, and to determine pharmacogenomic *trans*-interactions with other TADs using Hi-C chromosome conformation capture and ChIA-PET datasets (block 314) generated from cell types and tissues in which the drug of interest acts. Genes, which herein includes other functional elements such as long non-coding RNAs, are located within the same TADs that are targets of the enhancer that significantly alters drug response in human populations are selected for the drug pharmacogenomic network, if the TADs have strong boundaries as predicted by the amount of bound CTCF and significant association with super-enhancers (block 312). In the TADs that comprise the top 3 statistically significant pharmacogenomic contacts of the first set of pharmacogenomic TADs within the same cell and/or tissue type in which the drug of interest acts are then evaluated, and genes within these “*trans*-TADs” are chosen if they are controlled by the same cell and/or tissue-specific enhancers in which the drug of interest acts (block 316).

[0109] At block 318, the combined set of genes are evaluated for inter-connectivity, where the combined set of genes are selected from the first set of TADs that harbor the pharmacogenomic SNPs and the genes selected from the “*trans*-TADs”, comprising the genes controlled in concert with the first set of TAD genes. For example, third-party software may be utilized, such as Ingenuity Pathway AnalysisTM, for examination of connectivity of the combined set of genes. Using Fisher’s right-sided exact test, if there exists significant interconnectivity within the combined set of genes based on the published literature, then the genes are placed into the preliminary set of genes that comprise the pharmacogenomic network for the drug of interest.

Any genes not forming a connected network are discarded as non-candidate genes for the pharmacogenomic network (block 320).

Knowledge-based revision of the preliminary pharmacogenomic network of drug-specific interconnected genes

[0110] Then at block 322, manual, semi-automated or automated curation, or a combination thereof, is performed on each gene in this gene set comprising the preliminary drug pharmacogenomic network to remove genes whose function are not related to the drug of interest in the cell and/or tissue types in which it acts, or to add other genes not part of this preliminary set of the drug pharmacogenomic network should be added to the set if they are judged to be specifically impacted by the drug of interest in the cell and/or tissue types in which they act. The interrogation steps include definition of an individual gene's function, the phenotypic consequences of mutational impairment of the gene, and the human cells and tissues in which the gene is expressed, to see if it can become a candidate for membership in the pharmacogenomic network of the specific drug of interest.

[0111] In one embodiment, these determinations can be made using a manual, semi-automated, or automated strategy, combining curation of each gene, its mutational profile, and its localization of expression within human tissues. These are enabled by a variety of web-based search tools, including gene definitions, genome browser annotations, the GWAS catalogue and other bioinformatics resources. For example, application programming interfaces (APIs) may have executables written in R, Python, PERL or other programming languages to facilitate data access, data cleansing and data analysis. This embodiment is an enhanced model of manual curation but can become time limiting if there are many genes within a gene set of the drug pharmacogenomic networks or the gene subsets of the sub-networks, and especially in cases where functional genomic elements may include regulatory RNAs or functional RNAs such as long noncoding RNAs, or if the function of the genes are poorly understood. Listing and analysis of the mutational landscape of a given gene (± 10 Kb upstream and downstream) is the easiest of the 3 interrogation steps to be performed because these databases are the most comprehensive. Other resources exist for the analysis of the tissue distribution of a gene's expression pattern. In cases where these patterns are compared to sites where the specific drug of interest acts, the results from imaging modalities may be analyzed including from radiological

studies, light microscopic analysis in pathology and even more sophisticated methods. In some embodiments, this analysis is performed using machine learning techniques, such as neural networks.

[0112] In another embodiment, a Bayesian probabilistic classifier may be used, either based on machine learning or using Bayesian probabilistic computing. The automated methods can be used to reduce the complexity of data analyzed from disparate data resources in which a gene's function knowledge profile, its mutational landscape and its tissue expression mapping are inputs to a learning machine that has been trained on a number of such instances and tested independently on another set of instances for determination of accuracy. Predictive features selected by the trained neural network can be implemented on a support vector machine classifier to construct a gene's function and mutational prediction model, where subsequent machine states determine the adequacy of statistical fit to the drug pharmacogenomic network.

[0113] In some scenarios, machine learning is subject to over-fitting, outputting false positives or false negatives. In another embodiment, semi-automated and naïve Bayesian classification may be performed using machine learning in parallel to sharpen the accuracy of the final output.

[0114] Knowledge-based curation may be performed with the following steps. First, the gene definition is examined from multiple databases to understand if it is specifically, but not generically, impacted by the drug of interest. In addition, the published literature, including text word strings containing the gene name or precursor gene name or equivalent protein name plus any function related to the drug of interest is evaluated following thorough internet searches using for example, Google Scholar™ and/or PubMed. These may include binding affinity studies which have reproducibly found molecules which bind with an affinity that is within 10-fold that of the affinity of which the drug of interest binds to the same pharmacodynamic target. Second, the drug and dose decision server 102 examines each gene for all mutations, including SNPs, variable number of tandem repeats, duplications and all other known mutational alterations, extending in linear sequence ± 10 kb from the transcription start site(s) and stop codon(s) of the gene as examined in a genome browser such as the UCSC genome browser or the Ensembl genome browser. If any of these mutations are found in either the published literature or sources such as unpublished clinical trial data, and they are involved in the action of the drug of interest, including efficacy, adverse events or first pass metabolism, then they are added to the

preliminary set of genes comprising the pharmacogenomic network (block 324). Third, especially for complex tissues such as the brain, skin and the cardiovascular system, the drug and dose decision server 102 performs concordance mapping qualitatively to compare the expression of all genes in this final set to where the drug of interest exerts its action, if known. Genes whose expression does not match the pharmacodynamic substrate of the drug of interest are discarded (block 324). Finally, third-party software such as Ingenuity Pathway Analysis™ is used for examination of connectivity of this gene set (block 326). Using Fisher's right-sided exact test, if the drug and dose decision server 102 determines that there exists significant interconnectivity based on the published literature, then they are placed into the preliminary set of genes that comprise the pharmacogenomic network for the drug of interest. Any genes not forming a connected network are discarded as non-candidate genes for the drug pharmacogenomic network (block 328).

Iterative gene set optimization

[0115] As shown at block 330, and in more detail in Figure 10, iterative gene set optimization is performed on the identified set of candidate genes in the pharmacogenomic network for the particular drug of interest. An example method 400 for iterative gene set optimization to deconstruct a drug pharmacogenomic network into sub-networks is illustrated in the flow diagram of Figure 10. Iterative gene set optimization may be performed to identify sub-networks of the drug pharmacogenomic network. More specifically, iterative gene set optimization includes converting all input molecule terms into gene or long non-coding RNA names from for example, the Human Gene Nomenclature Committee (HGNC) names (block 402) using their API. The iterative gene set optimization differs from gene set enrichment methods, by not only combining a variety of statistical methods, but also not acting in a hierarchal manner ranking genes as in threshold-dependent methods, and iterative gene set optimization does not rely on comparisons of experimental results, such as in whole-distribution tests. Instead, the iterative gene set optimization groups genes or long noncoding RNAs from the pharmacogenomics pharmacogenomic network (block 404) using the Jaccard distance to first measure the similarity between two genes or long noncoding RNAs based on the dissimilarity of user-selected terms, where the Jaccard distance is as the ratio of the size of the symmetric difference $Gene\ A \Delta Gene\ B = A \cap B - A \cup B$ to the union (block 406). This is extensible into clusters of related dissimilar gene names. The drug and dose decision server 102 then automatically sorts

these sets, or using user-defined numbers of clusters, into subsets of clustered subsets of functionally related genes using a minimal entropy sorting algorithm, such as the COOLCAT algorithm (block 408). Following gene subset optimization using entropy minimization, manual curation may be employed to assign efficacy, adverse event or functional mechanistic sub-networks based on known attributes of the drug's mechanism of actions under consideration (blocks 410, 412).

Post-hoc validation using third party bioinformatics tools

[0116] For scientific validation of the deconstruction of the drug pharmacogenomic network into mechanistic sub-networks based on functional gene subset optimization, each drug pharmacogenomic network's sub-network is assessed post hoc for top Gene Ontology terms (molecular function and biological processes), top canonical pathways for example, as determined using other proprietary or open source pathway analysis software, disease risk gene variant analysis for example, as determined using other proprietary or open source pathway analysis software, and determination of upstream xenobiotic regulators using different bioinformatics resources (block 332). In addition, the GWAS catalogue of the European Bioinformatics Institute, the National Human Genome Research Institute, and the National Institutes of Health may be searched to find significant SNP-trait associations for each gene of the gene sets for each sub-network. By providing examples of SNPs from GWAS that are statistically significant, additional evidence may be provided that mutational impairment of the genes included in each sub-network provides insight into the normal, unimpaired function of the sub-network.

[0117] In some embodiments, after *post hoc* validation is performed, as shown in Figure 11, the resulting pharmacogenomic network and constituent sub-networks for the particular drug of interest are stored for example, in the database 154 as shown in Figure 1A.

[0118] For example, to map causal SNPs that discretize response to ketamine in human populations, their target genes within their TADs, and the pharmacogenomic contactome of these TADs, Hi-C chromosome conformation capture data may be used from publicly-available datasets that were mapped in an A735 astrocyte cell line, H1 neuronal cell line, SK-N-SH cell lines and in samples from a postmortem human brain.

[0119] Figure 12 shows an example of a comparison of the results of eight different algorithms testing the predicted causality of the GWAS SNP rs12967143-G, an intragenic enhancer located in the *TCF4* gene, a member of the ketamine pharmacogenomic efficacy sub-network, versus other GWAS SNPs, as described using the numerical output from the machine learning algorithms used in the analysis (* $p \leq 0.05$; ** $p \leq 0.01$; ANOVA).

[0120] Using H-GREEN, a user-adjustable binning software package, the *trans*-TADs are mapped that overlap between different data sources. The top 3 *trans*-TAD pharmacogenomic contacts genomewide may be selected for each originating causal SNP TAD locus. Using prior knowledge of ketamine as an anesthetic and analgesic, and in more recent studies and clinical trials of ketamine and other glutamate receptor modulators as antidepressants, the methods described herein may be used to score the top *trans*-TAD contacts, and for each causal SNP, the top 3 may be selected for inclusion in the pharmacogenomic network. The recent availability of databases of validated enhancers and their targets may be used for both originating and targeted TADs in this workflow to reconstruct the ketamine pharmacogenomic network.

[0121] The intra-TAD and *trans*-TAD gene sets may serve as seeds to initiate pathway analysis. Filters and thresholds may be applied that eliminate genes expressed in the cell types, neurons and astrocytes, and in brain regions where ketamine exerts its mechanism(s) of action. These do not just include PD genes, but also PK genes, the latter which have recently been shown to be expressed at high levels in relevant human brain regions where ketamine acts, and in the case of the *CYP2B6* gene, are induced by this psychotropic drug to much higher levels of expression than in the liver, gastrointestinal tract or kidney.

[0122] Following output of the automated pathway analysis, the drug pharmacogenomic network gene set is evaluated for plausibility, and genes may be added to the pathway that were not selected by the pathway analysis program. From earlier studies of binding affinities using methods in molecular pharmacology, genes are added back whose products exhibit within a 10-fold affinity of the racemic *R, S*-ketamine or the enantiomers to the NMDAR, as well as demonstrating molecular inter-connectivity. Other expression studies and research of the metabolism of ketamine may yield additional genes that are added back to the ketamine pharmacogenomic network.

[0123] The ketamine pharmacogenomic network is analyzed by gene set optimization into 3 sub-networks, of which 2 are significantly different sub-sets of genes and regulatory RNAs using iterative analysis. The 3 sub-networks include: (1) antidepressant efficacy and neuroplasticity, (2) glutamate receptor signaling, chromatin remodeling, and adverse events, and (3) pharmacokinetics and hormonal regulation associated with the drug. The second sub-network (2) glutamate receptor signaling, chromatin remodeling, and adverse events may include two separate sub-networks: a chromatin remodeling sub-network and a drug pharmacodynamics adverse events sub-network. To understand and validate the pharmacogenomic network and its mechanistic sub-networks, four types of additional analyses are performed. First, genes in the pharmacogenomic network and in each sub-network are interrogated for the presence of enhancer SNPs that are associated with pertinent traits in GWAS. Second, pathway enrichment including biological processes and molecular function are performed using the Gene Ontology standard to determine the most significant top pathways for these gene sets. Third, disease gene risk variant analysis is performed, which analyzes each gene super-set and subset for significance of the entire mutational contribution of these sets in humans for appropriate assignment to both the parent pathway and its constituent sub-networks and assigns the top diseases for super-set and sub-network set (most significant, Fisher's exact test). Fourth, the top (most significant, Fisher's exact test) xenobiotic drug that regulates the super-set of genes comprising the pharmacogenomic network is determined. In the last case, the pharmacogenomic network set of genes should be regulated by the drug that mediates the mechanism of the pharmacogenomic network, but for some of the sub-networks, depending on the mechanistic attributes of that network, drugs more relevant to that specific sub-network of the pharmacogenomic network mechanisms may be most significantly associated.

[0124] Figure 13 shows the top Gene Ontology terms of the 2 significantly different ketamine pharmacogenomic sub-networks in the human brain. More specifically, Figure 13A shows the sub-network that mediates efficacy and neuroplasticity. Figure 13B shows the ketamine sub-network that mediates glutamate receptor signaling and adverse events in the human CNS.

[0125] Figure 14A illustrates graphical depictions of the ketamine pharmacogenomic sub-network in the human brain that mediates efficacy and neuroplasticity. Figure 14B illustrates graphical depictions of the ketamine pharmacogenomic sub-network in the human brain that mediates glutamate receptor signaling and adverse events in the human brain. More specifically,

as shown in Figures 14A and 15, the genes and regulatory RNAs located in the ketamine efficacy and neuroplasticity sub-network include one or more of: Activity regulated cytoskeleton associated protein (*ARC*) gene, Achaete-Scute family bHLH transcription factor 1 (*ASCL1*) gene, Brain derived neurotrophic factor (*BDNF*) gene, BDNF antisense RNA (*BDNF-AS*) gene, Calcium/calmodulin dependent protein kinase II alpha (*CAMK2A*) gene, Cyclin dependent kinase inhibitor 1A (*CDKN1A*) gene, cAMP responsive element modulator (*CREM*) gene, Cut like homeobox 2 (*CUX2*) gene, DCC netrin 1 receptor (*DCC*) gene, Dopamine receptor D2 (*DRD2*) gene, Eukaryotic translation elongation factor 2 kinase (*EEF2K*) gene, Fragile X mental retardation 1 (*FMR1*) gene, Ganglioside induced differentiation associated protein 1 like 1 (*GDAP1L1*) gene, Glutamate metabotropic receptor 5 (*GRM5*) gene, Homer scaffold protein 1 (*HOMER1*) gene, 5-hydroxytryptamine receptor 1B (*HTR1B*) gene, 5-hydroxytryptamine receptor 2A (*HTR2A*) gene, Kruppel like factor 6 (*KLF6*) gene, Lin-7 homolog C, crumbs cell polarity complex component (*LIN7C*) long noncoding RNA, *LOC105379109* long noncoding RNA, Myocyte enhancer factor 2D (*MEF2D*) gene, Myosin VI (*MYO6*) gene, Myelin transcription factor 1 like (*MYTIL*) gene, Neuronal differentiation 1 (*NEUROD1*) gene, Neuronal differentiation 2 (*NEUROD2*) gene, Nescient helix-loop-helix 2 (*NHLH2*) gene, Neuromedin B (*NMB*) gene, NMDA receptor synaptonuclear signaling and neuronal migration factor (*NSMF*) gene, Neurotrophic receptor tyrosine kinase 2 (*NTRK2*) gene, Phosphatase and tensin homolog (*PTEN*) gene, Prostaglandin-endoperoxide synthase 2 (*PTGS2*) gene, Rac family small GTPase 1 (*RAC1*) gene, Ras protein specific guanine nucleotide releasing factor 2 (*RASGRF2*) gene, Ras homolog family member A (*RHOA*) gene, Roundabout guidance receptor 2 (*ROBO2*) gene, *RP11_360A181* long noncoding RNA, Semaphorin 3A (*SEMA3A*) gene, SH3 and multiple ankyrin repeat domains 1 (*SHANK1*) gene, SH3 and multiple ankyrin repeat domains 2 (*SHANK2*) gene, SH3 and multiple ankyrin repeat domains 3 (*SHANK3*) gene, Solute carrier family 22 member 15 (*SLC22A15*) gene, Solute carrier family 6 member 2 (*SLC6A2*) gene, Slit guidance ligand 1 (*SLIT1*) gene, Slit guidance ligand 2 (*SLIT2*) gene, Synaptosome associated protein 25 (*SNAP25*) gene, Synapsin I (*SYN1*) gene, Synapsin II (*SYN2*) gene, Synapsin III (*SYN3*) gene, T-box, brain 1 (*TBR1*) gene, or Transcription factor 4 (*TCF4*) gene.

[0126] Also, as shown in Figures 14B and 16, the genes and regulatory RNAs located in the ketamine glutamate receptor signaling and adverse event sub-network include one or more of: Acetylcholinesterase (*ACHE*) gene, Activating transcription factor 7 interacting protein

(*ATF7IP*) gene, Activating transcription factor 7 interacting protein 2 (*ATF7IP2*) gene, ATPase Na⁺/K⁺ Transporting Subunit Alpha 1 (*ATP1A1*) gene, BLOC-1 related complex unit 7 (*BORCS7*) gene, Bromodomain containing 4 (*BRD4*) gene, Calcium voltage-gated channel subunit alpha1 C (*CACNA1C*) gene, Calcium voltage-gated channel auxiliary subunit beta 1 (*CACNB1*) gene, Calcium voltage-gated channel auxiliary subunit beta 2 (*CACNB2*) gene, Calcium voltage-gated channel auxiliary subunit gamma 2 (*CACNG2*) gene, Cholinergic Receptor Muscarinic 2 (*CHRM2*) gene, Cholinergic Receptor Nicotinic Alpha 3 Subunit (*CHRNA3*) gene, Cholinergic Receptor Nicotinic Alpha 5 Subunit (*CHRNA5*) gene, Cholinergic Receptor Nicotinic Alpha 7 Subunit (*CHRNA7*) gene, Cannabinoid receptor 1 (*CNR1*) gene, Disks large homolog 3 (*DLG3*) gene, Disks large homolog 4 (*DLG4*) gene, DNA Methyltransferase 1 (*DNMT1*) gene, Euchromatic histone lysine methyltransferase 1 (*EHMT1*) gene, Gamma-aminobutyric acid type A receptor alpha2 subunit (*GABRA2*) gene, Gamma-aminobutyric acid type A receptor alpha5 subunit (*GABRA5*) gene, Glutamate decarboxylase 1 (*GADI*) gene, Glycine receptor alpha 1 (*GLRA1*) gene, Glycine receptor alpha 2 (*GLRA2*) gene, Glycine receptor beta (*GLRB*) gene, Glutamate ionotropic receptor AMPA type subunit 1 (*GRIA1*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA2*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA4*) gene, Glutamate ionotropic receptor NMDA type subunit 1 (*GRIN1*) gene, Glutamate ionotropic receptor NMDA type subunit 2A (*GRIN2A*) gene, Glutamate ionotropic receptor NMDA type subunit 2B (*GRIN2B*) gene, Glutamate ionotropic receptor NMDA type subunit 2C (*GRIN2C*) gene, Glutamate ionotropic receptor NMDA type subunit 2D (*GRIN2D*) gene, Glutamate ionotropic receptor NMDA type subunit 3A (*GRIN3A*) gene, Glutamate ionotropic receptor NMDA type subunit 3B (*GRIN3B*) gene, Hyperpolarization Activated Cyclic Nucleotide Gated Potassium Channel 1 (*HCN1*) gene, Histone deacetylase 5 (*HDAC5*) gene, Methyl-CpG binding domain protein 1 (*MBD1*) gene, M-Phase Phosphoprotein 8 (*MPHOSPH8*) gene, Neural cell adhesion molecule 1 (*NCAM1*) gene, Nitric acid synthase 1 (*NOS1*) gene, Nitric acid synthase 2 (*NOS2*) gene, Nitric acid synthase 3 (*NOS3*) gene, NAD(P)H quinone dehydrogenase 1 (*NQO1*) gene, Opioid receptor kappa 1 (*OPRK1*) gene, Opioid receptor mu 1 (*OPRM1*) gene, Roundabout guidance receptor 2 (*ROBO2*) gene, SET domain bifurcated 1 (*SETDB1*) gene, SH3 and Multiple Ankyrin Repeat Domains 2 (*SHANK2*) gene, Sigma Non-Opioid Intracellular Receptor 1 (*SIGMAR1*) gene, Solute carrier family 6 member 9 (*SLC6A9*) gene, Transcription Activation Suppressor (*TASOR*) gene, TOG

array regulator of axonemal microtubules 2 (*TOGORAM2*) gene, Tripartite Motif Containing 28 (*TRIM28*) gene, or Zinc Finger Protein 274 (*ZNF274*) gene.

[0127] As shown in Figure 17, the genes and regulatory RNAs located in the pharmacokinetic enzymes and hormones sub-network include one or more of: Anaphase promoting complex subunit 2 (*ANAPC2*) gene, Cytochrome P450 family 2 subfamily A member 6 (*CYP2A6*) gene, Cytochrome P450 family 2 subfamily B member 6 (*CYP2B6*) gene, Cytochrome P450 family 3 subfamily A member 4 (*CYP3A4*) gene, Disks large homolog 4 (*DLG4*), Eukaryotic Elongation Factor 2 Kinase (*EEF2K*) gene, Estrogen Receptor 1 (*ESR1*) gene, Glutamate ionotropic receptor AMPA type subunit 1 (*GRIA1*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA4*) gene, Glutamate ionotropic receptor NMDA type subunit 1 (*GRIN1*) gene, Glutamate ionotropic receptor NMDA type subunit 2B (*GRIN2B*) gene, Myosin VI (*MYO6*) gene, Roundabout Guidance Receptor 2 (*ROBO2*) gene, SH3 and Multiple Ankyrin Repeat Domains 2 (*SHANK2*) gene, and Transcription Elongation Regulator 1 (*TCERG1*) gene.

[0128] Automated iterative gene set optimization of the psychotropic pharmacogenomic network into sub-networks may be user-limited to investigate other features of the pharmacogenomic network. As described above with reference to Figure 10, the ketamine pharmacogenomic network is iteratively deconstructed until certain specific genes do not significantly associate with any sub-network or were associated with several sub-networks deconstructed from the drug pharmacogenomic network. The gene *ESR1* encodes the nuclear hormone receptor for estrogen and it regulates the expression of several genes in the ketamine pharmacogenomic network. It is well known that estrogen greatly induces the *CYP2B6* gene both in the human brain and elsewhere.

[0129] The learning architecture for training the pattern matching sub-networks includes pre-training the reference set (ref. no. 710). More specifically, at block 704, the drug and dose decision server 102 develops the patient's pattern matching sub-networks derived from the patient input biosample, and co-develops separate trained pattern metrics (block 712), which contain the features of the efficacy and adverse event sub-networks, to a joint feature representation metric. For determination of similarity to the reference set (blocks 706, 708), the two different pairs of reference-patient metrics include an accurate measurement of similarity and outputs similarity scores for each of the efficacy and adverse events (blocks 714, 716). At

block 702, the biosample obtained from a patient, which may be a cheek swab, saliva, blood or urine sample, undergoes targeted enhancer SNP genotyping, as well as combined chromosome conformation capture and RNA-seq. Then at block 704, the drug and dose decision server 102 performs analysis necessary to build the input patient-specific map of efficacy and adverse event sub-networks for a specific drug of interest. These patient-specific, drug-induced sub-network patterns could be further processed using Bayesian probabilistic computing to fill in sparse or missing data. As a new patient enters as an input, the pretrained reference set of drug-specific efficacy and adverse event sub-networks for pattern matching is once again optimized for subsequent patients, producing a more accurate measure of pharmacogenomic variability among humans with enhanced clinical utility. This matching task assumes that patches go through the same feature encoding before computing and outputting a similarity score, greatly increasing efficiency while reducing computational requirements.

[0130] Each set of inputs (reference set (ref. no. 710) and patient set (ref. no. 720)) are thus constructed differently with feature set extraction and inference of sparse data using probabilistic computing based on Bayesian distribution to increase the accuracy of reference and patient maps. The trained feature network is based on a “Siamese” network approach, with the constraint that the two sets must share the same parameters. When completed, the patient’s drug-induced trained pattern networks are coupled with those obtained from the reference database, pairing efficacy feature set pairs and adverse event feature set pairs. These provide the basis for the development of a trained efficacy metric and a trained adverse event metric that attempt to match all of the features from the patient and the reference set for the drug of interest. These pairwise matching scores yield separate efficacy and adverse event similarity scores between reference and patient.

[0131] In a further embodiment, a reference pattern matching set may be developed for each patient that could be used to create a patient-specific database of such reference maps, and updated in a periodic manner as additional biosamples are obtained from the patient in a longitudinal manner, obtained in a clinical setting or outpatient pharmacy over time.

[0132] In any event, the drug and dose decision server 102 may then use the similarity scores for the efficacy and adverse event sub-networks for the psychotropic drug of interest, generated via the method 700, to determine whether to administer the psychotropic drug of interest to the

patient. For example, the similarity score for the efficacy sub-network may be compared to a threshold similarity score. If the similarity score for the efficacy sub-network is above the threshold similarity score, the drug and dose decision server 102 may determine that the psychotropic drug of interest should be administered to the patient. The similarity score for the adverse event sub-network may also be compared to a threshold similarity score. If the similarity score for the adverse event sub-network is below the threshold similarity score, the drug and dose decision server 102 may determine that the psychotropic drug of interest should be administered to the patient. In another embodiment, the similarity scores for the efficacy sub-network and the adverse event sub-network may be combined or aggregated in any suitable manner. For example, the similarity score for the adverse event sub-network may be subtracted from the similarity score for the efficacy sub-network. If the combined score is greater than a threshold similarity score, the drug and dose decision server 102 may determine that the psychotropic drug of interest should be administered to the patient.

[0133] Otherwise, the drug and dose decision server 102 may determine not to administer the psychotropic drug of interest, and may provide a recommendation to the health care professional's client device 106-116 to administer another drug to treat the patient's depression.

[0134] In some embodiments, the drug and dose decision server 102 may determine whether to administer the psychotropic drug of interest to the patient by generating a machine learning model based on training data from drug responses from patients previously prescribed the psychotropic drug of interest. The machine learning model may be generated based on several characteristics of the previous patients including drug-induced sub-networks for the previous patients, PD and PK SNPs that stratify patients by drug response, neuroimaging data, direct TAD-specific measures including differential gene expression, and clinical variables for the previous patients such as age, weight, biological sex, body mass index, ethnicity, family history, patient history of substance abuse, diagnostic codes, hospitalization history, drug-drug interactions, mental illness history, whether the patient smokes or uses nicotine, and Hamilton Scale for Depression (HAM-D) score. The drug and dose decision server 102 may obtain the same characteristics for a current patient including molecular and clinical data and apply the current patient's characteristics to the generated machine learning model to determine whether to administer the psychotropic drug of interest to the patient.

[0135] In addition to determining whether to administer the psychotropic drug of interest to the patient, the drug and dose decision server 102 determines the dosage to administer to the patient. Figures 18A and 18B illustrate an analysis performed on an independent cohort dataset for the development of a regression model for the dose estimation of ketamine. The published literature and other sources have provided both pharmacokinetic SNP data and clinical values that help determine dose based on *CYP2B6* SNPs and clinical data. As can be seen from the differential analysis, the biggest contribution to ketamine dose is the presence or absence of the poor metabolizer phenotype, rs3745274, a variant that causes exon skipping and loss of the hyper-inducible *CYP2B6* first pass metabolism of ketamine. The range of quantitative intra-nasal ketamine doses in this model derivation cohort was 0.4 to 0.8 mg/kg. The drug and dose decision server 102 may generate the model based on published ketamine clinical trial results obtained from clinicaltrials.org. A generic example of summed values based on regression variables that could be included in the ketamine-dosing algorithm is illustrated in the equation below:

$$\begin{aligned} \text{Dose} = & \exp [2.00 \times \text{rs3745274} + 0.25 \times \text{female (biological sex)} + \\ & 0.22 \times \text{rs3786547} + 0.22 \times \text{clopidogrel} + 0.19 \times \text{rs11083595} + 0.11 \\ & \times \text{BSA} + 0.20 \times \text{smokes} + 0.17 \times \text{suicide attempt history} + 0.07 \times \\ & \text{age per decade} + 0.09 \times \text{Non-Hispanic white ethnicity} + 0.020 \times \\ & \text{ticlopidine} + 0.15 \times \text{previous psychiatric hospitalization}] \end{aligned}$$

[0136] More specifically, the drug and dose decision server 102 may generate the dosing algorithm based on published literature and may have predetermined constants to apply to each of several patient characteristics, such as biological characteristics, demographic characteristics, clinical characteristics, etc., as in the equation above. In other embodiments, the drug and dose decision server 102 may generate the dosing algorithm using machine learning techniques. For example, the drug and dose decision server 102 may collect dosing information on patients previously prescribed ketamine as training data. The dosing information may include the dosage each patient was prescribed along with indications of whether the patient's dosage was adjusted during treatment and/or whether the patient experienced adverse events. The drug and dose decision server 102 may then analyze the training data to generate a machine learning model (e.g., a neural network, a decision tree, a hyperplane, a regression model, etc.) to determine the dosage for a new patient based on the new patient's biological characteristics, demographic

characteristics, and clinical characteristics. The patient characteristics utilized in the dosing algorithm may include biological data, such as SNPs that have been reported to stratify response to ketamine in humans. The patient characteristics may also include demographic data for the patient, such as the patient's sex, height and weight, age, and ethnicity. Furthermore, the patient characteristics may include clinical data, such as family history, drug-drug interactions, mental illness history, whether the patient smokes or uses nicotine, and Hamilton Scale for Depression (HAM-D) score.

[0137] In any event, the drug and dose decision server 102 applies the patient's characteristics to the dosing algorithm to determine a dosage of ketamine to administer to the patient. Then the drug and dose decision server 102 provides the recommended dosage to a health care professional's client device 106-116.

[0138] Although regression analysis for patient-specific dose optimization cannot account for almost half of the pharmacogenomic and clinical variables required for accuracy, a few published studies have reported variables to include for algorithmic determination of antidepressant selection and dose estimation. Clinical values obtained from a medical record are also critical for determining decreases in the dosing of ketamine, as shown in Figure 13. These include a body mass index (BMI) over 30, a family history of alcohol use disorder (first degree), a history of suicide attempt(s), previous psychiatric hospitalization, a female biological sex (pre-menopausal), non-Hispanic white ethnicity, and individuals who smoke tobacco. As indicated, these values contribute to ketamine dosing that can be substantive, but do not rule out use of this medication.

[0139] In addition to comparing the patient's sub-networks for the psychotropic drug of interest to reference sub-networks for the psychotropic drug of interest, the drug and dose decision server 102 analyzes clinical data and neuroimaging data for the patient to determine whether to administer the drug to the patient. For example, the drug and dose decision server 102 may analyze the patient's HAMD score and/or patient symptoms to categorize the patient into one of four TRD patient subtypes.

[0140] Figure 19 shows the four TRD patient subtypes as determined by transcranial magnetic stimulation (TMS) coupled with neuroimaging of resting connectivity network in human brain. In patients with TRD, subtypes have been identified and replicated using transcranial magnetic

stimulation (TMS) and neuroimaging studies, which have discretized the subtypes by differential activation and repression of the resting state connectivity network in human brain. TMS has four different anatomical placements on the outside of the human head that activate different neuroanatomical structures that are part of limbic-cortical circuits, and include parts of the resting state connectivity network, the default mode network, the defense response that involves the amygdala, reward circuits located in the basal forebrain including the nucleus accumbens (NA) or orbitofrontal cortex (OFC) in depression subtype 3, gating of sensory stimuli to the cortex through the thalamus, cortical region S1 and the insula, prefrontal cortical restraint of impulsivity involving the dorsolateral and dorsomedial prefrontal cortex inhibition of the amygdala activation of limbic cortex, including the entire anterior cingulate cortex and memory consolidation in the hippocampal formation.

[0141] Figure 19 also illustrates that TRD subtypes can be identified using clinical data obtained from an EHR or other clinical records, either using structured values or from notes using natural language processing.

[0142] Figure 20 shows regions of the brain that are consistently activated during the ketamine antidepressant response and how they are differentially mapped to the four TRD depression subtypes. Although brain regions are involved, these are consistent with both the different depression subtypes as defined by TMS and clinical values, as well as results from the neuroimaging studies, which have examined ketamine-induced activation and suppression.

[0143] Figure 21 provides recommendations for medication switching from ketamine for the 4 different TRD subtypes based on defining HAMD-17 rating (Hamilton Scale of Depression), the neuroimaging meta-analysis, associated clinical values as shown in Figure 19, and available information concerning the efficacy, indications and recommendations for currently available antidepressants and professional guidelines from the American Psychiatric Association.

[0144] Figure 21 illustrates example drug recommendations and alternative medication options for each of the four different subtypes of TRD depressed patients.

[0145] To identify which depression subtypes should or should not be provided with ketamine and ketamine analogs, 24 publicly available neuroimaging datasets are analyzed to determine the neuroanatomical regions that are activated by ketamine and its analogs, depressed and TRD patients and healthy controls. Since TRD subtype 3 patients consistently exhibit hyperactive

sub-geniculate anterior cingulate cortex (sgACC), dorsolateral and dorsomedial prefrontal (executive) cortices (dlPFC, dmPFC) and hyperactive orbitofrontal cortex (OFC), it is recommended that these patients do not receive ketamine pharmacotherapy because this patient cohort will not respond or remit, but may instead experience exaggerated psychotropic adverse drug events. Independent analysis of the neuroanatomical localization of all of the genes found in the ketamine pharmacogenomic network shows that they are all expressed at high levels in the anterior cingulate gyrus, prefrontal cortex, supplementary motor cortex, orbitofrontal cortex, temporal cortex, amygdala, hippocampal formation, anterior caudate and nucleus accumbens, but not in other cortical brain regions, hypothalamus or brainstem. This is identical to the pattern of 24 functional neuroimaging studies that were examined showing where ketamine first acts in human brain to exert its antidepressant action (Table 1).

TITLE	PARTICIPANTS	KETAMINE'S SITE(S) OF ACTION	MOD.	PMID
Effects of sub-anesthetic doses of ketamine on regional cerebral blood flow, oxygen consumption, and blood volume in humans	9 healthy controls	Anterior cingulate cortex (ACC) and prefrontal cortex (PFC). Not recognized – anterior caudate (AC) and nucleus accumbens (NA).	PET	12960545
Effects of ketamine on anterior cingulate glutamate metabolism in healthy humans: a 4-T proton MRS study	10 healthy controls	Anterior cingulate cortex (ACC).	¹ H-MRS	15677610
Increased anterior cingulate cortical activity in response to fearful faces: A neurophysiological biomarker that predicts rapid antidepressant response to ketamine	11 healthy controls and 11 drug-free patients diagnosed with MDD	Patients with MDD exhibited increased activity in the anterior cingulate cortex (ACC) after pretreatment with fearful faces versus controls. Also, changes observed in right amygdala (AMY).	MEG	18822408
Anterior cingulate desynchronization and functional connectivity with the amygdala during a working memory task predict rapid antidepressant response to ketamine	15 drug-free patients diagnosed with MDD	Subgenual anterior cingulate cortex (ACC), supplementary motor area (SMA) and amygdala (AMY).	MEG	20393460
Ketamine decreases resting state functional network connectivity in healthy subjects: Implications for antidepressant drug action	17 healthy controls	Subgenual anterior cingulate cortex (sgACC), dorsomedial prefrontal cortex (PFC),	fMRI BOLD	23049758

Relationship of resting brain hyperconnectivity and schizophrenia-like symptoms produced by the NMDA receptor antagonist ketamine in humans	22 healthy controls; Replication in another 12 healthy controls	Ketamine administration increased global brain connectivity. Psychotomimetic (negative) effects following ketamine administration were localized to the nucleus accumbens (NA) and anterior caudate (AC). Positive symptoms were associated with changes in prefrontal cortex (PFC), supplementary motor area (SM), insula and posterior cortex.	rs-fcMRI	23337947
Neural correlates of rapid antidepressant response to ketamine in treatment-resistant unipolar depression: A preliminary PET study	20 drug-free patients diagnosed with TRD	Anterior cingulate cortex (ACC), prefrontal cortex (PFC), amygdala (AMY) and habenula.	PET	23540908
Neural correlates of rapid antidepressant response to ketamine in bipolar disorder	21 patients with bipolar depression	Sub-geniculate anterior cingulate cortex (ACC), supplementary motor area (SMA), prefrontal cortex (PFC). Also, unrecognized, but included amygdala (AMY), hippocampal formation (HF), anterior caudate (AC) and nucleus accumbens (NA).	PET	24103187
Anti-anhedonic effect of ketamine and its neural correlates in treatment-resistant bipolar depression	36 patients who are treatment-refractory diagnosed with bipolar disorder I or II	Ketamine significantly activated the dorsal anterior cingulate cortex (dACC) and the subcortex.	PET	25313512
Neural correlates of change in major depressive disorder anhedonia following open-label ketamine.	52 patients diagnosed with TRD	Supplementary motor area (SMA), hippocampal formation (HF), frontal gyrus and orbitofrontal cortex correlated with measures of decreased anhedonia in patients diagnosed with MDD. <i>Borderline significance.</i>	PET	25691504
A pilot in vivo proton magnetic resonance spectroscopy study of amino acid neurotransmitter response to ketamine treatment of major depressive disorder	11 patients diagnosed with MDD	Prefrontal cortex (PFC).	1H-MRS	26283639
The effects of low-dose ketamine on the prefrontal cortex and amygdala in treatment-resistant depression: A randomized controlled study	48 patients diagnosed with TRD	Prefrontal cortex (PFC), amygdala (AMY) and supplementary motor area (SMA).	PET	26821769
Ketamine modulates subgenual cingulate connectivity with the memory-related neural circuit-a mechanism of relevance to resistant depression?	13 healthy controls	Following ketamine infusion, largest changes observed in the connectivity of the subgenual anterior cingulate cortex (sgACC).	fMRI	26925332
Comparing the actions of Lanicemine and ketamine in depression: key role of the anterior cingulate	60 un-medicated patients diagnosed with MDD	Intravenous infusion of both ketamine and Lanicemine gradually increased activity in the subgenual anterior cingulate cortex (sgACC).	phMRI	27133029
Ketamine modulates hippocampal neurochemistry and functional connectivity – A combined magnetic resonance spectroscopy and resting state fMRI study in healthy volunteers	15 healthy controls	Dorsomedial prefrontal cortex (PFC) and anterior cingulate cortex (ACC). Psychosis severity produced by ketamine was associated with increased connectivity of the hippocampal formation (HF) with the middle cingulate cortex, insula, precuneus and superior frontal gyrus.	rs-fcMRI; 1H-MRS	27480949

Ketamine treatment and global brain connectivity in major depression	25 healthy controls and 18 drug-free patients diagnosed with MDD	Subgenual anterior cingulate cortex (sgACC), dorsolateral prefrontal cortex and dorsomedial prefrontal cortex (PFC), anterior caudate (AC), nucleus accumbens (NA).	rs-fcMRI	27604566
The nucleus accumbens and ketamine treatment in major depressive disorder	The first cohort was 34 patients diagnosed with MDD and 26 healthy controls. The second cohort was 16 patients diagnosed with MDD.	The volume of the nucleus accumbens (NA) was altered in MDD patients, while hippocampal formation (HF) volume was increased following ketamine in MDD patients who exhibited remission.	1H-MRS	28272497
Persistent antidepressant effect of low dose ketamine and activation in the supplementary motor area and anterior cingulate cortex in treatment-resistant depression: A randomized control study	24 patients diagnosed with TRD	TRD patients receiving the 0.5mg/kg ketamine infusion exhibited activation in supplementary motor area (SMA) and anterior cingulate cortex (ACC) than did those receiving the 0.2mg/kg ketamine infusion. The increase in the SUV in the ACC was negatively correlated with depressive symptoms after ketamine infusion.	PET	28922734
Glutamate levels and resting cerebral blood flow in anterior cingulate cortex are associated at rest and immediately following infusion of S-ketamine in healthy volunteers	25 healthy controls	Dorsomedial prefrontal cortex (PFC) and anterior cingulate cortex (ACC).	1H-MRS	29467681
Default mode connectivity in major depressive disorder measured up to 10 days after ketamine administration	33 patients diagnosed with MDD and 25 healthy controls in a cross-over study	MDD patients exhibited normalization of connectivity between the insular cortex (IC), posterior anterior cingulate cortex (pACC) and subgenual anterior cingulate cortex (sgACC).	fMRI	29580569
7T 1 H-MRS in major depressive disorder: A Ketamine Treatment Study	17 healthy controls and 20 patients diagnosed with MDD	Different MDD phenotypes exhibited different brain region alterations following ketamine infusions, ranging from subgenulate anterior cingulate cortex (ACC) to anterior caudate (AC).	1H-MRS	29748628
Pharmacological fMRI: Effects of sub-anesthetic ketamine on resting-state functional connectivity in the default mode network, salience network, dorsal attention network and executive control network	17 healthy male subjects	Anterior cingulate cortex (ACC), superior frontal gyrus including supplementary motor area (SMA), amygdala (AMY), hippocampal formation (HF), anterior caudate (AC), nucleus accumbens (NA), prefrontal cortex (PFC).	rs-fcMRI	30003027
Ketamine, but Not the NMDAR antagonist Lanicemine, Increases prefrontal global connectivity in depressed patients	56 un-medicated patients diagnosed with MDD	Ketamine increased global connectivity of the prefrontal cortex (PFC) in depressed patients.	fMRI	30263977
Functional connectivity between prefrontal cortex and Subgenual cingulate predicts antidepressant effects of ketamine	24 patients diagnosed with MDD	A single sub-anesthetic dose of ketamine increased functional connectivity between prefrontal Cortex (PFC) and the subgenual anterior cingulate cortex (sgACC).	rs-fcMRI	30819549

The antidepressant effect of ketamine is not associated with changes in occipital amino acid neurotransmitter content as measured by [¹ H]-MRS	10 patients diagnosed with MDD	Rapid (1 hour) and sustained (7 days) antidepressant effects produced by ketamine were not associated with changes in amino acid neurotransmitter content in occipital cortex (OC).	1H-MRS	21232924
--	--------------------------------	---	--------	----------

Table 1. Functional neuroimaging studies demonstrate the human CNS substrate where ketamine and other NMDAR modulators act, and in which all of the genes in the ketamine pharmacogenomic network are expressed at their highest levels.

Neuroimaging modalities (MOD.):

1H-MRS: 4-T 1H proton magnetic resonance spectroscopy

fMRI: Functional magnetic resonance imaging.

MEG: Magnetoencephalography;

PET: FDG positron emission tomography;

phMRI: Pharmacological magnetic resonance imaging.

rs-fcMRI: resting-state functional connectivity magnetic resonance imaging.

[0146] In another embodiment, disease risk and pharmacogenomic SNPs that discriminate the 2 significantly different ketamine sub-networks in human brain may be used to determine a patient's response and adverse events when treated with ketamine. Table 2A lists the enhancer and superenhancer SNPs that have been found in the ketamine efficacy sub-network that may be used to determine the representation of mutations significantly associated with efficacious response to ketamine. In contrast, Table 2B lists the enhancer and superenhancer SNPs that have been found in the ketamine adverse event sub-network that may be used to determine the representation of mutations significantly associated with adverse CNS events in response to ketamine.

GWAS SNP Reported / Population(s)	Reported gene(s)	Variant type	Reported trait	P-value	Odds ratio or beta	Confidence Interval (95%)	PubMed ID	EBI-NHGR I Accension Number
rs7623659-T / EUR	<i>RHOA</i>	Intonic	Cognitive performance	4.00E-57	0.0395	0.035-0.044 unit increase	30038396	GCST006570
rs12229654-G / ASN	<i>LINC01405 - CUX2</i>	Intergenic	Alcohol consumption (drinkers versus non-drinkers)	2.00E-48	2.31		21270382	GCST004404

rs30266-A / EUR	ENSG00000251574	Intergenic	Recurrent depression (F33)	2.00E-45	1.033	1.028-1.037	30718901	GCST007342
rs61902811-G / EUR	TMPRSS5, DRD2	Intergenic	Recurrent depression (F33)	4.00E-39	1.0288066	1.02-1.03	30718901	GCST007342
rs12229654-G / ASN	LINC01405 - CUX2	Intergenic	Alcohol consumption	4.00E-35	0.79	[0.67-0.91] unit decrease	21270382	GCST000954
rs6265-T / EUR	BDNF, BDNF-AS	Intragenic; non-synonymous	Smoking status	9.00E-29	0.029275492	0.023-0.036 unit decrease	30643251	GCST007468
rs7227069-A / EUR	DCC	3' UTR	Recurrent depression (F33)	2.00E-28	1.024	1.02-1.029	30718901	GCST007342
rs12967143-G / EUR	TCF4	Intragenic	Recurrent depression (F33)	2.00E-27	1.025641	1.02-1.03	30718901	GCST007342
rs4938021-T / EUR	TMPRSS5, DRD2	Intergenic	Wellbeing, life satisfaction	3.00E-26	0.010079761 unit increase	[0.0082-0.0119]	30643256	GCST007341
rs6589377-A / EUR	TMPRSS5, DRD2	Intergenic	Neuroticism, loneliness	4.00E-26	0.016052796 unit increase	0.016052796 unit increase	30718901	GCST007340
rs6589377-A / EUR	TMPS5, DRD2	Intergenic	Depressive symptom measurement	5.00E-26	0.016052796	0.013-0.019 unit increase	30643256	GCST007339
rs7932640-T / EUR	GRM5	Intragenic	Recurrent depression (F33)	3.00E-25	0.4417	1.023	30718901	GCST007342
rs7111031-A / EUR	TMPRSS5, DRD2	Intergenic	Well being, positive affect	3.00E-24	0.012320721 unit increase	[0.0099-0.0147]	30643256	GCST007338
rs11662271-T / EUR	DCC	Intragenic	Cognitive function	3.00E-24	0.0233 unit increase	[0.019-0.028]	30038396	GCST006570
rs1373178-G / EUR	DCC	Intragenic	Smoking status	2.00E-22	0.0107536	0.0086-0.0129 unit decrease	30643251	GCST007468
rs1925950-G / EUR	MEF2D	Intragenic; non-synonymous	Migraine	9.00E-22	1.07	1.06-1.09	27322543	GCST003720
rs8084280-T / EUR	DCC	Intragenic	Depressive symptom measurement	3.00E-19	0.008229027	0.0064-0.01 unit increase	30643256	GCST007340

rs7111031-A / EUR	<i>DRD2</i>	Intergenic	Neuroticism	2.00E-18	0.012320721	0.0099-0.0147 unit increase	29255261	GCST005232
rs1925950-G / EUR	<i>MEF2D</i>	Intragenic; non-synonymous	Migraine	2.00E-18	1.29	1.20-1.34	27182965	GCST003720
rs12520354-A / EUR	<i>RASGRF2-AS</i>	Intragenic	Risk-taking behavior	3.00E-17	0.0114	0.0087-0.0141 unit increase	30643258	GCST007325
rs599550-A / EUR	<i>TCF4</i>	Intragenic	Depressed affect, mood disorders	4.00E-17	6.53	z-score increase	29942085	GCST006475
rs613872-C / EUR	<i>TCF4</i>	Intragenic	Loneliness	4.00E-17	0.022766946	0.017-0.028 unit decrease	29970889	GCST006924
rs8084280-T / EUR	<i>DCC</i>	Intragenic	Wellbeing, life satisfaction	3.00E-16	0.010693542 unit increase	[0.0081-0.0133]	30643256	GCST007337
rs11662271-T / EUR	<i>DCC</i>	Intragenic	Increased cognition	4.00E-16	0.0233 unit increase	[0.019-0.028]	30018396	GCST006572
rs12967143-C / EUR	<i>TCF4</i>	Intragenic	Well being	9.00E-16	0.008096604 unit decrease	[0.0061-0.0101]	30643256	GCST007341
rs8181326-A / EUR	<i>ARHGAP19, SLIT1</i>	Intergenic	Risk-taking behavior	1.00E-15	0.016249152 unit decrease	[0.012-0.02]	30643258	GCST007324
rs72930774-A / EUR	<i>TCF4-AS2, TCF4</i>	Intergenic	Risky sexual behavior measurement	2.00E-15	0.04191511 unit increase	[0.032-0.052]	30643258	GCST007326
rs2958162 / EUR	<i>TCF4</i>	Intragenic	Depressive symptoms	3.00E-15	1.51	1.45-1.57	30643256	GCST007339
rs7949802-T / EUR	<i>TMPRSS5, DRD2</i>	Intergenic	Wellbeing, life satisfaction	6.00E-15	0.011424591 unit decrease	[0.0086-0.0143]	30643256	GCST007337
rs1660237-T / EUR	<i>TCF4</i>	Intragenic	Well being, positive affect	7.00E-15	0.00893267 unit increase	[0.0067-0.0112]	30643256	GCST007338
rs674437-A / EUR	<i>GRM5</i>	Intragenic	Depressive symptoms	9.00E-15	0.008528544	[0.0064-0.0107] unit decrease	30643256	GCST007340
rs624244 / EUR	<i>TCF4</i>	Intragenic	Risk-taking behavior	2.00E-14	0.0095 unit decrease	[0.0071-0.0119]	30643258	GCST007325

rs8099160 / EUR	<i>DCC</i>	Intragenic	Recurrent depression (F33)	2.00E-14	7.638 z score increase		29942085	GCST006477
rs674437-A / EUR	<i>GRM5</i>	Intragenic	Positive affect	2.00E-14	0.010211199 unit decrease	[0.0076-0.0128]	30643256	GCST007388
rs599550-A / EUR	<i>TCF4</i>	Intragenic	Feeling "fed-up" measurement	3.00E-14	7.6 z score increase		29500382	GCST006947
rs7117514-G / EUR	<i>SHANK2</i>	Intragenic	Recurrent depression (F33)	4.00E-14	1.0162601	[1.01-1.02]	30718901	GCST007342
rs2163971-T / EUR	<i>CADM2</i>	Intragenic	Risky sexual behavior measurement	5.00E-14	0.017939975 unit increase	[0.013-0.023]	30643258	GCST007326
rs4936277-A / EUR	<i>DRD2, TMPSS5</i>	Intergenic	Alcohol use disorder, alcohol dependence	1.00E-13	7.44 z score increase		29942085	GCST008259
rs13357015 / EUR	<i>RASGFR2</i>	Intragenic	Smoking status	1.00E-13			30643251	GCST007468
rs17601612-C / EUR	<i>DRD2, TMPSS5</i>	Intergenic	Alcohol consumption	2.00E-13			30643258	GCST007328
rs8084351 / EUR	<i>DCC</i>	Intragenic	Depressive symptom measurement	2.00E-13			29292387	GCST005323
rs61687445-A / EUR	<i>DRD2, TMPSS5</i>	Intergenic	Well being	2.00E-13	0.006787939 unit decrease	[0.005-0.0086]	30643256	GCST007341
rs35738585 / EUR	<i>DRD2, TMPSS5</i>	Intergenic	Depressed affect	2.00E-13	0.01722 unit decrease	[0.013-0.022]	29942085	GCST006475
rs9636107-G / EUR	<i>TCF4</i>	Intragenic	Schizophrenia	1.00E-12			26198764	GCST003048
rs12968428-A / EUR	<i>DCC</i>	Intragenic	Recurrent depression (F33)	2.00E-12	7.065 z score increase		29942085	GCST006477
rs8138473 / EUR	<i>SHANK3</i>	Intragenic	Cognitive performance	3.00E-12	0.0194 unit decrease	[0.014-0.025]	30038396	GCST006570
rs619466-G / EUR	<i>TCF4</i>	Intragenic	Depressive symptoms	3.00E-12	0.010945462 unit increase	[0.0079-0.014]	30643256	GCST007340
rs1431181-A / EUR	<i>DCC</i>	Intragenic	Recurrent depression (F33)	3.00E-12	6.958 z score increase		29942085	GCST006477

rs1261070-? / EUR	<i>TCF4</i>	Intragenic	Unipolar depression, mood disorders	6.00E-12	0.02838 unit decrease	[0.02-0.036]	29942085	GCST006475
rs611439-? / EUR	<i>TCF4</i>	Intragenic	Unipolar depression, mood disorders	6.00E-12	0.02861 unit decrease	[0.02-0.037]	29942085	GCST006475
rs7231748-A / EUR	<i>TCF4</i>	Intragenic	Irritable mood	7.00E-12	6.87 z score decrease		29500382	GCST006941
rs4277413-A / EUR	<i>DCC</i>	Intragenic	Recurrent depression (F33)	1.00E-11	6.77 z score decrease		29942085	GCST06477
rs1050316 / EUR	<i>MEF2D</i>	Intragenic	Headache	2.00E-11	0.0098 unit decrease	[0.0069-0.0127]	29397368	GCST005337
rs139438618 / AFR	<i>SEMA3A</i>	Intragenic	Major depression and alcoholism	2.00E-11	0.869 unit increase		29071344	GCST005022
rs8089865-A / EUR	<i>DCC</i>	Intragenic	Depressed affect, mood disorders	3.00E-11	6.624 z score increase		29942085	GCST06477
rs12958048-A / EUR	<i>TCF4</i>	Intragenic	Recurrent depression (F33)	4.00E-11	1.03	[1.02-1.04]	29700475	GCST005839
rs9636107 / EUR	<i>TCF4</i>	Intragenic	Autism spectrum disorder or schizophrenia	5.00E-11	1.0638298	[1.04-1.09]	28540026	GCST004521
rs17598729-C / ASN	<i>TCF4</i>	Intragenic	Schizophrenia	9.00E-11	1.0893246	[1.06-1.12]	30285260	GCST007201
rs4801157 / EUR	<i>TCF4</i>	Intragenic	Depressed affect, mood disorders	2.00E-10	0.01921 unit increase	[0.013-0.025]	29942085	GCST006475
rs4384683-G / EUR	<i>DCC</i>	Intragenic	Chronic back pain	2.00E-10	1.0309278	[1.02-1.04]	30261039	GCST007152
rs674437-A / EUR	<i>GRM5, TYR</i>	Intergenic	Neuroticism, vulnerability	3.00E-10	6.31 z score decrease		29500382	GCST006476
rs4938021-T / EUR	<i>DRD2 - TMPRSS5</i>	Intergenic	Neuroticism, loneliness	4.00E-10	0.02327652	[0.016-0.031] unit increase	27089181	GCST003770
rs624244-A / EUR	<i>TCF4</i>	Intragenic	Risk taking dependency	7.00E-10	0.01678442 unit decrease	[0.011-0.022]	30643258	GCST007323
rs674437-A / EUR	<i>GRM5, TYR</i>	Intragenic	Neuroticism	8.00E-10	6.146 z score		29942085	GCST006940

					decrease			
rs7228159-A / EUR	<i>TCF4</i>	Intragenic	Feeling worry	1.00E-09	6.046 unit increase		29500382	GCST006950
rs61905363-T / EUR	<i>DRD2</i>	Intragenic	Depressive symptom measurement	1.00E-09	0.014688093 unit decrease	[0.0099-0.0194]	30643256	GCST007340
rs4936277-G / EUR	<i>DRD2, TMPSS5</i>	Intragenic	Depressive symptom measurement	2.00E-09	0.006741934 unit decrease	[0.0045-0.0089]	30643256	GCST007340
rs17041417-A / EUR	<i>ASCL1</i>	Intragenic	Neuroticism	2.00E-09	0.011447053 unit increase	[0.0077-0.0152]	30643258	GCST007339
rs17041417-A / EUR	<i>ASCL1</i>	Intragenic	Depressive symptom measurement	2.00E-09	0.00732364 unit increase	[0.0049-0.0097]	30643258	GCST007340
rs17041417-A / EUR	<i>ASCL1</i>	Intragenic	Positive affect	3.00E-09	0.008780573 unit increase	[0.0059-0.0117]	30643256	GCST007338
rs9811546-A / EUR	<i>CADM2</i>	Intragenic	Feeling tense	6.00E-09	5.83 z score decrease		29500382	GCST006952
rs17041417-A / EUR	<i>ASCL1</i>	Intragenic	Wellbeing, life satisfaction	6.00E-09	0.009325971 unit increase	[0.0062-0.0125]	30643256	GCST007337
rs12575685 / EUR	<i>SHANK2</i>	Intragenic	Bipolar disorder	8.00E-09	1.07272	[1.05-1.1]	31043756	GCST008103
rs2274316-C / EUR	<i>MEF2D</i>	Intragenic	Migraine	1E-08	1.07	[1.05-1.10]	23793025	GCST002081
rs775766-A / EUR	<i>ROBO2</i>	Intragenic	Recurrent depression (F33)	2.00E-08	5.659 z score increase		29942085	GCST006477
rs310763-C / EUR	<i>SYN2</i>	Intragenic	Depressive symptom measurement	3.00E-08	0.006332982 unit decrease	[0.0041-0.0086]	30643256	GCST007340
rs310763-C / EUR	<i>SYN2</i>	Intragenic	Well being, positive affect	3.00E-08	0.007597797 unit decrease	[0.0049-0.0103]	30643256	GCST007338
rs310763-C / EUR	<i>SYN2</i>	Intragenic	Wellbeing, life satisfaction	3.00E-08	0.0062105684 unit	[0.004-0.0084]	30643256	GCST007341

					decrease			
rs1016306-T / EUR	CADM2	Intragenic	Well being	5.00E-08	0.005018757 unit decrease	[0.0032-0.0068]	30643256	GCST007341
rs935526-T / EUR	ROBO2	Intragenic	Recurrent depression (F33)	5.00E-08	5.452 z score decrease		29942085	GCST006477
rs161645-A / EUR	ENSG00000251574	Intergenic	Depression (quantitative trait)	8.00E-08			23290196	GCST001802
rs17211233-T / EUR	RASFGRF2	Intragenic	Response to ketamine in bipolar disorder or major depression (decrease in dissociation effects)	2.00E-07*	26.9757 unit decrease	[17.75-36.2]	<u>30552316</u>	GCST007317
rs11214606 / EUR	DRD2	Intragenic	Response to antipsychotic treatment in schizophrenia (working memory)	5.00E-07*			21107309	GCST000883
rs1400237 / EUR	ROBO2	Intragenic	Response to ketamine in bipolar disorder or major depression (increase in dissociation effects)	2.00E-06*	21.4345 unit increase	13.27-29.6	<u>30552316</u>	GCST007317
rs1846786-T / EUR	ENSG00000225960	Intergenic	Response to ketamine in bipolar disorder or major depression (decrease in dissociation effects)	3.00E-06*	13.9838 unit decrease	[8.54-19.43]	<u>30552316</u>	GCST007317
rs4855976 / EUR	ROBO2	Intragenic	Response to ketamine in bipolar disorder or major depression (increase in	8.00E-06*	23.7477 unit increase	[14.02-33.48]	<u>30552316</u>	GCST007317

			dissociation effects)					
rs79749176-A / EUR	<i>SLC22A15</i>	Intragenic	Response to ketamine in bipolar disorder or major depression (increase in antidepressant effects)	9.00E-06*	39.0894 unit increase	[22.49-55.69]	30552317	GCST007316

Table 2A, Part 1. Enhancer and superenhancer SNPs that have been found in the ketamine efficacy sub-network.

GWAS SNP Reported / Population (s)	Promoters (EPDnew); PromID	Enhancers	Validated casual human disease enhancer-promoter pairs	Superenhancers (dbSUPER)	eQTL
rs7623659-T / EUR	RHOA_1 (chr3:49411963-49412022)	Enhancer, astrocytes, bipolar neuron, brain ; GH03J049377: chr3:49414635-49417768 (ENCODE(Z-Lab), Ensembl, dbSUPER; GeneHancer DoubleElite)			
rs12229654-G / ASN	CUX2_1 (chr12:111033920-111033979)	Enhancer, Bipolar neuron, H9 neuronal cells, neural progenitor cells; chr12:111473237-111473713 (chr12:111035433-111035909, eRNA Score: 49 (ENCODE, FANTOM, Ensembl))			1E0E-11; Brain Frontal Cortex
rs30266-A / EUR		Enhancer, Bipolar neuron, H9 neuronal cells, prefrontal cortex, cingulate cortex; ENSR00000764485: chr5:105386601-105387599 (Vista,			7.5E-09, Testis

		GeneHancer Elite; Ensembl)			
rs61902811 -G / EUR	TMPR SS5_1 (chr11: 11370 6292- 11370 6351)	Enhancer, neural progenitor cell; GH11J11370: chr11:113705465 -113707068)			1.80E-11; Brain Hippocampus
rs12229654 -G / ASN	CUX2 _1 (chr12: 11103 3920- 11103 3979)	Enhancer, Bipolar neuron, H9 neuronal cells, neural progenitor cells; chr12:111473237 -111473713 (chr12:11103543 3-111035909, eRNA Score: 49 (ENCODE, FANTOM, Ensembl)			1E0E-11; Brain Frontal Cortex
rs6265-T / EUR		Enhancer, Brain Hippocampus Middle, Brain Anterior Caudate, Brain Cingulate Gyrus (ENCODE)	DE_00099: chr11:27739147- 27742290; Depression		5.08E-06; Nerve tibial
rs7227069- A / EUR	DCC_ 2 (chr18: 52340 148- 52340 207)	Enhancer, prefrontal cortex, cingulate cortex; FANTOM: chr18:52341963- 52342477, eRNA Score: 32, Cells: neural progenitor cells		SE_08791 (Brain - Mid frontal lobe)	1.0E-21; Brain Cingulate Gyrus
rs12967143 -G / EUR	TCF4_ 1 (chr18: 55401 678- 55401 737) TCF4_ 9 (chr18: 55401 970- 55402 029) TCF4_ 4 (chr18: 55403	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678- 55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1E-11; Brain Frontal Cortex

	630-55403689)				
rs4938021-T / EUR	TMPR SS5_1 (chr11:113706292-113706351)	Enhancer, neural progenitor cell; GH11J11370: chr11:113705465-113707068)			1.80E-23; Brain Amygdala
rs6589377-A / EUR	TMPR SS5_1 (chr11:113706292-113706351)	Enhancer, neural progenitor cell; GH11J11370: chr11:113705465-113707068)			1.80E-11; Brain Hippocampus
rs6589377-A / EUR	TMPR SS5_1 (chr11:113706292-113706351)	Enhancer, neural progenitor cell; GH11J11370: chr11:113705465-113707068)			1.0E-21; Brain Cingulate Gyrus
rs7932640-T / EUR		Enhancer, H1 progenitor neurons; ENSR00000438504 (chr11:89119401-89120000)			1.0E-03; Brain Cingulate Gyrus
rs7111031-A / EUR	TTC12_1 (chr11:113314539-113314598)	Enhancer, Bipolar neuron, Brain; ENSR0000045120 (chr11:113313800-113315601) (ENCODE, FANTOM, Ensembl)			1E-37; Brain Anterior Caudate
rs11662271-T / EUR	DCC_2 (chr18:52340148-52340207)	Enhancer, prefrontal cortex, cingulate cortex; FANTOM: chr18:52341963-52342477, eRNA Score: 32, Cells: neural progenitor cells			1.55E-51; Brain Frontal Cortex
rs1373178-G / EUR		Enhancer, hippocampus, ERNA score 21 (ENCODE, VISTA)			1E-15; Brain Amygdala

rs1925950-G / EUR	MEF2 D_2 (chr1:156490647-156490706) MEF2 D_1 (chr1:156500765-156500824)	Enhancer, bipolar neurons, brain (ENCODE, Ensembl, dbSUPER, GeneHancer Double Eite); FANTOM: chr1:156502901-156503160, eRNA Score: 319; Cells: Neural progenitor cells		SE_04141 (Brain - Anterior caudate); SE_08791 (Brain - Mid frontal lobe); SE_05851 SE_06826 (Brain - Hippocampus middle); SE_04925 (Brain - Cingulate gyrus); SE_07824 (Brain - Inferior temporal lobe); SE_03183 (Brain - Angular gyrus); SE_02565 (Astrocytes);	1E-89; Brain Cingulate Gyrus
rs8084280-T / EUR	DCC_2 (chr18:52340148-52340207)	Enhancer, neural progenitor cell (ENCODE)			1.0E-09; Brain Cingulate Cortex
rs7111031-A / EUR	ANKK1_1 (chr11:113387730-113387789)	Enhancer, H1 neuronal progenitor cells, brain, astrocytes, bipolar neurons; GH11J113505: chr11:113375857-113378219; (ENCODE, Ensemble, Vista, MASTERMIND); FANTOM: chr11:113375857-113376013 (chr11:113505135-113505291, eRNA Score: 2)			1E-06; Brain Hippocampus
rs1925950-G / EUR	MEF2 D_2 (chr1:156490647-156490706) MEF2 D_1 (chr1:156500765-156500824)	Enhancer, bipolar neurons, brain (ENCODE, Ensembl, dbSUPER, GeneHancer Double Eite); FANTOM: chr1:156502901-156503160, eRNA Score: 319; Cells: Neural progenitor cells		SE_04141 (Brain - Anterior caudate); SE_08791 (Brain - Mid frontal lobe); SE_05851 SE_06826 (Brain - Hippocampus middle); SE_04925 (Brain - Cingulate gyrus); SE_07824 (Brain - Inferior temporal lobe); SE_03183 (Brain - Angular gyrus); SE_02565 (Astrocytes);	1E-89; Brain Cingulate Gyrus
rs12520354-A / EUR		Enhancer, Bipolar neurons, brain; ENSR00000183204		SE_33104 (Brain - Cingulate gyrus)	

		(chr5:80955800-80956401)			
rs599550-A / EUR	TCF4_2 (chr18:55588182-55588241) TCF4_3 (chr18:55588605-55588664)	Enhancer, neural progenitor cells, brain (GeneHancer Elite, Vista, MASTERMIND)	DE_00452: chr18:55401678-55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate), SE_33242 (H1-ESC)	1E-52; Brain Frontal Cortex
rs613872-C / EUR	TCF4_2 (chr18:55588182-55588241) TCF4_3 (chr18:55588605-55588664)	Enhancer, neural progenitor cells, brain (GeneHancer Elite, Vista, MASTERMIND)	DE_00452: chr18:55401678-55401737; Depression	SE_33242 (H1-ESC)	1E-12; Brain Cingulate Gyrus
rs8084280-T / EUR	DCC_2 (chr18:52340148-52340207)	Enhancer, neural progenitor cell (ENCODE)			1.0E-09; Brain Cingulate Cortex
rs11662271-T / EUR	DCC_2 (chr18:52340148-52340207)	Enhancer, prefrontal cortex, cingulate cortex; FANTOM: chr18:52341963-52342477, eRNA Score: 32, Cells: neural progenitor cells			1.55E-51; Brain Frontal Cortex
rs12967143-C / EUR	TCF4_1 (chr18:55401678-55401737) TCF4_9	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678-55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus);	1E-11; Brain Frontal Cortex

	(chr18:55401970-55402029) TCF4_4 (chr18:55403630-55403689)			SE_04070 (Brain - Anterior caudate)	
rs8181326-A / EUR	SLIT1_4 (chr10:97185502-97185561)	Enhancer, Brain Hippocampus Middle, Brain Anterior Caudate, Brain Cingulate Gyrus (ENCODE)		SE_33104 (Brain - Cingulate gyrus)	
rs72930774-A / EUR	TCF4_1 (chr18:55401678-55401737) TCF4_9 (chr18:55401970-55402029) TCF4_4 (chr18:55403630-55403689)	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678-55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1E-11; Brain Frontal Cortex
rs2958162 / EUR	TCF4_2 (chr18:55588182-55588241) TCF4_3 (chr18:55588605-55588664)	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678-55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1.36E-20; Brain Cingulate Gyrus

rs7949802-T / EUR	ANKK1_1 (chr11:113387730-113387789)	Enhancer, H1 neuronal progenitor cells, brain, astrocytes, bipolar neurons; GH11J113505: chr11:113375857-113378219; (ENCODE, Ensemble, Vista, MASTERMIND) ; FANTOM: chr11:113375857-113376013 (chr11:113505135-113505291, eRNA Score: 2)			1E-06; Brain Hippocampus
rs1660237-T / EUR		Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678-55401737; Depression		
rs674437-A / EUR		Enhancer, H1 progenitor neurons; ENSR00000438504 (chr11:89119401-89120000)			1E-27; Brain Amygdala
rs624244 / EUR	TCF4_2 (chr18:55588182-55588241) TCF4_3 (chr18:55588605-55588664)	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678-55401737; Depression	SE_06352 SE_06762 (Brain - Hippocampus middle)SE_08840 (Brain - Mid frontal lobe)SE_04109 (Brain - Anterior caudate)SE_07745 (Brain - Inferior temporal lobe);SE_04840 (Brain - Cingulate gyrus)SE_03237 (Brain - Angular gyrus)	1.36E-20; Brain Cingulate Gyrus
rs8099160 / EUR	DCC_2 (chr18:52340148-52340207)	Enhancer, prefrontal cortex, cingulate cortex; FANTOM: chr18:52341963-52342477, eRNA Score: 32, Cells: neural progenitor cells			1E-12; Brain Cingulate Gyrus
rs674437-A / EUR		Enhancer, H1 progenitor			1E-27; Brain Amygdala

		neurons; ENSR000004385 04 (chr11:89119401- 89120000)			
rs599550- A / EUR	TCF4_2 (chr18: 55588 182- 55588 241) TCF4_3 (chr18: 55588 605- 55588 664)	Enhancer, neural progenitor cells, brain (GeneHancer Elite, Vista, MASTERMIND)	DE_00452: chr18:55401678- 55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate), SE_33242 (H1- ESC)	1E-52; Brain Cingulate Gyrus
rs7117514- G / EUR		Enhancer, prefrontal cortex			1E-05; Brain Frontal Cortex
rs2163971- T / EUR		Enhancer, Brain: ENSR000006926 82 (chr3:84983601- 84985999, Type: Proximal)			1E-11; Brain Frontal Cortex
rs4936277- A / EUR	ANKK1_1 (chr11: 11338 7730- 11338 7789)	Enhancer, H1 neuronal progenitor cells, brain, astrocytes, bipolar neurons; GH11J113505: chr11:113375857 -113378219; (ENCODE, Ensemble, Vista, MASTERMIND) ; FANTOM: chr11:113375857 -113376013 (chr11:11350513 5-113505291, eRNA Score: 2)			1E-06; Brain Hippocampus
rs13357015 / EUR	RASG RF2_1 (chr5:8 09606 23- 80960 682)	Enhancer, Bipolar Neuron, Brain, Astrocytes; GH05J080966		SE_33104 (Brain - Cingulate gyrus)	1E-10; Brain Cingulate Gyrus
rs17601612 -C / EUR	ANKK1_1 (chr11: 11338	Enhancer, H1 neuronal progenitor cells, brain, astrocytes,			1E-06; Nucleus accumbens

	7730-113387789)	bipolar neurons; GH11J113505: chr11:113375857-113378219; (ENCODE, Ensemble, Vista, MASTERMIND) ; FANTOM: chr11:113375857-113376013 (chr11:113505135-113505291, eRNA Score: 2)			
rs8084351 / EUR	DCC_2 (chr18:52340148-52340207)	Enhancer, prefrontal cortex, cingulate cortex; FANTOM: chr18:52341963-52342477, eRNA Score: 32, Cells: neural progenitor cells		SE_08791 (Brain - Mid frontal lobe)	1.0E-21; Brain Cingulate Gyrus
rs61687445 -A / EUR	TTC12_1 (chr11:113314539-113314598)	Enhancer, Bipolar neuron, Brain; ENSR00000045120 (chr11:113313800-113315601) (ENCODE, FANTOM, Ensembl)			1E-37; Brain Anterior Caudate
rs35738585 / EUR	TTC12_1 (chr11:113314539-113314598)	Enhancer, Bipolar neuron, Brain; ENSR00000045120 (chr11:113313800-113315601) (ENCODE, FANTOM, Ensembl)			1E-37; Brain Anterior Caudate
rs9636107-G / EUR	TCF4_2 (chr18:55588182-55588241) TCF4_3 (chr18:55588605-55588664)	Enhancer, neural progenitor cells, brain (GeneHancer Elite, Vista, MASTERMIND)	DE_00452: chr18:55401678-55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate), SE_33242 (H1-ESC)	1E-20; Brain Cingulate Gyrus
rs12968428 -A / EUR	DCC_2	Enhancer, prefrontal cortex,		SE_08791 (Brain - Mid frontal lobe)	1.0E-21; Brain

	(chr18:52340148-52340207)	cingulate cortex; FANTOM: chr18:52341963-52342477, eRNA Score: 32, Cells: neural progenitor cells			Cingulate Gyrus
rs8138473 / EUR		Enhancer, neural progenitor cells, brain (GeneHancer Elite, Vista, MASTERMIND)		SE_08247 (Brain - Inferior temporal lobe)SE_53463 (Spleen)SE_03550 (Brain - Angular gyrus)SE_06357 (Brain - Hippocampus middle)SE_04497 (Brain - Anterior caudate) SE_09211 (Brain - Amygdala)	1E-20; Brain Amygdala
rs619466-G / EUR	TCF4_2 (chr18:55588182-55588241) TCF4_3 (chr18:55588605-55588664)	Enhancer, neural progenitor cells, brain (GeneHancer Elite, Vista, MASTERMIND)	DE_00452: chr18:55401678-55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate), SE_33242 (H1-ESC)	1E-20; Brain Cingulate Gyrus
rs1431181-A / EUR	DCC_2 (chr18:52340148-52340207)	Enhancer, neural progenitor cell (ENCODE)			1.0E-09; Brain Cingulate Gyrus
rs1261070-? / EUR	TCF4_1 (chr18:55401678-55401737) TCF4_9 (chr18:55401970-55402029) TCF4_4 (chr18:55403630-	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678-55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1E-11; Brain Frontal Cortex

	55403 689)				
rs611439-? / EUR	TCF4_ 1 (chr18: 55401 678- 55401 737) TCF4_ 9 (chr18: 55401 970- 55402 029) TCF4_ 4 (chr18: 55403 630- 55403 689)	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678- 55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1E-11; Brain Frontal Cortex
rs7231748- A / EUR	TCF4_ 2 (chr18: 55588 182- 55588 241) TCF4_ 3 (chr18: 55588 605- 55588 664)	Enhancer, neural progenitor cells, brain (GeneHancer Elite, Vista, MASTERMIND)	DE_00452: chr18:55401678- 55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate), SE_33242 (H1- ESC)	1E-20; Brain Cingulate Gyrus
rs4277413- A / EUR	DCC_ 2 (chr18: 52340 148- 52340 207)	Enhancer, neural progenitor cell (ENCODE)			1.0E-09; Brain Cingulate Gyrus
rs1050316 / EUR	MEF2 D_2 (chr1:1 56490 647- 15649 0706) MEF2 D_1 (chr1:1 56500 765-	Enhancer, bipolar neurons, brain (ENCODE, Ensembl, dbSUPER, GeneHancer Double Eite); FANTOM: chr1:156502901- 156503160, eRNA Score: 319; Cells:		<u>SE_04141 (Brain - Anterior caudate); SE_08791 (Brain - Mid frontal lobe); SE_05851 SE_06826 (Brain - Hippocampus middle); SE_04925 (Brain - Cingulate gyrus); SE_07824 (Brain - Inferior temporal lobe); SE_03183 (Brain - Angular gyrus); SE_02565 (Astrocytes);</u>	1E-89; Brain Cingulate Gyrus

	15650 0824)	Neural progenitor cells			
rs13943861 8 / AFR	SEMA 3A_2 (chr7:8 41947 79- 84194 838) SEMA 3A_1 (chr7:8 41949 83- 84195 042)	Enhancer, Bipolar neurons, Brain, neural progenitor cells; ENSR000002145 78 (chr7:84190600- 84196801)	-	-	1E-10; Brain occipital Cortex
rs8089865- A / EUR	DCC_ 2 (chr18: 52340 148- 52340 207)	Enhancer, neural progenitor cell (ENCODE)			1.0E-09; Brain Cingulate Gyrus
rs12958048 -A / EUR	TCF4_ 2 (chr18: 55588 182- 55588 241) TCF4_ 3 (chr18: 55588 605- 55588 664)	Enhancer, neural progenitor cells, brain (GeneHancer Elite, Vista, MASTERMIND)	DE_00452: chr18:55401678- 55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe)SE_33496 (H2171); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1E-20; Brain Cingulate Gyrus
rs9636107 / EUR	TCF4_ 1 (chr18: 55401 678- 55401 737) TCF4_ 9 (chr18: 55401 970- 55402 029) TCF4_ 4 (chr18: 55403 630-	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678- 55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1E-11; Brain Frontal Cortex

	55403 689)				
rs17598729 -C / ASN	TCF4_ 1 (chr18: 55401 678- 55401 737) TCF4_ 9 (chr18: 55401 970- 55402 029) TCF4_ 4 (chr18: 55403 630- 55403 689)	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678- 55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1E-11; Brain Frontal Cortex
rs4801157 / EUR	TCF4_ 2 (chr18: 55588 182- 55588 241) TCF4_ 3 (chr18: 55588 605- 55588 664)	Enhancer, neural progenitor cells, brain (GeneHancer Elite, Vista, MASTERMIND)	DE_00452: chr18:55401678- 55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_33496 (H2171); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1E-20; Brain Cingulate Gyrus
rs4384683- G / EUR	DCC_ 2 (chr18: 52340 148- 52340 207)	Enhancer, neural progenitor cell (ENCODE)			1.0E-09; Brain Cingulate Gyrus
rs674437- A / EUR	-	Enhancer, H1 progenitor neurons; ENSR000004385 04 (chr11:89119401- 89120000)			1E-27; Brain Amygdala
rs4938021- T / EUR	TMPR SS5_1 (chr11: 11370 6292- 113707068)	Enhancer, neural progenitor cell; GH11J11370: chr11:113705465 -113707068)			1.0E-21; Brain Cingulate Gyrus

	11370 6351)				
rs624244- A / EUR	TCF4_ 1 (chr18: 55401 678- 55401 737) TCF4_ 9 (chr18: 55401 970- 55402 029) TCF4_ 4 (chr18: 55403 630- 55403 689)	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678- 55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1E-11; Brain Frontal Cortex
rs674437- A / EUR		Enhancer, H1 progenitor neurons; ENSR000004385 04 (chr11:89119401- 89120000)			1E-27; Brain Amygdala
rs7228159- A / EUR	TCF4_ 1 (chr18: 55401 678- 55401 737) TCF4_ 9 (chr18: 55401 970- 55402 029) TCF4_ 4 (chr18: 55403 630- 55403 689)	Enhancer, prefrontal cortex, cingulate cortex (Vista, GeneHancer Elite)	DE_00452: chr18:55401678- 55401737; Depression	SE_06758 SE_06128 (Brain - Hippocampus middle); SE_08823 (Brain - Mid frontal lobe); SE_04894 (Brain - Cingulate gyrus); SE_07784 (Brain - Inferior temporal lobe); SE_03220 (Brain - Angular gyrus); SE_04070 (Brain - Anterior caudate)	1E-11; Brain Frontal Cortex
rs61905363 -T / EUR	ANKK 1_1 (chr11: 11338 7730-	Enhancer, H1 neuronal progenitor cells, brain, astrocytes, bipolar neurons;			1E-06; Brain Hippocampus

	11338 7789)	GH11J113505: chr11:113375857 -113378219; (ENCODE, Ensemble, Vista, MASTERMIND) ; FANTOM: chr11:113375857 -113376013 (chr11:11350513 5-113505291, eRNA Score: 2)			
rs4936277- G / EUR	ANKK 1_1 (chr11: 11338 7730- 11338 7789)	Enhancer, H1 neuronal progenitor cells, brain, astrocytes, bipolar neurons; GH11J113505: chr11:113375857 -113378219; (ENCODE, Ensemble, Vista, MASTERMIND) ; FANTOM: chr11:113375857 -113376013 (chr11:11350513 5-113505291, eRNA Score: 2)			1E-06; Brain Hippocampus
rs17041417 -A / EUR		Enhancer, neural stem progenitor cell			1E-16: Brain Amygdala
rs17041417 -A / EUR		Enhancer, neural stem progenitor cell			1E-16: Brain Amygdala
rs17041417 -A / EUR		Enhancer, neural stem progenitor cell			1E-16: Brain Amygdala
rs9811546- A / EUR		Enhancer, Brain: ENSR000006926 82 (chr3:84983601- 84985999, Type: Proximal)			1E11: Brain Cingulate Gyrus
rs17041417 -A / EUR		Enhancer, Brain: ENSR000006926 82 (chr3:84983601- 84985999, Type: Proximal)			1E-16: Brain Amygdala
rs12575685 / EUR		Enhancer, brain (chr11:70367951- 70368077) FANTOM, Ensembl, VISTA			SE_69042 (H9 neurons)

rs2274316-C / EUR	MEF2 D_2 (chr1:156490647-156490706) MEF2 D_1 (chr1:156500765-156500824)	Enhancer, bipolar neurons, brain (ENCODE, Ensembl, dbSUPER, GeneHancer Double Eite); FANTOM: chr1:156502901-156503160, eRNA Score: 319; Cells: Neural progenitor cells		<u>SE_04141 (Brain - Anterior caudate); SE_08791 (Brain - Mid frontal lobe); SE_05851 SE_06826 (Brain - Hippocampus middle); SE_04925 (Brain - Cingulate gyrus); SE_07824 (Brain - Inferior temporal lobe); SE_03183 (Brain - Angular gyrus); SE_02565 (Astrocytes);</u>	1E-89: Brain Cingulate Gyrus
rs775766-A / EUR		Enhancer, neural stem progenitor cell, embryonic human cerebral cortex		SE_33104 (Brain - Cingulate gyrus)	
rs310763-C / EUR	PPAR G_2 (chr3:122875-12287934) PPAR G_3 (chr3:12288326-12288385) PPAR G_1 (chr3:12289021-12289080)	Enhancer, bipolar neurons, brain (ENCODE, Ensembl, dbSUPER, GeneHancer Double Eite); FANTOM: chr1:156502901-156503160, eRNA Score: 319; Cells: Neural progenitor cells			
rs310763-C / EUR	PPAR G_2 (chr3:122875-12287934) PPAR G_3 (chr3:12288326-12288385) PPAR G_1	Enhancer, bipolar neurons, brain (ENCODE, Ensembl, dbSUPER, GeneHancer Double Eite); FANTOM: chr1:156502901-156503160, eRNA Score: 319; Cells: Neural progenitor cells			

	(chr3:1 22890 21- 12289 080)				
rs310763-C / EUR	PPAR G_2 (chr3:1 22878 75- 12287 934) PPAR G_3 (chr3:1 22883 26- 12288 385) PPAR G_1 (chr3:1 22890 21- 12289 080)	Enhancer, bipolar neurons, brain (ENCODE, Ensembl, dbSUPER, GeneHancer Double Eite); FANTOM: chr1:156502901- 156503160, eRNA Score: 319; Cells: Neural progenitor cells			
rs1016306- T / EUR	-	Enhancer, Brain: ENSR000006926 82 (chr3:84983601- 84985999, Type: Proximal)	-		-
rs935526-T / EUR		Enhancer, frontol cortex, cingulate cortex, neurons; ENSR000006915 39 (chr3:75936001- 75936200,		SE_33104 (Brain - Cingulate gyrus)	
rs161645- A / EUR					
rs17211233 -T / EUR	RASG RF2_1 (chr5:8 09606 23- 80960 682)	Enhancer, Bipolar Neuron, Brain, Astrocytes; GH05J080966		SE_33104 (Brain - Cingulate gyrus)	
rs11214606 / EUR	TMPR SS5_1 (chr11: 11370 6292- 11370 6351)	Enhancer, neural progenitor cell; GH11J11370: chr11:113705465 -113707068)			1.0E-21; Brain Anterior Caudate

rs1400237 / EUR		Enhancer, frontal cortex, cingulate cortex, neurons; ENSR00000691539 (chr3:75936001-75936200,		SE_33104 (Brain - Cingulate gyrus)	
rs1846786-T / EUR					
rs4855976 / EUR		Enhancer, frontal cortex, cingulate cortex, neurons; ENSR00000691539 (chr3:75936001-75936200,		SE_33104 (Brain - Cingulate gyrus)	
rs79749176 - A / EUR	SLC22A15_1 (chr1:115976484-115976543)	Enhancer, frontal cortex(chr1:116520279-116520650)		SE_06669 SE_06902 (Brain - Hippocampus middle)SE_05076 (Brain - Cingulate gyrus)SE_09933 (CD14+ monocytes)SE_03600 (Brain - Angular gyrus)SE_04498 (Brain - Anterior caudate)SE_08098 (Brain - Inferior temporal lobe)	1E-08; Brain Anterior Caudate

Table 2A, Part 2. Regulatory element associated with enhancer and superenhancer SNPs that have been found in the ketamine efficacy sub-network.

GWAS SNP Reported / Population(s)	Hi-C Score	HGREEN score	Enhancer RNA co-expression p-value	Judged by machine learning to be causal in neural cell lines but not HepG2?
rs7623659-T / EUR	0.0001: Cingulate cortex	1.00E-12	2.00E-06	Yes
rs12229654-G / ASN	0.0001: Frontal cortex	1.00E-18	2.20E-09	Yes
rs30266-A / EUR	0.01: Frontal cortex			Yes
rs61902811-G / EUR	0.0001: Hippocampus	1.00E-07		Yes
rs12229654-G / ASN	0.001: Frontal cortex	1.00E-18	2.20E-23	Yes
rs6265-T / EUR		1.10E-10		Yes
rs7227069-A / EUR	0.0000000001: Cingulate cortex	1.50E-20	1.00E-05	Yes
rs12967143-G / EUR	0.0000000001: Frontal cortex	1.00E-05	1.10E-10	Yes
rs4938021-T / EUR	0.0000000001: Amygdala			Yes

rs6589377-A / EUR	0.0001: Hippocampus	1.00E-07		
rs6589377-A / EUR	0.00000000011: Cingulate cortex	1.00E-10		Yes
rs7932640-T / EUR	0.0001: Cingulate cortex	1.50E-10		Yes
rs7111031-A / EUR	0.00000000011: Anterior caudate			Yes
rs11662271-T / EUR	0.00000000011: Frontal cortex	1.00E-07		Yes
rs1373178-G / EUR	0.0001: Amygdala	1.50E-10		Yes
rs1925950-G / EUR	0.0000000001: Cingulate cortex		6.10E-11	Yes
rs8084280-T / EUR	0.0000000001: Cingulate cortex		6.30E-10	No
rs7111031-A / EUR	0.0000001: Hippocampus		3.30E-06	Yes
rs1925950-G / EUR	0.000000000000000000000000000000011: Cingulate cortex		6.10E-11	Yes
rs12520354-A / EUR	0.0000000001: Cingulate cortex			Yes
rs599550-A / EUR	0.00000000011: Frontal cortex	2.00E-05		Yes
rs613872-C / EUR	0.0001: Cingulate cortex			Yes
rs8084280-T / EUR	0.00000000011: Cingulate cortex		6.30E-10	Yes
rs11662271-T / EUR	0.0000000001: Frontal cortex	1.00E-07		Yes
rs12967143-C / EUR	0.0000000001: Frontal cortex	1.00E-05	1.10E-10	Yes
rs8181326-A / EUR	0.00000001: Cingulate cortex			Yes
rs72930774-A / EUR	0.0000000001: Frontal cortex	1.00E-05	1.10E-10	Yes
rs2958162 / EUR	0.0000000001: Cingulate cortex			Yes
<u>rs7949802-T / EUR</u>	0.0000000001: Hippocampus		3.30E-06	Yes
rs1660237-T / EUR	0.00001: Frontal cortex			Yes
rs674437-A / EUR	0.0000000001: Amygdala	1.80E-09		Yes
rs624244 / EUR	0.0000000001: Cingulate cortex			Yes
rs8099160 / EUR	0.0000000001: Cingulate cortex	1.00E-07	1.00E-21	Yes
rs674437-A / EUR	0.0000000001: Amygdala	1.80E-09		Yes
rs599550-A / EUR	0.0000000001: Cingulate cortex	2.00E-05		
rs7117514-G / EUR	0.001: Frontal cortex			Yes
rs2163971-T / EUR	0.00000001: Frontal cortex			
rs4936277-A / EUR	0.000001: Nucleus Accumbens		4.00E-05	
rs13357015 / EUR	0.0001: Cingulate cortex			Yes
rs17601612-C / EUR	0.000001: Nucleus Accumbens		4.00E-05	
rs8084351 / EUR	0.0000000001: Cingulate cortex	1.50E-20	1.00E-05	Yes

rs61687445-A / EUR	0.0000000001: Anterior caudate			Yes
rs35738585 / EUR	0.0000000001: Anterior caudate			
rs9636107-G / EUR	0.0000000001: Cingulate cortex	2.00E-05		
rs12968428-A / EUR	0.0000000001: Cingulate cortex	1.50E-20	1.00E-05	
rs8138473 / EUR	0.0000000001: Amygdala	1.00E-04		Yes
rs619466-G / EUR	0.0000000001: Cingulate cortex	2.00E-05		Yes
rs1431181-A / EUR	0.0000000001: Cingulate cortex		6.30E-10	Yes
rs1261070-? / EUR	0.0000000001: Frontal cortex	1.00E-05	1.10E-10	Yes
rs611439-? / EUR	0.00001: Frontal cortex	1.00E-05	1.10E-10	Yes
rs7231748-A / EUR	0.0000000001: Cingulate cortex	2.00E-05	1.00E-11	Yes
rs4277413-A / EUR	0.0000000001: Cingulate cortex		6.30E-10	Yes
rs1050316 / EUR	0.000001: Cingulate cortex		6.10E-11	Yes
rs139438618 / AFR	0.0000000001: Nucleus Accumbens	-	-	Yes
rs8089865-A / EUR	0.00000001: Cingulate cortex		6.30E-10	Yes
rs12958048-A / EUR	0.0000000001: Cingulate cortex	2.00E-05	1.00E-11	Yes
rs9636107 / EUR	0.0000000001: Frontal cortex	1.00E-05	1.10E-10	Yes
rs17598729-C / ASN	0.0000000001: Frontal cortex	1.00E-05	1.10E-10	Yes
rs4801157 / EUR	0.0000000001: Cingulate cortex	2.00E-05	1.00E-11	Yes
rs4384683-G / EUR	0.0000000001: Cingulate cortex		6.30E-10	Yes
rs674437-A / EUR	0.0000000001: Amygdala	1.80E-09	-	
rs4938021-T / EUR	0.0000000001: Cingulate cortex	1.00E-10	-	Yes
rs624244-A / EUR	0.0000000001: Frontal cortex	1.00E-05	1.10E-10	Yes
rs674437-A / EUR	0.0000000001: Amygdala	1.80E-09		
rs7228159-A / EUR	0.0000000001: Frontal cortex	1.00E-05	1.10E-10	Yes
rs61905363-T / EUR	0.0000000001: Hippocampus		4.00E-05	Yes
rs4936277-G / EUR	0.0000000001: Hippocampus		8.00E-08	Yes
rs17041417-A / EUR	0.0000000001: Amygdala		5.00E-11	Yes
rs17041417-A / EUR	0.0000000001: Amygdala		5.00E-11	Yes
rs17041417-A / EUR	0.0000000001: Amygdala		5.00E-11	
rs9811546-A / EUR	0.0000000001: Cingulate cortex		6.10E-11	Yes
rs17041417-A / EUR	0.0000000001: Amygdala		1.00E-11	
rs12575685 / EUR	0.0000000001: Fetal brain, female		5.00E-07	Yes
rs2274316-C / EUR	0.0000000001: Cingulate cortex		6.10E-11	Yes

[illegible]

Table 2A, Part 3. Chromatin interactions for enhancer and superenhancer SNPs that have been found in the ketamine efficacy sub-network..

GWAS SNP Reported / Population(s)	Reported gene(s)	Variant type	Reported trait	P-value	Odds ratio or beta	Confidence Interval (95%)	Pub Med ID	EBI-NHGR I Accesion Number
rs1051730-A / ASN, EUR	<i>CHRNA5, CHRNA3</i>	Intergenic	Smoking status	6.00 E-121	0.1 unit increase	[0.091-0.111]	30617275	GCST007602
rs1051730-G / EUR	<i>CHRNA5, CHRNA3</i>	Intergenic	Smoking status	3.00 E-73	1.02 CPD decrease	[0.91-1.13]	20418890	GCST000666
rs1051730-A / EUR	<i>CHRNA5, CHRNA3</i>	Intergenic	Smoking status	7.00 E-69	0.8 CPD increase	[0.70-0.90]	20418888	GCST000667
rs1051730-G / EUR	<i>CHRNA5, CHRNA3</i>	Intergenic	Smoking status	2.00 E-66	0.08	[0.07-0.09] unit decrease	20418889	GCST000668
rs2155646-C / EUR	<i>NCAM1</i>	Intragenic	Smoking status	3.00 E-61	0.0181277 unit increase	[0.016-0.02]	30643251	GCST007468
rs7938812-T / EUR	<i>NCAM1</i>	Intragenic	Smoking status	7.00 E-48	0.029930087 unit decrease	[0.026-0.034]	30643258	GCST007474
rs3130820 / EUR	<i>TRIM28</i>	Intergenic	Schizophrenia, chronic (F20)	2.00 E-44	1.281	[1.25-1.32]	29483656	GCST006803
rs3918226-T / EUR	<i>NOS3</i>	Intragenic	Medication use (agents acting on the renin-angiotensin system)	2.00 E-37	0.145321 unit increase	[0.12-0.17]	31015401	GCST007930
rs3918226 / EA (Han Chinese)	<i>NOS3</i>	Intragenic	Diastolic blood pressure and smoking status	4.00 E-33			29455858	GCS006187

rs3918226-T / AFR, AMR, ASN, EUR	NOS3	Intrag enic	Diastolic blood pressure x alcohol consumption interaction (2df test)	4.00 E-31			2991 2962	GCST0 06166
rs3918226-T / EUR	NOS3	Intrag enic	Medication use (diuretics)	7.00 E-29	0.1665414 unit increase	[0.14-0.2]	3101 5401	GCST0 07928
rs3918226-T / EUR	NOS3	Intrag enic	Medication use (calcium channel blockers)	4.00 E-26	0.16126491 unit increase	[0.13-0.19]	3101 5401	GCST0 07929
rs155290 / EUR	NCAM1	Intrag enic	Risk-taking behavior	4.00 E-24	0.026843483 unit decrease	[0.022-0.032]	3064 3258	GCST0 07323
rs182812355-A / ASN	TRIM27, TRIM28	Interg enic	Schizophrenia , chronic (F20)	7.00 E-23	1.206	[1.17-1.24]	3028 5260	GCST0 07201
rs3918226-T / EUR	NOS3	Intrag enic	Medication use (beta blocking agents)	8.00 E-21	0.14636576 unit increase	[0.12-0.18]	3101 5401	GCST0 07927
rs12764899 / EUR	BORCS7-ASMT, AS3MT	Interg enic	Cognitive ability, years of educational attainment or schizophrenia (pleiotropy)	3.00 E-20	0.02186565 unit increase	[0.017-0.027]	3137 4203	GCST0 08595
rs11191424-G / EUR	BORCS7-ASMT, AS3MT	Interg enic	Schizophrenia , chronic (F20)	4.00 E-20	1.0905125	[1.07-1.11]	2899 1256	GCST0 04946
rs2007044 / ASN	CACNA1C	Intrag enic	Schizophrenia , chronic (F20)	6.00 E-20	1.0928961	1.07-1.11	2948 3656	GCST0 06803
rs2159100 / ASN, EUR	CACNA1C	Intrag enic	Schizophrenia , chronic (F20)	3.00 E-19	1.102	1.08-1.12	2899 1256	GCST0 04946
rs514465-A / EUR	GABRA2	Intrag enic	Risk-taking behavior	2.00 E-18	0.0104 unit increase	0.008-0.0128	3064 3258	GCST0 07323
rs2007044-G / ASN, EUR	CACNA1C	Intrag enic	Schizophrenia , chronic (F20)	3.00 E-18	1.0964912	[1.07-1.12]	2505 6061	GCST0 02539
rs1024582-A / ASN	CACNA1C	Intrag enic	Schizophrenia , chronic (F20)	9.00 E-18	1.1037527	1.08-1.13	3028 5260	GCST0 07201
rs2007044 / EUR	CACNA1C	Intrag enic	Schizophrenia , chronic (F20)	1.00 E-17	1.098901		2619 8764	GCST0 02539
rs10774909 / EUR	NOS1	Intrag enic	Neuroticism, general	5.00 E-16	0.009250518 unit increase	0.007-0.0115	3064 3256	GCST0 07339
rs2007044 / EUR	CACNA1C	Intrag enic	Cognitive ability, years of educational attainment or schizophrenia (pleiotropy)	2.00 E-15	0.016178014 unit increase	[0.012-0.02]	3137 4203	GCST0 08595

rs7192140	<i>GRIN2A</i>	Intrag enic	Smoking status	2.00 E-15	0.00854911 unit decrease	[0.0064- 0.0107]	3064 3251	GCST0 07468
rs2239030-A / EUR	<i>CACNA1C</i>	Intrag enic	Risk-taking behavior	6.00 E-15	0.0093 unit increase	0.0069- 0.0117	3064 3258	GCST0 07323
rs3918226-T / EA (Han Chinese)	<i>NOS3</i>	Intrag enic	Systolic blood pressure x alcohol consumption interaction (2df test)	2.00 E-14			2991 2962	GCST0 06434
rs11055991- A / EUR	<i>ATF7IP</i>	Intrag enic	Cognitive performance (MTAG)	5.00 E-14	0.0175 unit decrease	[0.013- 0.022]	3003 8396	GCST0 06570
rs2007044 / EUR	<i>CACNA1C</i>	Intrag enic	Autism spectrum disorder or schizophrenia	6.00 E-14	1.0752687	1.05-1.1	2854 0026	GCST0 04521
rs1024582-A / EUR	<i>CACNA1C</i>	Intrag enic	Autism spectrum disorder or schizophrenia	8.00 E-14	1.093		2854 0026	GCST0 04521
rs7893279-T / ASN, EUR	<i>CACNB2</i>	Intrag enic	Schizophrenia , chronic (F20)	9.00 E-14	1.122	1.09-1.15	3028 5260	GCST0 07201
rs8042374-A / EA (Han Chinese)	<i>CHRNA3</i>	Intrag enic	Schizophrenia , chronic (F20)	2.00 E-13	1.093	[1.067- 1.119]	2899 1256	GCST0 04946
rs7893279-T / ASN , EUR	<i>CACNB2</i>	Intrag enic	Schizophrenia , chronic (F20)	3.00 E-13	1.117	[1.09-1.15]	2899 1256	GCST0 04946
rs7893279-T, ASN, EUR	<i>CACNB2</i>	Intrag enic	Schizophrenia , chronic (F20)	5.00 E-13	1.118	[1.09-1.15]	2899 1256	GCST0 04946
rs1006737 / EUR	<i>CACNA1C</i>	Intrag enic	Schizophrenia or bipolar I disorder	6.00 E-13			2428 0982	GCST0 02295
rs28681284- C / ASN	<i>CHRNA5</i> , <i>CHRNA3</i>	Interg enic	Schizophrenia , chronic (F20)	6.00 E-13	1.121	1.09-1.15	3028 5260	GCST0 07201
rs7893279-T / ASN, EUR	<i>CACNB2</i>	Intrag enic	Schizophrenia , chronic (F20)	9.00 E-13	1.117	1.09-1.15	2899 1256	GCST0 04946
rs3918226 / EUR	<i>NOS3</i>	Intrag enic	Systolic blood pressure (cigarette smoking interaction)	2.00 E-12			2945 5858	GCST0 06188
rs7893279-T / ASN (Han Chinese), EUR	<i>CACNB2</i>	Intrag enic	Schizophrenia , chronic (F20)	2.00 E-12	1.125	[1.088- 1.162]	2505 6061	GCST0 02539
rs1006737-A / EUR	<i>CACNA1C</i>	Intrag enic	Schizophrenia , chronic (F20)	5.00 E-12	1.103	[1.08-1.13]	2397 4872	GCST0 02149

rs111294930-A / EUR	<i>LINC01470, GRIA1</i>	Intergenic	Schizophrenia, chronic (F20)	9.00 E-12	1.086	[1.06-1.11]	2948 3656	GCST0 06803
rs7688285-C / AFR, EUR	<i>GLRB</i>	Intronic	Panic disorder, startle response, fear	7.00 E-12	1.50163 unit increase	1.27-1.67	2816 7838	
rs641574-A / EUR	<i>GRIA4</i>	Intragenic	Cognitive function	1.00 E-11	0.016 unit decrease	0.011-0.021	3003 8396	GCST0 06570
rs2298527-C / EUR	<i>NCAM1</i>	Intragenic	Increased neuroticism	3.00 E-11	6.653 z score decrease		2925 5261	GCST0 05232
rs7192140-C / EUR	<i>GRIN2A</i>	Intragenic	Smoking status	3.00 E-11	0.016883379 unit decrease	[0.012-0.022]	3064 3251	GCST0 07468
rs9292918-G / ASN	<i>HCN1</i>	Intragenic	Schizophrenia, chronic (F20)	4.00 E-11	1.0729614 unit increase	1.05-1.09	2899 1256	GCST0 04946
rs2155290-C / EUR	<i>NCAM1</i>	Intragenic	Risky sexual behavior measurement	5.00 E-11	0.015957858 unit decrease	[0.011-0.021]	3064 3258	GCST0 07326
rs16902086 / EUR	<i>HCN1</i>	Intragenic	Schizophrenia, chronic (F20)	6.00 E-11	1.0683761 unit increase	1.05-1.09	2928 3656	GCST0 06803
rs7893279-T / ASN (Han Chinese), EUR	<i>CACNB2</i>	Intragenic	Schizophrenia, chronic (F20)	6.00 E-11	1.12		2619 8764	GCST0 03048
rs2239030-A / EUR	<i>CACNA1C</i>	Intragenic	Risk-taking behavior	7.00 E-11	0.012764932 unit increase	0.0089-0.0166	3064 3258	GCST0 07323
rs1837016-T / EUR	<i>NQO1</i>	Intragenic	Risk-taking tendency (4-domain principal component model)	7.00 E-11	0.017263984 unit decrease	[0.012-0.022]	3064 3258	GCST0 07323
rs111294930-A / ASN, EUR	<i>LINC01470, GRIA1</i>	Intergenic	Schizophrenia, chronic (F20)	1.00 E-10	1.094	[1.064-1.124]	2505 6061	GCST0 02539
rs62367520 / EUR	<i>HCN1</i>	Intragenic	Smoking status	1.00 E-10	0.186		2928 3656	GCST0 07468
rs11647445-G / EUR	<i>GRIN2A</i>	Intragenic	Bipolar I disorder	1.00 E-10	1.0785276		3104 3756	GCST0 08103
rs7893279-T / ASN (Han Chinese), EUR	<i>CACNB2</i>	Intragenic	Schizophrenia, chronic (F20)	1.00 E-10	1.119	[1.08-1.15]	3028 5260	GCST0 07201
rs4782271-A / EUR	<i>GRIN2A</i>	Intragenic	Risk-taking behavior	2.00 E-10	0.01 unit increase	[0.0069-0.0131]	3064 3258	GCST0 07325
rs7893279-T / EUR	<i>CACNB2</i>	Intragenic	Schizophrenia, autism spectrum disorder	3.00 E-10	1.1	[1.07-1.14]	2854 0026	GCST0 04521
rs73047488 / EUR	<i>GRIN2B</i>	Intragenic	Risk-taking behavior	3.00 E-10	0.0078 unit increase	0.0054-0.0102	3064 3258	GCST0 07325

rs3825845-C / ASN	<i>CHRNA3</i>	Intragenic	Schizophrenia , chronic (F20)	4.00 E-10	1.12		3028 5260	GCST0 07201
rs10744560 / EUR	<i>CACNA1C, CACNA1C-IT3</i>	Intragenic	Bipolar I, II disorder	4.00 E-10	1.07595	[1.05-1.1]	3104 3756	GCST0 08103
rs113551349 / EUR	<i>SLC6A9</i>	Intragenic	ADHD and lifetime cannabis use	5.00 E-10	1.098901	[1.08-1.14]	3061 0198	GCST0 06983
rs2973155-C / EUR	<i>GRIA1, LINC01470</i>	Intergenic	Schizophrenia , chronic (F20)	8.00 E-10	1.0638298		2619 8764	GCST0 03048
rs13233131 / EUR	<i>CHRM2</i>	Intragenic	Risk-taking behavior	8.00 E-10	0.0095 unit decrease	[0.0066-0.0124]	3064 3258	GCST0 07325
rs758117-C / ASN	<i>CACNA1C</i>	Intragenic	Schizophrenia , chronic (F20)	8.00 E-10	1.0695187	[1.05-1.09]	3028 5260	GCST0 07201
rs872123 / EUR	<i>GAD1</i>	Intragenic	Cognitive function	1.00 E-09	0.0208 unit increase	[0.014-0.027]	3003 8396	GCST0 06572
rs2973155-C / EUR	<i>GRIA1</i>	Intragenic	Schizophrenia , chronic (F20)	1.00 E-09	1.0638298		2619 8764	GCST0 03048
rs13176930-T / ASN	<i>LINC01470, GRIA1</i>	Intergenic	Schizophrenia , chronic (F20)	1.00 E-09	1.0718113	1.05-1.09	2619 8764	GCST0 07201
rs9292918 / EUR	<i>HCN1</i>	Intragenic	Schizophrenia , chronic (F20)	1.00 E-09	1.0683761	[1.05-1.09]	2928 3656	GCST0 07201
rs1478364-T / EUR	<i>GRIA1, LINC01470</i>	Intragenic	Risk-taking behavior	2.00 E-09	0.0091 unit decrease	[0.0062-0.012]	3064 3258	GCST0 07325
<u>rs9922678 (rs9926303) / EUR</u>	<i>GRIN2A</i>	Intragenic	Schizophrenia , chronic (F20)	2.00 E-09	1.07		2619 8764	GCST0 03048
rs7191183 / EUR	<i>GRIN2A</i>	Intragenic	Autism spectrum disorder or schizophrenia	2.00 E-09	1.0638298	[1.04-1.09]	2854 0026	GCST0 04521
rs9922678-A / ASN, EUR	<i>GRIN2A</i>	Intragenic	Schizophrenia , chronic (F20)	3.00 E-09	1.065	[1.04-1.09]	2899 1256	GCST0 04946
rs17504622-T / ASN, EUR	<i>GRIN2A</i>	Intragenic	Schizophrenia , chronic (F20)	3.00 E-09	1.238	[1.17-1.31]	2899 1256	GCST0 04946
rs728022696 / EUR	<i>LINC01470, GRIA1</i>	Intragenic	Schizophrenia , chronic (F20)	3.00 E-09	1.24	[1.17-1.31]	2397 4872	GCST0 02149
rs4765913 / EUR	<i>CACNA1C</i>	Intragenic	Bipolar I, II disorder	3.00 E-09	1.13		2807 2414	GCST0 03962
rs9922678 / ASN, EUR	<i>GRIN2A</i>	Intragenic	Schizophrenia , chronic (F20)	3.00 E-09			2899 1256	
rs13176930 / EUR	<i>GRIA1, LINC01470</i>	Intergenic	Schizophrenia , chronic (F20)	1.00 E-09	1.0638298		2619 8764	GCST0 03048

rs117578877-T / EUR	<i>GRIN2B</i>	Intra-genic	Risk-taking behavior	4.00 E-09			3064 3258	GCST0 07324
rs1501357-C / ASN, EUR	<i>HCN1</i>	Intra-genic	Schizophrenia, chronic (F20)	5.00 E-09	1.08E+00	[1.05-1.11]	2505 6061	GCST0 02539
rs4765914 / EUR	<i>CACNA1C</i>	Intra-genic	Bipolar disorder	5.00 E-09			3062 6913	
rs1006737 / EUR	<i>CACNA1C</i>	Intra-genic	Attention deficit hyperactivity disorder, unipolar depression, schizophrenia, autism spectrum disorder, bipolar disorder	5.00 E-09	1.071	[1.05-1.10]	2345 3885	GCST0 01877
rs9922678-A / ASN	<i>GRIN2A</i>	Intra-genic	Schizophrenia, chronic (F20)	6.00 E-09	1.0708	[1.05-1.09]	3028 5260	GCST0 07201
rs10744560-T	<i>CACNA1C, CACNA1C-IT3</i>	Inter-genic	Bipolar I disorder	8.00 E-09	1.123444		3104 3756	GCST0 08115
rs1501357-C / EUR	<i>HCN1</i>	Intra-genic	Schizophrenia, chronic (F20)	1.00 E-08	1.0752687		2928 3656	GCST0 03048
rs9922678-A / ASN, EUR	<i>GRIN2A</i>	Intra-genic	Schizophrenia, chronic (F20)	1.00 E-08	1.062	[1.04-1.08]		GCST0 07201
rs68081839 / EUR	<i>GRIA4</i>	Intra-genic	Nicotine dependence and major depression	2.00 E-08	0.6587 unit increase	[0.43-0.89]	3028 7806	GCST0 06631
rs28607014-C / EA (Han Chinese)	<i>NOS1</i>	Intra-genic	Schizophrenia, chronic (F20)	2.00 E-08	1.0570824	[1.04-1.08]	2899 1256	GCST0 04946
rs12522290-C / EUR	<i>LINC01470, GRIA1</i>	Inter-genic	Autism spectrum disorder, schizophrenia	2.00 E-08	1.08	[1.05-1.11]	2854 0026	GCST0 04521
rs1006737-A / EUR	<i>CACNA1C</i>	Intra-genic	Bipolar II disorder or major depressive disorder	3.00 E-08			2035 1715	GCST0 00641
rs73568641-C / AFR	<i>OPRM1</i>	Intra-genic	Methadone maintenance, heroin addiction	3.00 E-08	0.6808 unit increase	[0.44-0.92]	2637 7243	GCST0 04136
rs13170232-T / EUR	<i>GRIA1</i>	Intra-genic	Schizophrenia, chronic (F20)	5.00 E-08	1.098901		2619 8764	GCST0 03048

rs9292918 / EUR	<i>HCN1</i>	Intra-genic	Autism spectrum disorder, schizophrenia	5.00 E-08	1.0638298	[1.04-1.1]	2854 0026	GCST0 04521
rs12522290-C	<i>GRIA1</i>	Intra-genic	Schizophrenia, chronic (F20)	5.00 E-08	1.08		2619 8764	GCST0 03048
rs13008299-G / EUR	<i>TOGARAM2</i>	Intra-genic	Diastolic blood pressure and alcoholism	7.00 E-07*	0.068 unit decrease	0.033-0.103	2437 6456	GCST0 02309
rs117578877-T / EUR	<i>AC007527.1, GRIN2B</i>	Inter-genic	Schizophrenia, chronic (F20)	9.00 E-07*	1.15		2619 8764	GCST0 03048
rs11127199-G / EUR	<i>TOGARAM2</i>	Intra-genic	Response to ketamine in bipolar disorder or major depression (increase, dissociation effects)	7.00 E-06*	11.445 unit increase	6.82-16.07	3055 2317	GCST0 07317

Table 2B, Part 1. Enhancer and superenhancer SNPs that have been found in the ketamine adverse event sub-network.

GWA S SNP Reported / Population(s)	Promoters (EPDnew); PromID	Enhancers	Validated casual human disease enhancer-promoter pairs	Superenhancers (dbSUPER)	eQTL
rs1051730-A / ASN, EUR	CHRN A3_1 (chr15:7862098-6-78621045)	Enhancer: neural stem progenitor cell, SK-N-SH cells; ENCODE(ZLab), Ensembl; FANTOM: eRNA score = 40		SE_07079 SE_05923 (Brain - Hippocampus middle)SE_07917 (Brain - Inferior temporal lobe)SE_32861 (H1-ESC)SE_05045 (Brain - Cingulate gyrus)SE_68844 (H9)	5E-06, Brain - Nucleus accumbens (basal ganglia)
rs1051730-G / EUR	CHRN A3_1 (chr15:7862098-6-78621045)	Enhancer: neural stem progenitor cell, SK-N-SH cells; ENCODE(ZLab), Ensembl; FANTOM: eRNA score = 40		SE_07079 SE_05923 (Brain - Hippocampus middle)SE_07917 (Brain - Inferior temporal lobe)SE_32861 (H1-ESC)SE_05045 (Brain - Cingulate	5E-06, Brain - Nucleus accumbens (basal ganglia)

				gyrus)SE_68844 (H9)	
rs1051730-A / EUR	<u>CHRN</u> <u>A3_1 (chr15:78620986-78621045)</u>	Enhancer: neural stem progenitor cell, SK-N-SH cells; ENCODE(ZLab), Ensembl; FANTOM: eRNA score = 40		SE_07079 SE_05923 (Brain - Hippocampus middle)SE_07917 (Brain - Inferior temporal lobe)SE_32861 (H1-ESC)SE_05045 (Brain - Cingulate gyrus)SE_68844 (H9)	5E-06, Brain - Nucleus accumbens (basal ganglia)
rs1051730-G / EUR	<u>CHRN</u> <u>A3_1 (chr15:78620986-78621045)</u>	Enhancer: neural stem progenitor cell, SK-N-SH cells; ENCODE(ZLab), Ensembl; FANTOM: eRNA score = 40		SE_07079 SE_05923 (Brain - Hippocampus middle)SE_07917 (Brain - Inferior temporal lobe)SE_32861 (H1-ESC)SE_05045 (Brain - Cingulate gyrus)SE_68844 (H9)	5E-06, Brain - Nucleus accumbens (basal ganglia)
rs2155646-C / EUR		Enhancer: H1-hESC, neural stem progenitor cell, Brain (chr11:113059055-113059658 (chr11:113188333-113188936, eRNA Score: 482) ENCODE, Ensembl, FANTOM, Vista		SE_05136 (Brain - Cingulate gyrus)	8.2E-111, Brain Cingulate Gyrus
rs7938812-T / EUR		Enhancer: H1-hESC, neural stem progenitor cell		SE_05136 (Brain - Cingulate gyrus)	1.1E-17, Brain Cingulate Gyrus
rs3130820 / EUR	TRIM28_1 (chr19:58544407-58544466) TRIM28_2 (chr19:58544703-58544762)	Enhancer, Astrocytes, bipolar neuron, brain; ENSR00000111889 (chr19:58543000-58546201); ENSR00000594490 (chr19:58546400-58547001)		SE_33104 (Brain - Cingulate gyrus)	1E-23; Brain Cingulate Gyrus
rs3918226-T / EUR	NOS3_2 (chr7:1509910)	Enhancer, Astrocytes, bipolar neuron, brain; ENSR00000843798 (chr7:151007800-			1.1E-07, Brain

	10-150991069)	151009201); ENSR00000843799 (chr7:151013000-151014601) ENSR00000843800 (chr7:151010400-151011201)			Cerebellum
rs3918226 / EA (Han Chinese)	NOS3_2 (chr7:150991010-150991069)	Enhancer, Astrocytes, bipolar neuron, brain; ENSR00000843798 (chr7:151007800-151009201); ENSR00000843799 (chr7:151013000-151014601) ENSR00000843800 (chr7:151010400-151011201)			1.1E-07, Brain Cerebellum
rs3918226-T / AFR, AMR, ASN, EUR	NOS3_2 (chr7:150991010-150991069)	Enhancer, Astrocytes, bipolar neuron, brain; ENSR00000843798 (chr7:151007800-151009201); ENSR00000843799 (chr7:151013000-151014601) ENSR00000843800 (chr7:151010400-151011201)			1.1E-07, Brain Cerebellum
rs3918226-T / EUR	NOS3_2 (chr7:150991010-150991069)	Enhancer, Astrocytes, bipolar neuron, brain; ENSR00000843798 (chr7:151007800-151009201); ENSR00000843799 (chr7:151013000-151014601) ENSR00000843800 (chr7:151010400-151011201)			1.1E-07, Brain Cerebellum
rs3918226-T / EUR	NOS3_2 (chr7:150991010-150991069)	Enhancer, Astrocytes, bipolar neuron, brain; ENSR00000843798 (chr7:151007800-151009201); ENSR00000843799 (chr7:151013000-151014601) ENSR00000843800 (chr7:151010400-151011201)			1.1E-07, Brain Cerebellum
rs2155290 / EUR		Enhancer: H1-hESC, neural stem progenitor cell, Brain (chr11:113059055-113059658 (chr11:113188333-		SE_05136 (Brain - Cingulate gyrus)	8.2E-111, Brain Cingul

		113188936, eRNA Score: 482) ENCODE, Ensembl, FANTOM, Vista			ate Gyrus
rs182812355-A / ASN	TRIM28_1 (chr19:58544407-58544466) TRIM28_2 (chr19:58544703-58544762)	Enhancer, Astrocytes, bipolar neuron, brain; ENSR00000111889 (chr19:58543000-58546201); ENSR00000594490 (chr19:58546400-58547001)		SE_33104 (Brain - Cingulate gyrus)	1E-23; Brain Cingulate Gyrus
rs3918226-T / EUR	NOS3_2 (chr7:150991010-150991069)	Enhancer, Astrocytes, bipolar neuron, brain; ENSR00000843798 (chr7:151007800-151009201); ENSR00000843799 (chr7:151013000-151014601); ENSR00000843800 (chr7:151010400-151011201)			1.1E-07, Brain Cerebellum
rs12764899 / EUR	BORCS7_1 (chr10:102854213-102854272)	Enhancer, ENSR00000414241 (chr10:102782600-102782801)		SE_04641 (Brain - Anterior caudate) SE_06458 (Brain - Hippocampus middle)	1.1E-19, Brain Hippocampus
rs11191424-G / EUR	BORCS7_1 (chr10:102854213-102854272)	Enhancer, ENSR00000414241 (chr10:102782600-102782801)		SE_04641 (Brain - Anterior caudate) SE_06458 (Brain - Hippocampus middle)	1.1E-19, Brain Hippocampus
rs2007044 / ASN		Enhancer: H1-hESC, neural stem progenitor cell	DE_00452: chr12:2339802-2367400; Schizophrenia		3.0E-15, Brain Cingulate Gyrus
<u>rs2159100 / ASN, EUR</u>		Enhancer: H1-hESC, neural stem progenitor cell	DE_00452: chr12:2339802-2367400; Schizophrenia		3.0E-15, Brain Cingulate Gyrus

rs5144 65-A / EUR	GABR A2_3 (chr4:4 638945 6- 463895 15) GABR A2_1 (chr4:4 638997 0- 463900 29) GABR A2_2 (chr4:4 639011 8- 463901 77)	Enhancer, Bipolar neuron, Brain; GH04J046508:			6E-20; Nerve tibial
rs2007 044-G / ASN, EUR		Enhancer: H1-hESC, neural stem progenitor cell	DE_00452: chr12 :2339802- 2367400; Schizophrenia		3.0E- 15, Brain Cingul ate Gyrus
rs1024 582-A / ASN		Enhancer, Bipolar neuron, Brain	DE_00452: chr12 :2339802- 2367400; Schizophrenia		3.0E- 15, Brain Cingul ate Gyrus
rs2007 044 / EUR		Enhancer: H1-hESC, neural stem progenitor cell	DE_00452: chr12 :2339802- 2367400; Schizophrenia		3.0E- 15, Brain Cingul ate Gyrus
rs1077 4909 / EUR		Enhancer: H1-hESC, neural stem progenitor cell, SK-N- SH cells; GH12J117579: chr12:118017798- 118019205; ENCODE(ZLab), Ensembl; FANTOM: eRNA score = 3			
rs2007 044 / EUR		Enhancer: H1-hESC, neural stem progenitor cell	DE_00452: chr12 :2339802- 2367400; Schizophrenia		3.0E- 15, Brain Cingul ate Gyrus
rs7192 140	GRIN2 A_3 (chr16: 101819	Enhancer, Bipolar neuron, H1 neuronal progenitor cells; GH16J010079: chr16:10173268-10175436;			1.1E- 12, Brain Fronta

	41-10182000) GRIN2A_2 (chr16:10182377-10182436) GRIN2A_4 (chr16:10182692-10182751) GRIN2A_1 (chr16:10182872-10182931)	ENCODE(ZLab), Ensembl, dbSUPER			1 Cortex
rs2239030-A / EUR		Enhancer, Cingulate Gyrus; GH12J002226: chr12:2335414-2336748; dbSUPER, MASTERMIND	DE_00452: chr12:2339802-2367400; Schizophrenia		7E-25: Brain Cingulate Gyrus
rs3918226-T / EA (Han Chinese)	NOS3_2 (chr7:150991010-150991069)	Enhancer, Astrocytes, bipolar neuron, brain; ENSR00000843798 (chr7:151007800-151009201); ENSR00000843799 (chr7:151013000-151014601) ENSR00000843800 (chr7:151010400-151011201)			1.1E-07, Brain Cerebellum
rs11055991-A / EUR					
rs2007044 / EUR		Enhancer: H1-hESC, neural stem progenitor cell	DE_00452: chr12:2339802-2367400; Schizophrenia		3.0E-15, Brain Cingulate Gyrus
rs1024582-A / EUR		Enhancer: H1-hESC, neural stem progenitor cell	DE_00452: chr12:2339802-2367400; Schizophrenia		5.5E-35, Brain Cingulate Gyrus

rs7893 279-T / ASN, EUR		Enhancer, Astrocytes,Bipolar neuron,Brain			2.00E- 15; Brain Frontal Cortex
rs8042 374-A / EA (Han Chinese)	<u>CHRN</u> <u>A3_2</u> (<u>chr15:7</u> <u>862126</u> <u>9-</u> <u>786213</u> <u>28</u>)	Enhancer: neural stem progenitor cell, SK-N-SH cells; ENCODE(ZLab), Ensembl; FANTOM: eRNA score = 40		SE_07079 SE_05923 (Brain - Hippocampus middle)SE_07917 (Brain - Inferior temporal lobe)SE_32861 (H1- ESC)SE_05045 (Brain - Cingulate gyrus)SE_68844 (H9)	5.5E- 35, Brain Cingulate Gyrus
rs7893 279-T / ASN , EUR		Enhancer, Astrocytes,Bipolar neuron,Brain			2.00E- 15; Brain Frontal Cortex
rs7893 279-T, ASN, EUR		Enhancer, Astrocytes,Bipolar neuron,Brain			2.00E- 15; Brain Frontal Cortex
rs1006 737 / EUR		Enhancer, Cingulate Gyrus; GH12J002226: chr12:2335414-2336748; dbSUPER	DE_00452: chr12 :2339802- 2367400; Schizophrenia;23andMe blog rs1006737 or (rs2159100) Each T at this SNP increased the odds of bipolar disorder by 1.9-fold		1E-12: Brain Frontal Cortex
rs2868 1284- C / ASN		Enhancer: neural stem progenitor cell, SK-N-SH cells; ENCODE(ZLab), Ensembl; FANTOM: eRNA score = 40		SE_07079 SE_05923 (Brain - Hippocampus middle)SE_07917 (Brain - Inferior temporal lobe)SE_32861 (H1- ESC)SE_05045 (Brain - Cingulate gyrus)SE_68844 (H9)	5.5E- 35, Brain Cingulate Gyrus
rs7893 279-T / ASN, EUR		Enhancer, Astrocytes,Bipolar neuron,Brain			2.00E- 15; Brain Frontal Cortex
rs3918 226 / EUR	NOS3_ 2 (chr7:1	Enhancer, Astrocytes, bipolar neuron, brain; ENSR00000843798			1.1E- 07, Brain

	509910-10-150991069)	(chr7:151007800-151009201); ENSR00000843799 (chr7:151013000-151014601) ENSR00000843800 (chr7:151010400-151011201)			Cerebellum
rs7893279-T / ASN (Han Chinese), EUR		Enhancer, Astrocytes, Bipolar neuron, Brain			2.00E-15; Brain Frontal Cortex
rs1006737-A / EUR		Enhancer, Cingulate Gyrus; GH12J002226: chr12:2335414-2336748; dbSUPER	DE_00452: chr12:2339802-2367400; Schizophrenia; 23andMe blog rs1006737 or (rs2159100) Each T at this SNP increased the odds of bipolar disorder by 1.9-fold		1E-12; Brain Frontal Cortex
rs111294930-A / EUR	GRIA1_1 (chr5:153490621-153490680)	Enhancer, Brain, neural progenitor cell: ENSR00000774341 (chr5:153490200-153492801) Ensemble, ENCODE, FANTOM			1E-25; Brain Cingulate Gyrus
rs7688285-C / AFR, EUR	<u>GLRB_1 (chr4:157076101-157076160)</u>	Enhancer, <i>GLRB</i> , <i>GRIA2</i> , <i>PDGFC</i> , Astrocytes, Brain; ENCODE(ZLab), Ensembl, dbSUPER			1E-22, Amygdala
rs641574-A / EUR	GRIA4_1 (chr11:105610024-105610083) GRIA4_3 (chr11:105610666-105610725) GRIA4_2 (chr11:105610842-105610901)	chr11:105609674-105612903		SE_05045 (Brain - Cingulate gyrus)	1E-25; Brain Cingulate Gyrus

rs2298 527-C / EUR		Enhancer: H1-hESC, neural stem progenitor cell, Brain (chr11:113059055-113059658 (chr11:113188333-113188936, eRNA Score: 482) ENCODE, Ensembl, FANTOM, Vista		SE_05136 (Brain - Cingulate gyrus)	8.2E-111, Brain Cingulate Gyrus
rs7192 140-C / EUR	GRIN2 A_3 (chr16:10181941-10182000) GRIN2 A_2 (chr16:10182377-10182436) GRIN2 A_4 (chr16:10182692-10182751) GRIN2 A_1 (chr16:10182872-10182931)	Enhancer, Bipolar neuron, H1 neuronal progenitor cells; GH16J010079: chr16:10173268-10175436; ENCODE(ZLab), Ensembl, dbSUPER			1.1E-12, Brain Frontal Cortex
rs9292 918-G / ASN	HCN1_1 (chr5:45696271-45696330)	Enhancer, Bipolar Neuron, Brain, neural progenitor cell; ENSR00000754146 (chr5:45453802-45454473, Type: Proximal): ENOCDE, Ensembl, FANTOM		SE_05045 (Brain - Cingulate gyrus)	1E-11; Frontal Cortex
rs2155 290-C / EUR		Enhancer: H1-hESC, neural stem progenitor cell, Brain (chr11:113059055-113059658 (chr11:113188333-113188936, eRNA Score: 482) ENCODE, Ensembl, FANTOM, Vista		SE_05136 (Brain - Cingulate gyrus)	8.2E-111, Brain Cingulate Gyrus
rs1690 2086 / EUR	HCN1_1 (chr5:45696271-45696330)	Enhancer, Bipolar Neuron, Brain, neural progenitor cell; ENSR00000754146 (chr5:45453802-45454473, Type: Proximal):		SE_05045 (Brain - Cingulate gyrus)	1E-11; Brain Frontal Cortex

	45696330)	ENOCDE, Ensembl, FANTOM			
rs7893279-T / ASN (Han Chinese), EUR		Enhancer, Astrocytes, Bipolar neuron, Brain			2.00E-15; Brain Frontal Cortex
rs2239030-A / EUR		Enhancer, Cingulate Gyrus; GH12J002226: chr12:2335414-2336748; dbSUPER	DE_00452: chr12:2339802-2367400; Schizophrenia; 23andMe blog rs1006737 or (rs2159100) Each T at this SNP increased the odds of bipolar disorder by 1.9-fold		1E-12; Brain Frontal Cortex
rs1837016-T / EUR	NQO1_1 (chr16:69726550-69726609) NQO1_2 (chr16:69726912-69726971)	Promoter/Enhancer, Brain, Bipolar neurons, neural progenitor cells, liver; GH16J069721: chr16:69755550-69762759; ENCODE(Z-Lab), EPDnew, Ensembl, FANTOM5, dbSUPER; Elite	-	SE_35409 (HepG2) SE_05045 (Brain-Cingulate Gyrus)	-
rs111294930-A / ASN, EUR	GRIA1_1 (chr5:153490621-153490680)	Enhancer, Brain, neural progenitor cell: ENSR00000774341 (chr5:153490200-153492801) Ensemble, ENCODE, FANTOM			1E-25; Brain Cingulate Gyrus
rs62367520 / EUR	HCN1_1 (chr5:45696271-45696330)	Enhancer, Bipolar Neuron, Brain, neural progenitor cell; ENSR00000754146 (chr5:45453802-45454473, Type: Proximal): ENOCDE, Ensembl, FANTOM		SE_05045 (Brain - Cingulate gyrus)	1E-11; Brain Frontal Cortex
rs11647445-G / EUR	GRIN2A_3 (chr16:10181941-10182000) GRIN2A_2 (chr16:10182377-	Enhancer, Bipolar neuron, H1 neuronal progenitor cells; GH16J010079: chr16:10173268-10175436; ENCODE(ZLab), Ensembl, dbSUPER			1.1E-12, Brain Frontal Cortex

	10182436) GRIN2A_4 (chr16:10182692-10182751) GRIN2A_1 (chr16:10182872-10182931)				
rs7893279-T / ASN (Han Chinese), EUR		Enhancer, Astrocytes, Bipolar neuron, Brain			2.00E-15; Brain Frontal Cortex
rs4782271-A / EUR	GRIN2A_3 (chr16:10181941-10182000) GRIN2A_2 (chr16:10182377-10182436) GRIN2A_4 (chr16:10182692-10182751) GRIN2A_1 (chr16:10182872-10182931)	Enhancer, Bipolar neuron, H1 neuronal progenitor cells; GH16J010079: chr16:10173268-10175436; ENCODE(ZLab), Ensembl, dbSUPER			1.1E-12, Brain Frontal Cortex
rs7893279-T / EUR		Enhancer, Astrocytes, Bipolar neuron, Brain			2.00E-15; Brain Frontal

					1 Cortex
rs7304 7488 / EUR	GRIN2 B_1 (chr12: 139804 10- 139804 69) GRIN2 B_2 (chr12: 139819 66- 139820 25)	Enhancer, Bipola Neuron, Brain; ENSR00000451168 (chr12:13980400- 13982401) Ensembl, VISTA, FANTOM		SE_33104 (Brain - Cingulate gyrus)	3.00E- 10; Amyg ala
rs3825 845-C / ASN	<u>CHRN</u> <u>A3_2</u> (<u>chr15:7</u> <u>862126</u> <u>9-</u> <u>786213</u> <u>28</u>)	Enhancer: neural stem progenitor cell, SK-N-SH cells; ENCODE(ZLab), Ensembl; FANTOM: eRNA score = 40		SE_07079 SE_05923 (Brain - Hippocampus middle)SE_07917 (Brain - Inferior temporal lobe)SE_32861 (H1- ESC)SE_05045 (Brain - Cingulate gyrus)SE_68844 (H9)	5.5E- 35, Brain Cingul ate Gryus
rs1074 4560 / EUR	-	Enhancer, Cingulate Gyrus; GH12J002226: chr12:2335414-2336748; dbSUPER	DE_00452: chr12 :2339802- 2367400; Schizophrenia;23andMe blog rs1006737 or (rs2159100) Each T at this SNP increased the odds of bipolar disorder by 1.9-fold		1E-12: Brain Fronta l Cortex
rs1135 51349 / EUR	SLC6A 9_1 (chr1:4 403145 2- 440315 11) SLC6A 9_4 (chr1:4 403218 7- 440322 46)	Enhancer, Brain,H1 neuronal progenitor,H9, H9 neuron progenitor cells,H9 neuron cells; Ensembl: ENSR00000355772 (chr1:44016001- 44017400); MASTERMIND	-	SE_05770 SE_06677 (Brain - Hippocampus middle)SE_08888 (Brain - Mid frontal lobe)SE_03147 (Brain - Angular gyrus)SE_03879 (Brain - Anterior caudate)SE_04765 (Brain - Cingulate gyrus)SE_07718 (Brain - Inferior temporal lobe)	-
rs2973 155-C / EUR	GRIA1 _1 (chr5:1 534906 21- 153490 680)	Enhancer, Brain, neural progenitor cell: ENSR00000774341 (chr5:153490200- 153492801) Ensemble, ENCODE. FANTOM			1E-25; Brain Cingul ate Gyrus

rs1323 3131 / EUR		Enhancer, Bipolar Neuron, Brain; ENSR00000840912 (chr7:136997601-136998801 (Ensembl, Vista0		SE_05136 (Brain - Cingulate gyrus)	1E-32, Brain Cingulate Gyrus
rs7581 17-C / ASN		Enhancer, Cingulate Gyrus; GH12J002226: chr12:2335414-2336748; dbSUPER	DE_00452: chr12:2339802- 2367400; Schizophrenia;23andMe blog rs1006737 or (rs2159100) Each T at this SNP increased the odds of bipolar disorder by 1.9-fold		1E-12: Brain Frontal Cortex
rs8721 23 / EUR	-	Enhancer, Brain, neural progenitor cells, H1ESC cells; ENSR00000627779 (chr2:170809001-170814605, Type: Proximal) ENCODE, Z labs	-	-	1E-05, Brain Anterior Caudate
rs2973 155-C / EUR	GRIA1 _1 (chr5:1 534906 21- 153490 680)	Enhancer, Brain, neural progenitor cell: ENSR00000774341 (chr5:153490200-153492801) Ensemble, ENCODE. FANTOM			1E-25; Brain Cingulate Gyrus
rs1317 6930- T / ASN	GRIA1 _1 (chr5:1 534906 21- 153490 680)	Enhancer, Brain, neural progenitor cell: ENSR00000774341 (chr5:153490200-153492801) Ensemble, ENCODE. FANTOM			1E-25; Brain Cingulate Gyrus
rs9292 918 / EUR	HCN1_ 1 (chr5:4 569627 1- 456963 30)	Enhancer, Bipolar Neuron, Brain, neural progenitor cell; ENSR00000754146 (chr5:45453802-45454473, Type: Proximal): ENCODE, Ensembl, FANTOM		SE_05045 (Brain - Cingulate gyrus)	1E-11; Frontal Cortex
rs1478 364-T / EUR	GRIA1 _1 (chr5:1 534906 21- 153490 680)	Enhancer, Brain, neural progenitor cell: ENSR00000774341 (chr5:153490200-153492801) Ensemble, ENCODE. FANTOM			1E-25; Brain Cingulate Gyrus
<u>rs9922</u> <u>678</u> <u>(rs992</u> <u>6303)</u> <u>/EUR</u>	GRIN2 A_3 (chr16: 101819 41- 101820 00) GRIN2 A_2 (chr16:	Enhancer, dorsolateral frontal cortex, astrocytes, bipolar neurons, neural progenitor cells; ENCODE, FANTOM5, Vista.			1.1E-12, Brain Frontal Cortex

	101823 77- 101824 36) GRIN2 A_4 (chr16: 101826 92- 101827 51) GRIN2 A_1 (chr16: 101828 72- 101829 31)				
rs7191 183 / EUR	GRIN2 A_3 (chr16: 101819 41- 101820 00) GRIN2 A_2 (chr16: 101823 77- 101824 36) GRIN2 A_4 (chr16: 101826 92- 101827 51) GRIN2 A_1 (chr16: 101828 72- 101829 31)	Enhancer, dorsolateral frontal cortex, astrocytes, bipolar neurons, neural progenitor cells; ENCODE, FANTOM5, Vista.			1.1E- 12, Brain Frontal Cortex
rs9922 678-A / ASN, EUR	GRIN2 A_3 (chr16: 101819 41- 101820 00) GRIN2 A_2 (chr16: 101826 92- 101827 51) GRIN2 A_1 (chr16: 101828 72- 101829 31)	Enhancer, dorsolateral frontal cortex, astrocytes, bipolar neurons, neural progenitor cells; ENCODE, FANTOM5, Vista.			1.1E- 12, Brain Frontal Cortex

	101823 77- 101824 36) GRIN2 A_4 (chr16: 101826 92- 101827 51) GRIN2 A_1 (chr16: 101828 72- 101829 31)				
rs1750 4622- T / ASN, EUR	GRIN2 A_3 (chr16: 101819 41- 101820 00) GRIN2 A_2 (chr16: 101823 77- 101824 36) GRIN2 A_4 (chr16: 101826 92- 101827 51) GRIN2 A_1 (chr16: 101828 72- 101829 31)	Enhancer, dorsolateral frontal cortex, astrocytes, bipolar neurons, neural progenitor cells; ENCODE, FANTOM5, Vista.			1.1E- 12, Brain Frontal Cortex
rs7280 22696 / EUR	GRIA1 _1 (chr5:1 534906 21- 153490 680)	Enhancer, Brain, neural progenitor cell: ENSR00000774341 (chr5:153490200- 153492801) Ensemble, ENCODE, FANTOM			1E-25; Brain Cingulate Gyrus
rs4765 913 / EUR		Enhancer, Cingulate Gyrus; GH12J002226:	DE_00452: chr12 :2339802- 2367400; Schizophrenia;23andMe		1E-12: Brain Frontal

		chr12:2335414-2336748; dbSUPER	blog rs1006737 or (rs2159100) Each T at this SNP increased the odds of bipolar disorder by 1.9-fold		1 Cortex
rs9922 678 / ASN, EUR	GRIN2 A_3 (chr16: 101819 41- 101820 00) GRIN2 A_2 (chr16: 101823 77- 101824 36) GRIN2 A_4 (chr16: 101826 92- 101827 51) GRIN2 A_1 (chr16: 101828 72- 101829 31)	Enhancer, dorsolateral frontal cortex, astrocytes, bipolar neurons, neural progenitor cells; ENCODE, FANTOM5, Vista.			1.1E- 12, Brain Fronta l Cortex
rs1317 6930 / EUR	GRIA1 _1 (chr5:1 534906 21- 153490 680)	Enhancer, Brain, neural progenitor cell: ENSR00000774341 (chr5:153490200- 153492801) Ensemble, ENCODE, FANTOM			1E-25; Brain Cingul ate Gyrus
rs1175 78877 -T / EUR	GRIN2 B_1 (chr12: 139804 10- 139804 69) GRIN2 B_2 (chr12: 139819 66- 139820 25)	Enhancer, Bipolar Neuron, Brain; ENSR00000451168 (chr12:13980400- 13982401) Ensemble, VISTA, FANTOM		SE_33104 (Brain - Cingulate gyrus)	3.00E- 10: Brain Cingul ate Gyrus
rs1501 357-C	HCN1_ 1	Enhancer, Bipolar Neuron, Brain, neural progenitor		SE_05045 (Brain - Cingulate gyrus)	1E-11; Fronta

/ ASN, EUR	(chr5:4 569627 1- 456963 30)	cell; ENSR00000754146 (chr5:45453802-45454473, Type: Proximal): ENOCDE, Ensembl, FANTOM			1 Cortex
rs4765 914 / EUR		Enhancer, Cingulate Gyrus; GH12J002226: chr12:2335414-2336748; dbSUPER	DE_00452: chr12 :2339802- 2367400; Schizophrenia;23andMe blog rs1006737 or (rs2159100) Each T at this SNP increased the odds of bipolar disorder by 1.9-fold		1E-12: Brain Frontal Cortex
rs1006 737 / EUR		Enhancer, Cingulate Gyrus; GH12J002226: chr12:2335414-2336748; dbSUPER	DE_00452: chr12 :2339802- 2367400; Schizophrenia;23andMe blog rs1006737 or (rs2159100) Each T at this SNP increased the odds of bipolar disorder by 1.9-fold		1E-12: Brain Frontal Cortex
rs9922 678-A / ASN	GRIN2 A_3 (chr16: 101819 41- 101820 00) GRIN2 A_2 (chr16: 101823 77- 101824 36) GRIN2 A_4 (chr16: 101826 92- 101827 51) GRIN2 A_1 (chr16: 101828 72- 101829 31)	Enhancer, dorsolateral frontal cortex, astrocytes, bipolar neurons, neural progenitor cells; ENCODE, FANTOM5, Vista.			1.1E- 12, Brain Frontal Cortex
rs1074 4560- T		Enhancer, Cingulate Gyrus; GH12J002226: chr12:2335414-2336748; dbSUPER	DE_00452: chr12 :2339802- 2367400; Schizophrenia;23andMe blog rs1006737 or (rs2159100) Each T at this SNP increased the odds of bipolar disorder by 1.9-fold		1E-12: Brain Frontal Cortex

rs1501 357-C / EUR	HCN1_1 (chr5:45696271-45696330)	Enhancer, Bipolar Neuron, Brain, neural progenitor cell; ENSR00000754146 (chr5:45453802-45454473, Type: Proximal); ENOCDE, Ensembl, FANTOM		SE_05045 (Brain - Cingulate gyrus)	1E-11; Frontal Cortex
rs9922 678-A / ASN, EUR	GRIN2A_3 (chr16:10181941-10182000) GRIN2A_2 (chr16:10182377-10182436) GRIN2A_4 (chr16:10182692-10182751) GRIN2A_1 (chr16:10182872-10182931)	Enhancer, dorsolateral frontal cortex, astrocytes, bipolar neurons, neural progenitor cells; ENCODE, FANTOM5, Vista.			1.1E-12, Brain Frontal Cortex
rs6808 1839 / EUR	GRIA4_1 (chr11:105610024-105610083) GRIA4_3 (chr11:105610666-105610725) GRIA4_2 (chr11:105610842-105610901)	chr11:105609674-105612903		SE_05045 (Brain - Cingulate gyrus)	1E-25; Brain Cingulate Gyrus

rs28607014-C / EA (Han Chinese)		Enhancer: H1-hESC, neural stem progenitor cell, SK-N-SH cells; GH12J117579: chr12:118017798-118019205; ENCODE(ZLab), Ensembl; FANTOM: eRNA score = 3			
rs12522290-C / EUR	GRIA1_1 (chr5:153490621-153490680)	Enhancer, Brain, neural progenitor cell: ENSR00000774341 (chr5:153490200-153492801) Ensemble, ENCODE. FANTOM			1E-25; Brain Cingulate Gyrus
rs1006737-A / EUR		Enhancer, Cingulate Gyrus; GH12J002226: chr12:2335414-2336748; dbSUPER	DE_00452: chr12:2339802-2367400; Schizophrenia;23andMe blog rs1006737 or (rs2159100) Each T at this SNP increased the odds of bipolar disorder by 1.9-fold		1E-12: Brain Frontal Cortex
rs73568641-C / AFR	OPRM1_2 (chr6:154039211-154039270) OPRM1_3 (chr6:154039315-154039374) OPRM1_4 (chr6:154039500-154039559)	Enhancer, Bipolar Neurons, Brain; ENSR00000810176 (chr6:154039001-154040001) Ensembl, ENCODE, FANTOM		SE_03879 (Brain - Anterior caudate)	1E-30: Brain Nucleus Accumbens
rs13170232-T / EUR	GRIA1_1 (chr5:153490621-153490680)	Enhancer, Brain, neural progenitor cell: ENSR00000774341 (chr5:153490200-153492801) Ensemble, ENCODE. FANTOM			1E-25; Brain Cingulate Gyrus
rs9292918 / EUR	HCN1_1 (chr5:45696271-45696330)	Enhancer, Bipolar Neuron, Brain, neural progenitor cell; ENSR00000754146 (chr5:45453802-45454473, Type: Proximal); ENCODE, Ensembl, FANTOM		SE_05045 (Brain - Cingulate gyrus)	1E-11; Frontal Cortex

rs12522290-C	GRIA1_1 (chr5:153490621-153490680)	Enhancer, Brain, neural progenitor cell; ENSR00000774341 (chr5:153490200-153492801) Ensemble, ENCODE, FANTOM			1E-25; Brain Cingulate Gyrus
rs13008299-G / EUR	WDR43_1 (chr2:28894641-28894700)	Enhancer, Brain, H1-hESC, H9, neural stem progenitor cell; ENSR00000114662 (chr2:28893601-28897801) Ensembl, ENCODE, FANTOM, VISTA		SE_05045 (Brain - Cingulate gyrus)	
rs117578877-T / EUR	GRIN2B_1 (chr12:13980410-13980469) GRIN2B_2 (chr12:13981966-13982025)	Enhancer, Bipolar Neuron, Brain; ENSR00000451168 (chr12:13980400-13982401) Ensembl, VISTA, FANTOM		SE_33104 (Brain - Cingulate gyrus)	3.00E-10; Amygala
rs11127199-G / EUR	WDR43_1 (chr2:28894641-28894700)	Enhancer, Brain, H1-hESC, H9, neural stem progenitor cell; ENSR00000114662 (chr2:28893601-28897801) Ensembl, ENCODE, FANTOM, VISTA		SE_05045 (Brain - Cingulate gyrus)	

Table 2B, Part 2. Regulatory elements associated with enhancer and superenhancer SNPs that have been found in the ketamine adverse event sub-network.

GWAS SNP Reported / Population(s)	Hi-C Score	HGREEN score	Enhancer RNA co-expression p-value	Judged by machine learning to be causal in neural cell lines but not HepG2?
rs1051730-A / ASN, EUR	1E-27: Nucleus accumbens	1.00E-15	1.00E-50	Yes
rs1051730-G / EUR	1E-27: Nucleus accumbens	1.00E-15	1.00E-50	Yes
rs1051730-A / EUR	1E-27: Nucleus accumbens	1.00E-15	1.00E-50	Yes
rs1051730-G / EUR	1E-27: Nucleus accumbens	1.00E-15	1.00E-50	Yes

rs2155646-C / EUR	1E-35: Cingulate cortex	1.00E-10	1.00E-14	Yes
rs7938812-T / EUR	1E-35: Cingulate cortex	1.00E-10	1.00E-10	Yes
rs3130820 / EUR	1E-10: Cingulate cortex	1.00E-08	1.56E-10	Yes
rs3918226-T / EUR	1E.00E-20: Cerebellum	1.00E-08		Yes
rs3918226 / EA (Han Chinese)	1E.00E-20: Cerebellum	1.00E-08		Yes
rs3918226-T / AFR, AMR, ASN, EUR	1E.00E-20: Cerebellum	1.00E-08		Yes
rs3918226-T / EUR	1E.00E-20: Cerebellum	1.00E-08		Yes
rs3918226-T / EUR	1E.00E-20: Cerebellum	1.00E-08		Yes
rs2155290 / EUR	1E-35: Cingulate cortex	1.00E-10	1.00E-14	Yes
rs182812355-A / ASN	1E-10: Cingulate cortex	1.00E-08	1.56E-10	Yes
rs3918226-T / EUR	1E.00E-20: Cerebellum			Yes
rs12764899 / EUR	0.00000001: Hippocampus	1.00E-11	5.00E-34	Yes
rs11191424-G / EUR	0.00000001: Hippocampus	1.00E-11	5.00E-34	Yes
rs2007044 / ASN	0.0000000001: Cingulate cortex	1.00E-15	1.30E-89	Yes
rs2159100 / ASN, EUR	0.0000000001: Cingulate cortex	1.00E-30	1.00E-14	Yes
rs514465-A / EUR	0.00000000000001: Frontal cortex	1.00E-15		Yes
rs2007044-G / ASN, EUR	0.0000000001: Cingulate cortex	1.00E-30	1.30E-89	Yes
rs1024582-A / ASN	0.0000000001: Cingulate cortex	1.00E-30		Yes
rs2007044 / EUR	0.0000000001: Cingulate cortex	1.00E-15		Yes
rs10774909 / EUR	0.0000001: Frontal cortex	1.00E-10	1.00E-02	Yes
rs2007044 / EUR	0.0000000001: Cingulate cortex	1.00E-30	1.30E-89	Yes
rs7192140	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	Yes
rs2239030-A / EUR	0.0000000001: Cingulate cortex	1.00E-15	1.00E-03	Yes
rs3918226-T / EA (Han Chinese)	1E.00E-20: Cerebellum	1.00E-08		Yes
rs11055991-A / EUR	0.01: Frontal cortex	1.00E-12		
rs2007044 / EUR	0.0000000001: Cingulate cortex	1.00E-15	1.30E-89	Yes
rs1024582-A / EUR	0.0000000001: Cingulate cortex	1.00E-15	1.00E-17	Yes
rs7893279-T / ASN, EUR	0.0000000001: Frontal cortex	1.00E-15	E-08	Yes
rs8042374-A / EA (Han Chinese)	1E-27: Cingulate cortex	1.00E-27	1.00E-50	Yes
rs7893279-T / ASN, EUR	0.000001: Frontal cortex	1.00E-05	E-23	
rs7893279-T, ASN, EUR	0.000001: Frontal cortex	1.00E-05	E-23	Yes
rs1006737 / EUR	0.0000000001: Cingulate cortex	1.00E-10	1.00E-03	Yes

rs28681284-C / ASN	1E-27: Nucleus accumbens	1.00E-27	1.00E-50	No
rs7893279-T / ASN, EUR	0.000001: Frontal cortex	1.00E-15	1.00E-08	Yes
rs3918226 / EUR	1E.00E-20: Cerebellum	1.00E-08		Yes
rs7893279-T / ASN (Han Chinese), EUR	0.000001: Frontal cortex	1.00E-15	E-08	Yes
rs1006737-A / EUR	0.0000000001: Cingulate cortex	1.00E-10	1.00E-03	Yes
rs111294930-A / EUR	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	Yes
rs7688285-C / AFR, EUR	0.00000000001: Amygdala			Yes
rs641574-A / EUR	0.000000001: Cingulate cortex	1.00E-41	1.25E-27	Yes
rs2298527-C / EUR	1E-35: Cingulate cortex	1.00E-10	1.00E-14	Yes
rs7192140-C / EUR	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	Yes
rs9292918-G / ASN	0.0001: Frontal cortex	1.00E-05		Yes
rs2155290-C / EUR	1E-35: Cingulate cortex	1.00E-10	1.00E-14	Yes
rs16902086 / EUR	0.0001: Frontal cortex	1.00E-05		Yes
rs7893279-T / ASN (Han Chinese), EUR	0.000001: Frontal cortex	1.00E-15	1.00E-08	
rs2239030-A / EUR	0.0000000001: Cingulate cortex	1.00E-20	1.00E-03	Yes
rs1837016-T / EUR	0.001: Cingulate cortex	-	-	Yes
rs111294930-A / ASN, EUR	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	Yes
rs62367520 / EUR	0.0001: Frontal cortex	1.00E-05		Yes
rs11647445-G / EUR	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	Yes
rs7893279-T / ASN (Han Chinese), EUR	0.000001: Frontal cortex	1.00E-15	1.00E-08	Yes
rs4782271-A / EUR	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	Yes
rs7893279-T / EUR	1.00E-10	1.00E-15	1.00E-08	Yes
rs73047488 / EUR	0.0000000001: Cingulate cortex	1.00E-15	1.00E-33	Yes
rs3825845-C / ASN	1E-27: Nucleus accumbens	1.00E-27	1.00E-50	Yes
rs10744560 / EUR	0.0000000001: Frontal cortex	1.00E-20	1.00E-03	Yes
rs113551349 / EUR	0.0000000000001: Frontal cortex	2.00E-20	1.00E-53	Yes
rs2973155-C / EUR	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	Yes
rs13233131 / EUR	0.00001: Cingulate cortex	1.00E-10	5.00E-12	Yes
rs758117-C / ASN	0.0000000001: Frontal cortex	1.00E-20	1.00E-03	Yes

rs872123 / EUR	0.0000000001: Cingulate cortex	1.00E-10	1.2E-15; Tibial nerve	Yes
rs2973155-C / EUR	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	Yes
rs13176930-T / ASN	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	Yes
rs9292918 / EUR	0.0001: Frontal cortex	1.00E-05		Yes
rs1478364-T / EUR	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	
rs9922678 (rs9926303) / EUR	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	Yes
rs7191183 / EUR	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	Yes
rs9922678-A / ASN, EUR	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	
rs17504622-T / ASN, EUR	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	Yes
rs728022696 / EUR	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	Yes
rs4765913 / EUR	0.0000000001: Frontal cortex	1.00E-20	1.00E-03	Yes
rs9922678 / ASN, EUR	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	Yes
rs13176930 / EUR	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	Yes
rs117578877-T / EUR	0.00000000000000000000000000000001: Cingulate cortex	1.00E-15	1.00E-33	Yes
rs1501357-C / ASN, EUR	0.0001: Frontal cortex	1.00E-05		Yes
rs4765914 / EUR	0.0000000001: Frontal cortex	1.00E-20	1.00E-03	Yes
rs1006737 / EUR	0.0000000001: Frontal cortex	1.00E-10	1.00E-03	Yes
rs9922678-A / ASN	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	Yes
rs10744560-T	0.0000000001: Frontal cortex	1.00E-20	1.00E-03	Yes
rs1501357-C / EUR	0.0001: Frontal cortex	1.00E-05	-	Yes
rs9922678-A / ASN, EUR	0.000000000000000001: Frontal cortex	1.00E-20	3.00E-12	Yes
rs68081839 / EUR	0.0000000001: Cingulate cortex	1.00E-41	1.25E-27	Yes
rs28607014-C / EA (Han Chinese)	0.0000001: Frontal cortex	1.00E-10	1.00E-02	Yes
rs12522290-C / EUR	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	Yes
rs1006737-A / EUR	0.0000000001: Frontal cortex	1.00E-10	1.00E-03	Yes
rs73568641-C / AFR	0.0000000000000001: Nucleus accumbens	1.00E-10	1.00E-41	Yes
rs13170232-T / EUR	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	Yes
rs9292918 / EUR	0.0001: Frontal cortex	1.00E-05		Yes
rs12522290-C	0.000000000001: Cingulate cortex	1.00E-25	1.25E-19	Yes
rs13008299-G / EUR	0.0001: Cingulate cortex			Yes
rs117578877-T / EUR	0.0000000001: Amygdala	1.00E-15	1.00E-33	Yes

rs11127199-G / EUR	0.0001: Cingulate cortex			Yes
-----------------------	--------------------------	--	--	-----

Table 2B, Part 3. Chromatin interactions for enhancer and superenhancer SNPs that have been found in the ketamine adverse event sub-network.

[0147] In another embodiment of the methods in this disclosure, generalization of this method may be used to reveal combinations of FDA-approved medications that may be used to enhance therapeutics in neuropsychiatric disorders through their corresponding network or sub-network mechanisms in biology. Figure 22 illustrates an example of how the valproic acid pharmacogenomic network and the ketamine pharmacogenomic network work in a complementary manner to support neurogenesis. Valproic acid induces the conversion of neural progenitor cells to committed neural progenitors through the npBAF complex (1, top), and ketamine may act on committed neural progenitors through the human silencing complex (HUSH) to turn progenitors into differentiation neurons (1, bottom).

[0148] Figure 23 illustrates how the process shown in Figure 22 acts through progressive deacetylation of the histone 3 lysine 9 (H3K9) moiety as caused by the valproic pharmacogenomic network (Figure 23A), and acetylation of the H3K9 moiety following activation of the ketamine pharmacogenomic network (Figure 23B).

[0149] Figure 24 illustrates how the complementary pharmacogenomic networks of valproic acid and ketamine bring neural progenitors to become mature, differentiated neurons.

[0150] In another embodiment of this disclosure, these methods can be used for other antidepressant medications that target the NMDAR network. For example, other NMDAR partial antagonists, including AVP-786 and GLYX-13 (Rapastinel), are in clinical trials as antidepressant medications. Also, blockers of the GLRB on the NMDAR are also under development as antidepressants, including AV101 and D-cycloserine (Seromycin). Selective antagonists of the GRIN2B of the NMDAR are also in development as antidepressants, examples including EVT103, CP101 and MK-0657. Downstream in this pathway is the AMPAR, and several antidepressants are being developed as agonists at GRIA1 and GRIA2 such as ORG 265576.

[0151] In another embodiment, these methods can be used for optimization of medication selection for other antidepressants providing greater power than commercially available

pharmacogenomic clinical decision support assays that just rely on coding SNPs for classifying patients as to medication. Methods covered by the techniques disclosed herein exploit knowledge of the pharmacogenomic epigenome, including its organization into TADs and TAD-TAD pharmacogenomic connections, which provide enhanced insight into CNS drug mechanisms. In addition, these methods permit objective monitoring of drug-drug interactions and dosing, as well as measurement of parent drugs and their metabolites from serum, as is the case for *S*-ketamine and its active metabolite nor-ketamine to provide additional insight into individual metabolizer subtypes.

[0152] Throughout this specification, plural instances may implement components, operations, or structures described as a single instance. Although individual operations of one or more methods are illustrated and described as separate operations, one or more of the individual operations may be performed concurrently, and nothing requires that the operations be performed in the order illustrated. Structures and functionality presented as separate components in example configurations may be implemented as a combined structure or component. Similarly, structures and functionality presented as a single component may be implemented as separate components. These and other variations, modifications, additions, and improvements fall within the scope of the subject matter herein.

[0153] Additionally, certain embodiments are described herein as including logic or a number of routines, subroutines, applications, or instructions. These may constitute either software (e.g., code embodied on a machine-readable medium or in a transmission signal) or hardware. In hardware, the routines, etc., are tangible units capable of performing certain operations and may be configured or arranged in a certain manner. In example embodiments, one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware modules of a computer system (e.g., a processor or a group of processors) may be configured by software (e.g., an application or application portion) as a hardware module that operates to perform certain operations as described herein.

[0154] In various embodiments, a hardware module may be implemented mechanically or electronically. For example, a hardware module may comprise dedicated circuitry or logic that is permanently configured (e.g., as a special-purpose processor, such as a field programmable gate array (FPGA) or an application-specific integrated circuit (ASIC)) to perform certain operations.

A hardware module may also comprise programmable logic or circuitry (e.g., as encompassed within a general-purpose processor or other programmable processor) that is temporarily configured by software to perform certain operations. It will be appreciated that the decision to implement a hardware module mechanically, in dedicated and permanently configured circuitry, or in temporarily configured circuitry (e.g., configured by software) may be driven by cost and time considerations.

[0155] Accordingly, the term “hardware module” should be understood to encompass a tangible entity, be that an entity that is physically constructed, permanently configured (e.g., hardwired), or temporarily configured (e.g., programmed) to operate in a certain manner or to perform certain operations described herein. Considering embodiments in which hardware modules are temporarily configured (e.g., programmed), each of the hardware modules need not be configured or instantiated at any one instance in time. For example, where the hardware modules comprise a general-purpose processor configured using software, the general-purpose processor may be configured as respective different hardware modules at different times. Software may accordingly configure a processor, for example, to constitute a particular hardware module at one instance of time and to constitute a different hardware module at a different instance of time.

[0156] Hardware modules can provide information to, and receive information from, other hardware modules. Accordingly, the described hardware modules may be regarded as being communicatively coupled. Where multiple of such hardware modules exist contemporaneously, communications may be achieved through signal transmission (e.g., over appropriate circuits and buses) that connect the hardware modules. In embodiments in which multiple hardware modules are configured or instantiated at different times, communications between such hardware modules may be achieved, for example, through the storage and retrieval of information in memory structures to which the multiple hardware modules have access. For example, one hardware module may perform an operation and store the output of that operation in a memory device to which it is communicatively coupled. A further hardware module may then, at a later time, access the memory device to retrieve and process the stored output. Hardware modules may also initiate communications with input or output devices, and can operate on a resource (e.g., a collection of information).

[0157] The various operations of example methods described herein may be performed, at least partially, by one or more processors that are temporarily configured (e.g., by software) or permanently configured to perform the relevant operations. Whether temporarily or permanently configured, such processors may constitute processor-implemented modules that operate to perform one or more operations or functions. The modules referred to herein may, in some example embodiments, comprise processor-implemented modules.

[0158] Similarly, the methods or routines described herein may be at least partially processor-implemented. For example, at least some of the operations of a method may be performed by one or more processors or processor-implemented hardware modules. The performance of certain of the operations may be distributed among the one or more processors, not only residing within a single machine, but deployed across a number of machines. In some example embodiments, the processor or processors may be located in a single location (e.g., within a home environment, an office environment or as a server farm), while in other embodiments the processors may be distributed across a number of locations.

[0159] The performance of certain of the operations may be distributed among the one or more processors, not only residing within a single machine, but deployed across a number of machines. In some example embodiments, the one or more processors or processor-implemented modules may be located in a single geographic location (e.g., within a home environment, an office environment, or a server farm). In other example embodiments, the one or more processors or processor-implemented modules may be distributed across a number of geographic locations.

[0160] Unless specifically stated otherwise, discussions herein using words such as “processing,” “computing,” “calculating,” “determining,” “presenting,” “displaying,” or the like may refer to actions or processes of a machine (e.g., a computer) that manipulates or transforms data represented as physical (e.g., electronic, magnetic, or optical) quantities within one or more memories (e.g., volatile memory, non-volatile memory, or a combination thereof), registers, or other machine components that receive, store, transmit, or display information.

[0161] As used herein any reference to “one embodiment” or “an embodiment” means that a particular element, feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. The appearances of the phrase “in one

embodiment” in various places in the specification are not necessarily all referring to the same embodiment.

[0162] Some embodiments may be described using the expression “coupled” and “connected” along with their derivatives. For example, some embodiments may be described using the term “coupled” to indicate that two or more elements are in direct physical or electrical contact. The term “coupled,” however, may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other. The embodiments are not limited in this context.

[0163] As used herein, the terms “comprises,” “comprising,” “includes,” “including,” “has,” “having” or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, “or” refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[0164] In addition, use of the “a” or “an” are employed to describe elements and components of the embodiments herein. This is done merely for convenience and to give a general sense of the description. This description, and the claims that follow, should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

This detailed description is to be construed as providing examples only and does not describe every possible embodiment, as describing every possible embodiment would be impractical, if not impossible. One could implement numerous alternate embodiments, using either current technology or technology developed after the filing date of this application.

WE CLAIM:

1. A computing device for determining a drug or drugs to administer to a patient suffering from a neuropsychiatric, neurological, or analgesia/pain disorder, the computing device comprising:

a communication network,

one or more processors; and

a non-transitory computer-readable memory coupled to the one or more processors and storing thereon instructions that, when executed by the one or more processors, cause the computing device to:

obtain a biological sample of a patient;

analyze the biological sample using one or more of: targeted single nucleotide polymorphisms (SNP) genotyping, RNA sequencing, and chromatin conformation capture based on the differential activation and repression of topologically associating domains (TADs) in the patient indicative of drug efficacy and adverse drug events;

determine a pharmacogenomic network representation for a drug gene set for a glutamate N-methyl-d-aspartate receptor (NMDAR) antagonist or partial antagonist, a glycine receptor beta (GLRB) modulator, or an α -amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid receptor (AMPA) agonist for the patient based on the analysis;

compare the pharmacogenomic network representation for the drug gene set for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient to a drug pharmacogenomic network and constituent sub-networks for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist from a reference database;

determine to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for administering to the patient based on the comparison; and

cause the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist to be administered to the patient.

2. The computing device of claim 1, wherein:

the pharmacogenomic network representation for the drug gene set for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient includes a patient drug pharmacodynamic efficacy sub-network, a patient drug pharmacodynamic adverse event sub-network, a chromatin remodeling sub-network, and a pharmacokinetic enzymes and hormones sub-network, and the constituent sub-networks for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist from the reference database includes a set of reference drug pharmacodynamic efficacy sub-networks, reference drug pharmacodynamic adverse event sub-networks, reference chromatin remodeling sub-networks, and reference pharmacokinetic enzymes and hormones sub-networks spanning human drug response variation, and

to compare the pharmacogenomic representation for the drug gene set for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient to a drug pharmacogenomic network and constituent sub-networks for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist from a reference database, the instructions cause the computing device to:

assign a first score to the patient drug pharmacodynamic efficacy sub-network based on an amount of similarity between the patient drug pharmacodynamic efficacy sub-network and the set of reference drug pharmacodynamic efficacy sub-networks;

assign a second score to the patient drug pharmacodynamic adverse event sub-network based on an amount of similarity between the patient drug pharmacodynamic adverse event sub-network and the set of reference drug pharmacodynamic adverse-event sub-networks.

3. The computing device of claim 2, wherein to determine to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for administering to the patient based on the comparison, the instructions cause the computing device to:

determine to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient when the first score is above a first threshold score or the second score is below a second threshold score.

4. The computing device of claim 3, wherein to determine to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient when the first score is above a first threshold score or the second score is below a second threshold score, the instructions cause the computing device to:

- combine the first and second scores to generate an overall score; and
- determine to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient when the overall score is above a third threshold score.

5. The computing device of any one of claim 1-4, wherein the instructions further cause the computing device to:

- determine a dosage of the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for administering to the patient based on the comparison; and
- cause the determined dosage of the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist to be administered to the patient.

6. The computing device of claim 5, wherein to determine a dosage of the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for administering to the patient, the instructions cause the computing device to:

- determine the dosage using a regression model based on a combination of two or more of: the sex of the patient, the age of the patient, whether the patient smokes, ethnicity of the patient, height of the patient, weight of the patient, and mental illness history of the patient.

7. The computing device of claim 5, wherein the instructions further cause the computing device to:

- obtain clinical data for the patient;
- analyze the biological sample using pharmacometabolomics to determine pre-existing medications and metabolites of the pre-existing medications in the patient; and
- determine whether to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist to the patient or the dosage to administer based at least in part on drug-gene or drug-drug interactions between the pre-existing medications in the patient and the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist.

8. The computing device of any one of claim 1-7, wherein the drug pharmacogenomic network for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist from the reference database is a ketamine pharmacogenomic network and includes one or more of: Activity regulated cytoskeleton associated protein (*ARC*) gene, Achaete-Scute family bHLH transcription factor 1 (*ASCL1*) gene, Brain derived neurotrophic factor (*BDNF*) gene, BDNF antisense RNA (*BDNF-AS*) gene, Calcium/calmodulin dependent protein kinase II alpha (*CAMK2A*) gene, Cyclin dependent kinase inhibitor 1A (*CDKN1A*) gene, cAMP responsive element modulator (*CREM*) gene, Cut like homeobox 2 (*CUX2*) gene, DCC netrin 1 receptor (*DCC*) gene, Dopamine receptor D2 (*DRD2*) gene, Eukaryotic translation elongation factor 2 kinase (*EEF2K*) gene, Fragile X mental retardation 1 (*FMRI*) gene, Ganglioside induced differentiation associated protein 1 like 1 (*GDAP1L1*) gene, Glutamate metabotropic receptor 5 (*GRM5*) gene, Homer scaffold protein 1 (*HOMER1*) gene, 5-hydroxytryptamine receptor 1B (*HTR1B*) gene, 5-hydroxytryptamine receptor 2A (*HTR2A*) gene, Kruppel like factor 6 (*KLF6*) gene, Lin-7 homolog C, crumbs cell polarity complex component (*LIN7C*) long noncoding RNA, *LOC105379109* long noncoding RNA, Myocyte enhancer factor 2D (*MEF2D*) gene, Myosin VI (*MYO6*) gene, Myelin transcription factor 1 like (*MYT1L*) gene, Neuronal differentiation 1 (*NEUROD1*) gene, Neuronal differentiation 2 (*NEUROD2*) gene, Nescient helix-loop-helix 2 (*NHLH2*) gene, Neuromedin B (*NMB*) gene, NMDA receptor synaptonuclear signaling and neuronal migration factor (*NSMF*) gene, Neurotrophic receptor tyrosine kinase 2 (*NTRK2*) gene, Phosphatase and tensin homolog (*PTEN*) gene, Prostaglandin-endoperoxide synthase 2 (*PTGS2*) gene, Rac family small GTPase 1 (*RAC1*) gene, Ras protein specific guanine nucleotide releasing factor 2 (*RASGRF2*) gene, Ras homolog family member A (*RHOA*) gene, Roundabout guidance receptor 2 (*ROBO2*) gene, *RP11_360A181* long noncoding RNA, Semaphorin 3A (*SEMA3A*) gene, SH3 and multiple ankyrin repeat domains 1 (*SHANK1*) gene, SH3 and multiple ankyrin repeat domains 2 (*SHANK2*) gene, SH3 and multiple ankyrin repeat domains 3 (*SHANK3*) gene, Solute carrier family 22 member 15 (*SLC22A15*) gene, Solute carrier family 6 member 2 (*SLC6A2*) gene, Slit guidance ligand 1 (*SLIT1*) gene, Slit guidance ligand 2 (*SLIT2*) gene, Synaptosome associated protein 25 (*SNAP25*) gene, Synapsin I (*SYN1*) gene, Synapsin II (*SYN2*) gene, Synapsin III (*SYN3*) gene, T-box, brain 1 (*TBR1*) gene, Transcription factor 4 (*TCF4*) gene, Acetylcholinesterase (*ACHE*) gene, Activating transcription

factor 7 interacting protein (*ATF7IP*) gene, Activating transcription factor 7 interacting protein 2 (*ATF7IP2*) gene, ATPase Na⁺/K⁺ Transporting Subunit Alpha 1 (*ATPIA1*) gene, BLOC-1 related complex unit 7 (*BORCS7*) gene, Bromodomain containing 4 (*BRD4*) gene, Calcium voltage-gated channel subunit alpha1 C (*CACNA1C*) gene, Calcium voltage-gated channel auxiliary subunit beta 1 (*CACNB1*) gene, Calcium voltage-gated channel auxiliary subunit beta 2 (*CACNB2*) gene, Calcium voltage-gated channel auxiliary subunit gamma 2 (*CACNG2*) gene, Cholinergic Receptor Muscarinic 2 (*CHRM2*) gene, Cholinergic Receptor Nicotinic Alpha 3 Subunit (*CHRNA3*) gene, Cholinergic Receptor Nicotinic Alpha 5 Subunit (*CHRNA5*) gene, Cholinergic Receptor Nicotinic Alpha 7 Subunit (*CHRNA7*) gene, Cannabinoid receptor 1 (*CNRI*) gene, Disks large homolog 3 (*DLG3*) gene, Disks large homolog 4 (*DLG4*) gene, DNA Methyltransferase 1 (*DNMT1*) gene, Euchromatic histone lysine methyltransferase 1 (*EHMT1*) gene, Gamma-aminobutyric acid type A receptor alpha2 subunit (*GABRA2*) gene, Gamma-aminobutyric acid type A receptor alpha5 subunit (*GABRA5*) gene, Glutamate decarboxylase 1 (*GADI*) gene, Glycine receptor alpha 1 (*GLRA1*) gene, Glycine receptor alpha 2 (*GLRA2*) gene, Glycine receptor beta (*GLRB*) gene, Glutamate ionotropic receptor AMPA type subunit 1 (*GRIA1*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA2*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA4*) gene, Glutamate ionotropic receptor NMDA type subunit 1 (*GRIN1*) gene, Glutamate ionotropic receptor NMDA type subunit 2A (*GRIN2A*) gene, Glutamate ionotropic receptor NMDA type subunit 2B (*GRIN2B*) gene, Glutamate ionotropic receptor NMDA type subunit 2C (*GRIN2C*) gene, Glutamate ionotropic receptor NMDA type subunit 2D (*GRIN2D*) gene, Glutamate ionotropic receptor NMDA type subunit 3A (*GRIN3A*) gene, Glutamate ionotropic receptor NMDA type subunit 3B (*GRIN3B*) gene, Hyperpolarization Activated Cyclic Nucleotide Gated Potassium Channel 1 (*HCN1*) gene, Histone deacetylase 5 (*HDAC5*) gene, Methyl-CpG binding domain protein 1 (*MBD1*) gene, M-Phase Phosphoprotein 8 (*MPHOSPH8*) gene, Neural cell adhesion molecule 1 (*NCAM1*) gene, Nitric acid synthase 1 (*NOS1*) gene, Nitric acid synthase 2 (*NOS2*) gene, Nitric acid synthase 3 (*NOS3*) gene, NAD(P)H quinone dehydrogenase 1 (*NQO1*) gene, Opioid receptor kappa 1 (*OPRK1*) gene, Opioid receptor mu 1 (*OPRM1*) gene, Roundabout guidance receptor 2 (*ROBO2*) gene, SET domain bifurcated 1 (*SETDB1*) gene, SH3 and Multiple Ankyrin Repeat Domains 2 (*SHANK2*) gene, Sigma Non-Opioid Intracellular Receptor 1 (*SIGMAR1*) gene, Solute carrier family 6 member 9 (*SLC6A9*) gene, Transcription Activation Suppressor (*TASOR*) gene, TOG

array regulator of axonemal microtubules 2 (*TOGORAM2*) gene, Tripartite Motif Containing 28 (*TRIM28*) gene, Zinc Finger Protein 274 (*ZNF274*) gene, Anaphase promoting complex subunit 2 (*ANAPC2*) gene, Cytochrome P450 family 2 subfamily A member 6 (*CYP2A6*) gene, Cytochrome P450 family 2 subfamily B member 6 (*CYP2B6*) gene, Cytochrome P450 family 3 subfamily A member 4 (*CYP3A4*) gene, Disks large homolog 4 (*DLG4*), Eukaryotic Elongation Factor 2 Kinase (*EEF2K*) gene, Estrogen Receptor 1 (*ESR1*) gene, Glutamate ionotropic receptor AMPA type subunit 1 (*GRIA1*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA4*) gene, Glutamate ionotropic receptor NMDA type subunit 1 (*GRIN1*) gene, Glutamate ionotropic receptor NMDA type subunit 2B (*GRIN2B*) gene, Myosin VI (*MYO6*) gene, Roundabout Guidance Receptor 2 (*ROBO2*) gene, SH3 and Multiple Ankyrin Repeat Domains 2 (*SHANK2*) gene, or Transcription Elongation Regulator 1 (*TCERG1*) gene.

9. A method for treating a patient suffering from neuropsychiatric, neurological, or analgesia/pain disorders, the method comprising:

obtaining a biological sample of a patient;

analyzing or having analyzed the biological sample using one or more of: RNA sequencing or expression microarray analysis, chromatin conformation capture, or targeted genotyping based on differential activation and repression of topologically associating domains (TADs) in the biological sample of the patient indicative of drug efficacy and adverse drug events;

determining or having determined a pharmacogenomic network representation for a drug gene set for a glutamate N-methyl-d-aspartate receptor (NMDAR) antagonist or partial antagonist, a glycine receptor beta (GLRB) modulator, or an α -amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid receptor (AMPA) agonist for the patient based on the analysis;

comparing or having compared the pharmacogenomic network representation for the drug gene set for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient to a drug pharmacogenomic network and constituent sub-networks for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist from a reference database;

determining to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for administering to the patient based on the comparison; and

administering the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist to the patient.

10. The method of claim 9, wherein:

the pharmacogenomic network representation for the drug gene set for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient includes a patient drug pharmacodynamic efficacy sub-network, a patient drug pharmacodynamic adverse event sub-network, a chromatin remodeling sub-network, and a pharmacokinetic enzymes and hormones sub-network and the constituent sub-networks for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist from the reference database includes a set of reference drug pharmacodynamic efficacy sub-networks, reference drug pharmacodynamic adverse event sub-networks, reference chromatin remodeling sub-networks, and reference pharmacokinetic enzymes and hormones sub-networks, and

comparing the pharmacogenomic network representation for the drug gene set for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient to a drug pharmacogenomic network and constituent sub-networks for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist from a reference database includes:

assigning a first score to the patient drug efficacy sub-network based on an amount of similarity between the patient drug pharmacodynamic efficacy sub-network and the reference drug pharmacodynamic efficacy sub-network

assigning a second score to the patient drug pharmacodynamic adverse event sub-network based on an amount of similarity between the patient drug pharmacodynamic adverse event sub-network and the reference drug pharmacodynamic adverse-event sub-network; and.

11. The method of claim 10, wherein determining to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for administering to the patient based on the comparison includes:

determining to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient when the first score is above a first threshold score or the second score is below a second threshold score.

12. The method of claim 11, wherein determining to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient when the first score is above a first threshold score of the second score is below a second threshold score includes:

combining the first and second scores to generate an overall score; and
determining to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for the patient when the overall score is above a third threshold score.

13. The method of any one of claims 9-12, further comprising:
determining a dosage of the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for administering to the patient based on the comparison; and
administering the determined dosage of the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist to the patient.

14. The method of claim 13, wherein determining a dosage of the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist for administering to the patient includes:

determining the dosage using a regression model based on a combination of two or more of: the sex of the patient, the age of the patient, whether the patient smokes, ethnicity of the patient, height of the patient, weight of the patient, and mental illness history of the patient.

15. The method of claim 13, further comprising:
obtaining clinical data for the patient;
analyzing the biological sample using pharmacometabolomics to determine pre-existing medications and metabolites of the pre-existing medications in the patient; and
determining whether to administer the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist to the patient or the dosage to administer based at least in part on drug-gene or drug-drug interactions between the pre-existing medications in the patient and the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist.

16. The method of any one of claims 9-15, wherein the drug pharmacogenomic network for the NMDAR antagonist or partial antagonist, GLRB modulator, or AMPAR agonist from the reference database is a ketamine pharmacogenomic network and includes one or more of: Activity regulated cytoskeleton associated protein (*ARC*) gene, Achaete-Scute family bHLH transcription factor 1 (*ASCL1*) gene, Brain derived neurotrophic factor (*BDNF*) gene, BDNF antisense RNA (*BDNF-AS*) gene, Calcium/calmodulin dependent protein kinase II alpha (*CAMK2A*) gene, Cyclin dependent kinase inhibitor 1A (*CDKN1A*) gene, cAMP responsive element modulator (*CREM*) gene, Cut like homeobox 2 (*CUX2*) gene, DCC netrin 1 receptor (*DCC*) gene, Dopamine receptor D2 (*DRD2*) gene, Eukaryotic translation elongation factor 2 kinase (*EEF2K*) gene, Fragile X mental retardation 1 (*FMRI*) gene, Ganglioside induced differentiation associated protein 1 like 1 (*GDAP1L1*) gene, Glutamate metabotropic receptor 5 (*GRM5*) gene, Homer scaffold protein 1 (*HOMER1*) gene, 5-hydroxytryptamine receptor 1B (*HTR1B*) gene, 5-hydroxytryptamine receptor 2A (*HTR2A*) gene, Kruppel like factor 6 (*KLF6*) gene, Lin-7 homolog C, crumbs cell polarity complex component (*LIN7C*) long noncoding RNA, *LOC105379109* long noncoding RNA, Myocyte enhancer factor 2D (*MEF2D*) gene, Myosin VI (*MYO6*) gene, Myelin transcription factor 1 like (*MYT1L*) gene, Neuronal differentiation 1 (*NEUROD1*) gene, Neuronal differentiation 2 (*NEUROD2*) gene, Nescient helix-loop-helix 2 (*NHLH2*) gene, Neuromedin B (*NMB*) gene, NMDA receptor synaptonuclear signaling and neuronal migration factor (*NSMF*) gene, Neurotrophic receptor tyrosine kinase 2 (*NTRK2*) gene, Phosphatase and tensin homolog (*PTEN*) gene, Prostaglandin-endoperoxide synthase 2 (*PTGS2*) gene, Rac family small GTPase 1 (*RAC1*) gene, Ras protein specific guanine nucleotide releasing factor 2 (*RASGRF2*) gene, Ras homolog family member A (*RHOA*) gene, Roundabout guidance receptor 2 (*ROBO2*) gene, *RP11_360A181* long noncoding RNA, Semaphorin 3A (*SEMA3A*) gene, SH3 and multiple ankyrin repeat domains 1 (*SHANK1*) gene, SH3 and multiple ankyrin repeat domains 2 (*SHANK2*) gene, SH3 and multiple ankyrin repeat domains 3 (*SHANK3*) gene, Solute carrier family 22 member 15 (*SLC22A15*) gene, Solute carrier family 6 member 2 (*SLC6A2*) gene, Slit guidance ligand 1 (*SLIT1*) gene, Slit guidance ligand 2 (*SLIT2*) gene, Synaptosome associated protein 25 (*SNAP25*) gene, Synapsin I (*SYN1*) gene, Synapsin II (*SYN2*) gene, Synapsin III (*SYN3*) gene, T-box, brain 1 (*TBR1*) gene, Transcription factor 4 (*TCF4*) gene, Acetylcholinesterase (*ACHE*) gene, Activating transcription factor 7 interacting protein (*ATF7IP*) gene, Activating transcription factor 7 interacting protein 2 (*ATF7IP2*) gene, ATPase

Na⁺/K⁺ Transporting Subunit Alpha 1 (*ATP1A1*) gene, BLOC-1 related complex unit 7 (*BORCS7*) gene, Bromodomain containing 4 (*BRD4*) gene, Calcium voltage-gated channel subunit alpha1 C (*CACNA1C*) gene, Calcium voltage-gated channel auxiliary subunit beta 1 (*CACNB1*) gene, Calcium voltage-gated channel auxiliary subunit beta 2 (*CACNB2*) gene, Calcium voltage-gated channel auxiliary subunit gamma 2 (*CACNG2*) gene, Cholinergic Receptor Muscarinic 2 (*CHRM2*) gene, Cholinergic Receptor Nicotinic Alpha 3 Subunit (*CHRNA3*) gene, Cholinergic Receptor Nicotinic Alpha 5 Subunit (*CHRNA5*) gene, Cholinergic Receptor Nicotinic Alpha 7 Subunit (*CHRNA7*) gene, Cannabinoid receptor 1 (*CNR1*) gene, Disks large homolog 3 (*DLG3*) gene, Disks large homolog 4 (*DLG4*) gene, DNA Methyltransferase 1 (*DNMT1*) gene, Euchromatic histone lysine methyltransferase 1 (*EHMT1*) gene, Gamma-aminobutyric acid type A receptor alpha2 subunit (*GABRA2*) gene, Gamma-aminobutyric acid type A receptor alpha5 subunit (*GABRA5*) gene, Glutamate decarboxylase 1 (*GAD1*) gene, Glycine receptor alpha 1 (*GLRA1*) gene, Glycine receptor alpha 2 (*GLRA2*) gene, Glycine receptor beta (*GLRB*) gene, Glutamate ionotropic receptor AMPA type subunit 1 (*GRIA1*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA2*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA4*) gene, Glutamate ionotropic receptor NMDA type subunit 1 (*GRIN1*) gene, Glutamate ionotropic receptor NMDA type subunit 2A (*GRIN2A*) gene, Glutamate ionotropic receptor NMDA type subunit 2B (*GRIN2B*) gene, Glutamate ionotropic receptor NMDA type subunit 2C (*GRIN2C*) gene, Glutamate ionotropic receptor NMDA type subunit 2D (*GRIN2D*) gene, Glutamate ionotropic receptor NMDA type subunit 3A (*GRIN3A*) gene, Glutamate ionotropic receptor NMDA type subunit 3B (*GRIN3B*) gene, Hyperpolarization Activated Cyclic Nucleotide Gated Potassium Channel 1 (*HCN1*) gene, Histone deacetylase 5 (*HDAC5*) gene, Methyl-CpG binding domain protein 1 (*MBD1*) gene, M-Phase Phosphoprotein 8 (*MPHOSPH8*) gene, Neural cell adhesion molecule 1 (*NCAM1*) gene, Nitric acid synthase 1 (*NOS1*) gene, Nitric acid synthase 2 (*NOS2*) gene, Nitric acid synthase 3 (*NOS3*) gene, NAD(P)H quinone dehydrogenase 1 (*NQO1*) gene, Opioid receptor kappa 1 (*OPRK1*) gene, Opioid receptor mu 1 (*OPRM1*) gene, Roundabout guidance receptor 2 (*ROBO2*) gene, SET domain bifurcated 1 (*SETDB1*) gene, SH3 and Multiple Ankyrin Repeat Domains 2 (*SHANK2*) gene, Sigma Non-Opioid Intracellular Receptor 1 (*SIGMAR1*) gene, Solute carrier family 6 member 9 (*SLC6A9*) gene, Transcription Activation Suppressor (*TASOR*) gene, TOG array regulator of axonemal microtubules 2 (*TOGORAM2*) gene, Tripartite Motif Containing 28

(*TRIM28*) gene, Zinc Finger Protein 274 (*ZNF274*) gene, Anaphase promoting complex subunit 2 (*ANAPC2*) gene, Cytochrome P450 family 2 subfamily A member 6 (*CYP2A6*) gene, Cytochrome P450 family 2 subfamily B member 6 (*CYP2B6*) gene, Cytochrome P450 family 3 subfamily A member 4 (*CYP3A4*) gene, Disks large homolog 4 (*DLG4*), Eukaryotic Elongation Factor 2 Kinase (*EEF2K*) gene, Estrogen Receptor 1 (*ESR1*) gene, Glutamate ionotropic receptor AMPA type subunit 1 (*GRIA1*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA4*) gene, Glutamate ionotropic receptor NMDA type subunit 1 (*GRIN1*) gene, Glutamate ionotropic receptor NMDA type subunit 2B (*GRIN2B*) gene, Myosin VI (*MYO6*) gene, Roundabout Guidance Receptor 2 (*ROBO2*) gene, SH3 and Multiple Ankyrin Repeat Domains 2 (*SHANK2*) gene, or Transcription Elongation Regulator 1 (*TCERG1*) gene.

17. The method of claim 16, wherein the constituent sub-networks for the ketamine pharmacogenomic network include a drug pharmacodynamic efficacy sub-network, and wherein the drug pharmacodynamic efficacy sub-network includes one or more of: Activity regulated cytoskeleton associated protein (*ARC*) gene, Achaete-Scute family bHLH transcription factor 1 (*ASCL1*) gene, Brain derived neurotrophic factor (*BDNF*) gene, BDNF antisense RNA (*BDNF-AS*) gene, Calcium/calmodulin dependent protein kinase II alpha (*CAMK2A*) gene, Cyclin dependent kinase inhibitor 1A (*CDKN1A*) gene, cAMP responsive element modulator (*CREM*) gene, Cut like homeobox 2 (*CUX2*) gene, DCC netrin 1 receptor (*DCC*) gene, Dopamine receptor D2 (*DRD2*) gene, Eukaryotic translation elongation factor 2 kinase (*EEF2K*) gene, Fragile X mental retardation 1 (*FMRI*) gene, Ganglioside induced differentiation associated protein 1 like 1 (*GDAP1L1*) gene, Glutamate metabotropic receptor 5 (*GRM5*) gene, Homer scaffold protein 1 (*HOMER1*) gene, 5-hydroxytryptamine receptor 1B (*HTR1B*) gene, 5-hydroxytryptamine receptor 2A (*HTR2A*) gene, Kruppel like factor 6 (*KLF6*) gene, Lin-7 homolog C, crumbs cell polarity complex component (*LIN7C*) long noncoding RNA, *LOC105379109* long noncoding RNA, Myocyte enhancer factor 2D (*MEF2D*) gene, Myosin VI (*MYO6*) gene, Myelin transcription factor 1 like (*MYT1L*) gene, Neuronal differentiation 1 (*NEUROD1*) gene, Neuronal differentiation 2 (*NEUROD2*) gene, Nescient helix-loop-helix 2 (*NHLH2*) gene, Neuromedin B (*NMB*) gene, NMDA receptor synaptonuclear signaling and neuronal migration factor (*NSMF*) gene, Neurotrophic receptor tyrosine kinase 2 (*NTRK2*) gene, Phosphatase and tensin homolog (*PTEN*) gene, Prostaglandin-endoperoxide synthase 2 (*PTGS2*)

gene, Rac family small GTPase 1 (*RAC1*) gene, Ras protein specific guanine nucleotide releasing factor 2 (*RASGRF2*) gene, Ras homolog family member A (*RHOA*) gene, Roundabout guidance receptor 2 (*ROBO2*) gene, *RP11_360A181* long noncoding RNA, Semaphorin 3A (*SEMA3A*) gene, SH3 and multiple ankyrin repeat domains 1 (*SHANK1*) gene, SH3 and multiple ankyrin repeat domains 2 (*SHANK2*) gene, SH3 and multiple ankyrin repeat domains 3 (*SHANK3*) gene, Solute carrier family 22 member 15 (*SLC22A15*) gene, Solute carrier family 6 member 2 (*SLC6A2*) gene, Slit guidance ligand 1 (*SLIT1*) gene, Slit guidance ligand 2 (*SLIT2*) gene, Synaptosome associated protein 25 (*SNAP25*) gene, Synapsin I (*SYN1*) gene, Synapsin II (*SYN2*) gene, Synapsin III (*SYN3*) gene, T-box, brain 1 (*TBR1*) gene, or Transcription factor 4 (*TCF4*) gene.

18. The method of claim 16, wherein the constituent sub-networks for the ketamine pharmacogenomic network include a drug pharmacodynamic adverse events sub-network, and wherein the drug pharmacodynamic adverse events sub-network includes one or more of: Acetylcholinesterase (*ACHE*) gene, Activating transcription factor 7 interacting protein (*ATF7IP*) gene, Activating transcription factor 7 interacting protein 2 (*ATF7IP2*) gene, ATPase Na⁺/K⁺ Transporting Subunit Alpha 1 (*ATPIA1*) gene, BLOC-1 related complex unit 7 (*BORCS7*) gene, Bromodomain containing 4 (*BRD4*) gene, Calcium voltage-gated channel subunit alpha1 C (*CACNA1C*) gene, Calcium voltage-gated channel auxiliary subunit beta 1 (*CACNB1*) gene, Calcium voltage-gated channel auxiliary subunit beta 2 (*CACNB2*) gene, Calcium voltage-gated channel auxiliary subunit gamma 2 (*CACNG2*) gene, Cholinergic Receptor Muscarinic 2 (*CHRM2*) gene, Cholinergic Receptor Nicotinic Alpha 3 Subunit (*CHRNA3*) gene, Cholinergic Receptor Nicotinic Alpha 5 Subunit (*CHRNA5*) gene, Cholinergic Receptor Nicotinic Alpha 7 Subunit (*CHRNA7*) gene, Cannabinoid receptor 1 (*CNRI*) gene, Disks large homolog 3 (*DLG3*) gene, Disks large homolog 4 (*DLG4*) gene, DNA Methyltransferase 1 (*DNMT1*) gene, Euchromatic histone lysine methyltransferase 1 (*EHMT1*) gene, Gamma-aminobutyric acid type A receptor alpha2 subunit (*GABRA2*) gene, Gamma-aminobutyric acid type A receptor alpha5 subunit (*GABRA5*) gene, Glutamate decarboxylase 1 (*GADI*) gene, Glycine receptor alpha 1 (*GLRA1*) gene, Glycine receptor alpha 2 (*GLRA2*) gene, Glycine receptor beta (*GLRB*) gene, Glutamate ionotropic receptor AMPA type subunit 1 (*GRIA1*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA2*) gene, Glutamate

ionotropic receptor AMPA type subunit 2 (*GRIA4*) gene, Glutamate ionotropic receptor NMDA type subunit 1 (*GRIN1*) gene, Glutamate ionotropic receptor NMDA type subunit 2A (*GRIN2A*) gene, Glutamate ionotropic receptor NMDA type subunit 2B (*GRIN2B*) gene, Glutamate ionotropic receptor NMDA type subunit 2C (*GRIN2C*) gene, Glutamate ionotropic receptor NMDA type subunit 2D (*GRIN2D*) gene, Glutamate ionotropic receptor NMDA type subunit 3A (*GRIN3A*) gene, Glutamate ionotropic receptor NMDA type subunit 3B (*GRIN3B*) gene, Hyperpolarization Activated Cyclic Nucleotide Gated Potassium Channel 1 (*HCN1*) gene, Histone deacetylase 5 (*HDAC5*) gene, Methyl-CpG binding domain protein 1 (*MBD1*) gene, M-Phase Phosphoprotein 8 (*MPHOSPH8*) gene, Neural cell adhesion molecule 1 (*NCAM1*) gene, Nitric acid synthase 1 (*NOS1*) gene, Nitric acid synthase 2 (*NOS2*) gene, Nitric acid synthase 3 (*NOS3*) gene, NAD(P)H quinone dehydrogenase 1 (*NQO1*) gene, Opioid receptor kappa 1 (*OPRK1*) gene, Opioid receptor mu 1 (*OPRM1*) gene, Roundabout guidance receptor 2 (*ROBO2*) gene, SET domain bifurcated 1 (*SETDB1*) gene, SH3 and Multiple Ankyrin Repeat Domains 2 (*SHANK2*) gene, Sigma Non-Opioid Intracellular Receptor 1 (*SIGMAR1*) gene, Solute carrier family 6 member 9 (*SLC6A9*) gene, Transcription Activation Suppressor (*TASOR*) gene, TOG array regulator of axonemal microtubules 2 (*TOGORAM2*) gene, Tripartite Motif Containing 28 (*TRIM28*) gene, or Zinc Finger Protein 274 (*ZNF274*) gene.

19. The method of claim 16, wherein the constituent sub-networks for the ketamine pharmacogenomic network include a pharmacokinetic enzymes and hormones sub-network, and wherein the pharmacokinetic enzymes and hormones sub-network includes one or more of: Anaphase promoting complex subunit 2 (*ANAPC2*) gene, Cytochrome P450 family 2 subfamily A member 6 (*CYP2A6*) gene, Cytochrome P450 family 2 subfamily B member 6 (*CYP2B6*) gene, Cytochrome P450 family 3 subfamily A member 4 (*CYP3A4*) gene, Disks large homolog 4 (*DLG4*), Eukaryotic Elongation Factor 2 Kinase (*EEF2K*) gene, Estrogen Receptor 1 (*ESR1*) gene, Glutamate ionotropic receptor AMPA type subunit 1 (*GRIA1*) gene, Glutamate ionotropic receptor AMPA type subunit 2 (*GRIA4*) gene, Glutamate ionotropic receptor NMDA type subunit 1 (*GRIN1*) gene, Glutamate ionotropic receptor NMDA type subunit 2B (*GRIN2B*) gene, Myosin VI (*MYO6*) gene, Roundabout Guidance Receptor 2 (*ROBO2*) gene, SH3 and Multiple Ankyrin Repeat Domains 2 (*SHANK2*) gene, or Transcription Elongation Regulator 1 (*TCERG1*) gene.