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(54) Title: CELL-PERMEABLE INHIBITORY AGENT AND METHODS OF USE THEREOF IN TREATMENT OF COGNITIVE AND MOOD DISORDERS

(57) Abstract: The present application provides an inhibitory compound, such as a peptide, and methods for using the inhibitory compound in the treatment, diagnosis or monitoring of cognitive and mood disorders that are typically associated with memory loss and/or loss of executive function. In one example, the inhibitory compound is a peptide that mimics the N-terminal sequence of the intracellular loop of α5 subunit of $\alpha5GABA_A$ receptors. Also provided are compositions and methods for treating a disorder associated with memory loss or loss of executive function. The therapeutic method comprises the step of inhibiting binding of radixin to $\alpha5GABA_A$ receptors, for example, by administration of the presently described inhibitory compound or peptide.

CELL-PERMEABLE INHIBITORY AGENT AND METHODS OF USE THEREOF IN TREATMENT OF COGNITIVE AND MOOD DISORDERS

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims the benefit of U.S. Provisional Application No. 62/268,137, filed December 16, 2015, the entirety of which is hereby incorporated by reference herein.

TECHNICAL FIELD

[0002] This disclosure relates to the field of therapies for the treatment or prevention of cognitive or mood disorders. More particularly, the present disclosure relates to treatment or prevention of cognitive and mood disorders using an inhibitory agent, such as a peptide, that targets α5GABA$_A$ receptor activity.

BACKGROUND

[0003] γ-Aminobutyric acid (GABA) is the major inhibitory neurotransmitter in the mammalian brain. The majority of GABA actions are mediated by type A GABA (GABA$_A$) receptors, which are ligand-gated anion channels. These ion channels are pentameric complexes that contain an integral chloride-permeable pore. Binding of GABA to the receptor activates the channel by opening the pore. This increases chloride permeability and typically reduces neuronal excitability. There are at least 19 different genes (Olsen & Sieghart, 2008) that encode the various subunits of the GABA$_A$ receptors. Most mature GABA$_A$ receptors are formed from two α subunits, two β subunits and a subunit that is γ, δ, ε, θ, π or ρ. The subunit composition of the receptors confers distinct pharmacological properties to the receptors and distinct patterns of distribution in terms of locations in the brain and subcellular expression patterns (Nutt 2006).

[0004] GABA$_A$ receptors are involved in a multitude of physiological processes and neurological disorders. An increase in GABAergic inhibition has been associated with cognitive disorders such as memory loss associated with aging, Alzheimer's disease, Down syndrome, Fragile X syndrome and postoperative cognitive dysfunction.

Normalizing inhibitory neurotransmission may be of great therapeutic value in treating these disorders.

[0005] Pharmacological approaches that non-selectively target $GABA_A$ receptors and inhibit their function are not clinically useful because of the adverse pro-convulsant and anxiogenic properties of the drugs. However, a strategy that selectively targets a specific subtype of $GABA_A$ receptors, particularly if the receptor has a restricted pattern of expression, represents a promising therapeutic approach that has not previously been explored.

[0006] $\alpha5GABA_A$ receptors are expressed in several brain regions but are predominantly in the hippocampus where they primarily localize to extrasynaptic regions of the neurons. These receptors generate a tonic inhibitory conductance that powerfully regulates neuronal excitability and network plasticity. Alterations in the activity and expression levels of $\alpha5GABA_A$ receptors in experimental animal models modify memory, problem solving and mood-related behaviors. More specifically, an increase in $\alpha5GABA_A$ receptors typically causes memory deficits, whereas a reduction in receptor function improves memory performance for certain types of hippocampus-dependent memory-related tasks (Caraiscos et al., 2004a; Martin et al., 2010).

[0007] Abnormal activity and dysregulation of $\alpha5GABA_A$ receptors in humans has been implicated in multiple clinical disorders including age-related dementia, schizophrenia, Down syndrome, stroke and anesthetic-induced amnesia. These receptors also contribute to inflammation-induced injury in neuronal and non-neuronal structures, such as the lung and pancreas. As a result, drugs or compounds that allosterically modulate $\alpha5GABA_A$ receptor function have been developed. Most of these drugs, acting as negative or positive allosteric modulators (so called NAMs and PAMs), showed potential therapeutic effects in animal models; however, to date, few have been successfully implemented in clinical trials. Low therapeutic efficacy, serious adverse side-effects and off-target toxicity (e.g., renal toxicity) in humans have limited the use of these compounds (Rudolph & Mohler 2014; Soh & Lync 2015). Several examples of these compounds are described below.

[0008] The negative allosteric modulator $\alpha5IA$ improves ethanol-induced impaired performance in healthy subjects (Nutt et al., 2007). However, a clinical trial that probed

the effectiveness of α5IA in patients was stopped due to renal toxicity (Atack 2010). At high concentrations, α5IA also activates α1 subunit-containing $GABA_A$ receptors, an action that is predicted to cause undesirable sedation. Another negative allosteric inhibitor of α5$GABA_A$ receptors, L-655,708, is 30-70 fold more selective for α5$GABA_A$ receptors. However, L-655,708 has a relatively low efficacy for reducing α5$GABA_A$ receptor function (Atack, et al., 2005). Finally, drugs that act as allosteric inhibitors often fail to differentiate α5$GABA_A$ receptors that are necessary for baseline or physiological functions (e.g., support memory processes such as memory erasing).

[0009] Other than NAMs, no alternative treatments are currently available to treat cognitive, mood and inflammation-induced dysfunctions that result from up-regulation of α5$GABA_A$ receptor function. As noted above, almost all of the compounds that have been developed, act as reversible allosteric modulators at the benzodiazepine-recognition domain of the receptor and reduce channel function. There remains widespread interest in developing pharmacological agents that reduce α5$GABA_A$ receptor function by alternative mechanisms.

[0010] Genetically manipulating *Gabar5* gene expression has been used as an alternative approach to reduce α5$GABA_A$ receptor function and treatments based on this approach showed improvements in memory performance in animal models (Crestani, et al., 2002; Yee, et al., 2004; Prut et al., 2010). Recently, the roles of endogenous specific antibodies in psychiatric disorders have gained some attention (Varley et al., 2015; Pettingill et al., 2015). Pettingill et al (2015) reported that incubation of primary hippocampal neurons with $GABA_A$ receptor IgG1 sera reduced surface $GABA_A$ receptor membrane expression; however, any impactful utility of $GABA_A$ receptor antibodies in the IgG1 sera in physiological and pathological conditions has not yet been reported.

[0011] The above information is provided for the purpose of making known information believed by the applicant to be of possible relevance to the present invention. No admission is necessarily intended, nor should be construed, that any of the preceding information constitutes prior art against the present invention.

SUMMARY

[0012] An object of the present invention is to provide a cell-permeable inhibitory agent and methods of use thereof in treatment of cognitive and mood disorders. In accordance with an aspect of the present application, there is provided an inhibitory compound that interrupts binding of radixin to α5GABA$_A$ receptors. In some embodiments, the inhibitory compound is an antibody, a peptide, a peptidomimetic or a small molecule. In a particular embodiment, the inhibitory compound is an isolated or synthetic peptide that binds to an α5 subunit binding domain on radixin or that binds to a radixin binding domain on an α5GABA$_A$ receptor.

[0013] In accordance with an aspect of the present application, there is provided an isolated or synthetic peptide comprising the sequence of SEQ ID NO: 4, a conservative variant thereof or a sequence having at least 80% homology with SEQ ID NO:4. Optionally, the peptide comprises the sequence of SEQ ID NO:3, SEQ ID NO:2, SEQ ID NO:1, or a conservative variant thereof. In accordance with another aspect of the application, there is provided a method for treatment or prevention of a cognitive or mood disorder characterized or associated with impairment of memory or executive function or both in a subject, wherein said method comprises administering to the subject an agent that interrupts binding of radixin to α5GABA$_A$ receptors. In some embodiments, the inhibitory agent is an antibody, a peptide, a peptidomimetic or a small molecule. Optionally, the agent is an antibody or a peptide, such as an isolated or synthetic peptide comprising the sequence of SEQ ID NO: 4, a conservative variant thereof or a sequence having at least 80% homology with SEQ ID NO:4. In another alternative, the agent is a peptide-biomimicking small molecule that mimics the activity of the isolated or synthetic peptide comprising the sequence of SEQ ID NO: 4 in interrupting the binding of radixin to α5GABA$_A$ receptors.

[0014] In accordance with another aspect of the application, there is provided a method for improving memory or executive function or both in a subject, wherein said method comprises administering to the subject an agent that interrupts binding of radixin to α5GABA$_A$ receptors. In some embodiments, the inhibitory agent is an antibody, a peptide, a peptidomimetic or a small molecule. Optionally, the agent is an antibody or a peptide, such as an isolated or synthetic peptide comprising the sequence of SEQ ID NO:

4, a conservative variant thereof or a sequence having at least 80% homology with SEQ ID NO:4. In another alternative, the agent is a peptide-biomimicking small molecule that mimics the activity of the isolated or synthetic peptide comprising the sequence of SEQ ID NO: 4 in interrupting the binding of radixin to $\alpha5GABA_A$ receptors.

[0015] In accordance with another aspect of the application, there is provided a pharmaceutical composition for use in (i) treating or preventing a cognitive or mood disorder characterized or associated with impairment of memory or executive function or both; or (ii) improving memory or executive function or both, said composition comprising an inhibitory agent and a pharmaceutically acceptable carrier or excipient, wherein the inhibitory agent interferes with binding of radixin to $\alpha5GABA_A$ receptors.

[0016] In accordance with another aspect of the application, there is provided a pharmaceutical composition comprising a peptide comprising the sequence of SEQ ID NO: 4, a conservative variant thereof or a sequence having at least 80% homology with SEQ ID NO:4. In accordance with another aspect of the application, there is provided a pharmaceutical composition comprising a small molecule biomimetic that mimics the activity of the isolated or synthetic peptide comprising the sequence of SEQ ID NO: 4 in interrupting the binding of radixin to $\alpha5GABA_A$ receptors.

[0017] The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description, taken in conjunction with the accompanying drawings, which description is by way of example only.

BRIEF DESCRIPTION OF DRAWINGS

[0018] For a better understanding of the present invention, as well as other aspects and further features thereof, reference is made to the following description which is to be used in conjunction with the accompanying drawings, where:

[0019] **Figure 1** depicts the $GABA_A$ receptor α5 subunit binding domain for radixin according to an embodiment of the present invention. Figure 1A depicts the α5 subunit and radixin binding motif, and Figure 1B illustrates how the small inhibitory peptide uncouples the interaction between radixin and α5 subunit;

[0020] **Figure 2** depicts the results of immunoprecipitation and Western Blot studies performed using anti-α5 and anti-pThr564-radixin antibodies according to an embodiment of the present invention. Figure 2A depicts an example of Western blot and co-immunoprecipitation experiments and Figure 2B graphically depicts the quantified data summarised from 3 experiments (** $P < 0.01$, ANOVA, one way, $n = 3$);

[0021] **Figure 3** depicts the results of immunoprecipitation and Western Blot studies performed using anti-α5 and anti-gephyrin antibodies according to an embodiment of the present invention. Figure 3A depicts an example of Western blot and co-immunoprecipitation experiments, and Figure 3B graphically depicts the data quantified from four experiments (NS indicates no significance between these two groups);

[0022] **Figure 4** depicts the results of immunoprecipitation and Western Blot studies performed using anti-α1, anti-α2 and anti-gephyrin antibodies according to an embodiment of the present invention. Figure 4A depicts an example of co-immunoprecipitation and Western blot experiments and Figure 4B graphically depicts the data quantified from 4 experiments ($P > 0.05$, t-test, $n = 4$);

[0023] **Figure 5** depicts the results of the study of neurotoxicity of the inhibitory peptide in cultured hippocampal neurons according to an embodiment of the present invention;

[0024] **Figures 6A and 6B** depict the results of a study demonstrating the preventive effect of the inhibitory peptide on the etomidate-induced increase in $GABA_A$ receptor α5 subunit cell surface expression in neurons according to an embodiment of the present invention (Mean ± SD , * $P < 0.05$, ANOVA, $n = 3$);

[0025] **Figure 7** graphically depicts the effect of truncation of the inhibitory peptide sequence on α5$GABA_A$ receptor surface expression according to an embodiment of the present invention (Mean ± SD, $P < 0.05$, $n = 3$, ANOVA, one way);

[0026] **Figure 8** graphically depicts the effect of the peptide length on the inhibition of α5$GABA_A$ receptor cell surface expression in cells treated with etomidate according to an embodiment of the present invention (Mean ± SD, $P < 0.05$, $n=3$, ANOVA, one way);

[0027] **Figure 9** depicts the electrophysiological data showing the effect of the co-treatment with etomidate and the α5 peptide in hippocampal neurons when the α5 peptide is used to prevent etomidate-induced increase in tonic current according to an

embodiment of the present invention. **Figure 9A** shows the tonic current measured one day after treatment. **Figure 9B** shows the quantified data (Statistical analysis was performed with one-way ANOVA followed by Newman-Keuls *post hoc* test, * $P < 0.05$, ** $P < 0.01$, n = 10 for Ctrl, n = 12 for Etom, n = 13 for Etom+Pep, and n = 11 for Etom+sPep);

[0028] **Figure 10** depicts the results of studies to demonstrate radixin phosphorylation and total protein expression in mouse model treated with saline or etomidate according to an embodiment of the present invention. **Figure 10A** depicts an example of a Western blot from tissue lysate prepared from the hippocampus of adult mice (C57BL/6J x SvEv129) injected (i.p.) with 8 mg/kg of etomidate, and the results shown in **Figure 10B** and **Figure 10C** depict the effect of etomidate on radixin phosphorylation, and total radixin expression (the data was quantified from 3 separate experiments, * $P < 0.05$, t-test, two – tailed test, n = 3; NS stands for no significance).

[0029] **Figure 11** depicts the effects of the peptide and scramble peptide on the etomidate-induced α5 subunit surface expression *ex vivo* according to an embodiment of the present invention. **Figure 11A** depicts an example of co-immunoprecipitation and Western blot experiments and the data quantified for α5 surface expression and **Figure 11B** depicts an example of co-immunoprecipitation and Western blot experiments and the data quantified for total protein expression of α5 subunit (Data shown as Mean ± SD, * $P < 0.05$, t-test, two – tail, n=4);

[0030] **Figure 12** shows a schematic illustration of the timeline experimentation for the prevention paradigm according to an embodiment of the present invention;

[0031] **Figure 13** provides data for the preventive effect of the α5 peptide on the memory impairment caused by the general anesthetic etomidate according to an embodiment of the present invention (data shown as mean ± SEM, * $P < 0.05$, one – way ANOVA and Tukey's multiple comparison test, 4 - 9 mice per group);

[0032] **Figure 14** shows a schematic illustration of the timeline experimentation for the treatment paradigm according to an embodiment of the present invention; and

[0033] **Figure 15** provides data for the treatment effect of the α5 peptide on the memory impairment caused by the general anesthetic etomidate according to an embodiment of the present invention (data shown as mean ± SEM, 4 mice per group); and

[0034] **Figure 16** depicts the persistent increase of tonic current caused by inhaled anesthetics (isoflurane, sevoflurane), benzodiazepines (midazolam), and propofol according to an embodiment of the present invention ((a) midazolam (MDZ, 200 nM); (b) propofol (Prop, 3 μM); and (c) isoflurane (ISO, 250 μM) and sevoflurance (SEVO, 266 μM)) in neurons grown in co-cultures.

DETAILED DESCRIPTION

[0035] Definitions

[0036] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

[0037] As used in the specification and claims, the singular forms "a", "an" and "the" include plural references unless the context clearly dictates otherwise.

[0038] The term "comprising," as used herein will be understood to mean that the list following is non-exhaustive and may or may not include any other additional suitable items, for example one or more further feature(s), component(s) and/or ingredient(s) as appropriate.

[0039] Terms of degree such as "substantially", "about" and "approximately" as used herein mean a reasonable amount of deviation of the modified term such that the end result is not significantly changed. These terms of degree should be construed as including a deviation of at least ±5% of the modified term if this deviation would not negate the meaning of the word it modifies.

[0040] The term "homology" is used herein to refer to the degree of similarity, or identity, between sequences, such as amino acid sequences. The term is not intended to require any shared ancestry among the sequences.

[0041] The term "subject" as used herein includes all members of the animal kingdom including mammals, and suitably refers to humans.

[0042] The term "pharmaceutically acceptable" means compatible with the treatment of subjects, in particular humans.

[0043] The term "pharmaceutically acceptable salt" means an acid addition salt or a base addition salt which is suitable for, or compatible with, the treatment of subjects.

[0044] An acid addition salt suitable for, or compatible with, the treatment of subjects is any non-toxic organic or inorganic salt of any basic compound. Basic compounds that form an acid addition salt include, for example, compounds comprising an amine group. Illustrative inorganic acids which form suitable salts include hydrochloric, hydrobromic, sulfuric and phosphoric acids, as well as metal salts such as sodium monohydrogen orthophosphate and potassium hydrogen sulfate. Illustrative organic acids that form suitable salts include mono-, di-, and tricarboxylic acids such as glycolic, lactic, pyruvic, malonic, succinic, glutaric, fumaric, malic, tartaric, citric, ascorbic, maleic, benzoic, phenylacetic, cinnamic and salicylic acids, as well as sulfonic acids such as p-toluene sulfonic and methanesulfonic acids. Either the mono- or di-acid salts can be formed and such salts can exist in either a hydrated, solvated or substantially anhydrous form. In general, acid addition salts are more soluble in water and various hydrophilic organic solvents, and generally demonstrate higher melting points in comparison to their free base forms. The selection of the appropriate salt will be known to one skilled in the art.

[0045] A base addition salt suitable for, or compatible with, the treatment of subjects is any non-toxic organic or inorganic base addition salt of any acidic compound. Acidic compounds that form a basic addition salt include, for example, compounds comprising a carboxylic acid group. Illustrative inorganic bases which form suitable salts include lithium, sodium, potassium, calcium, magnesium, or barium hydroxide. Illustrative organic bases that form suitable salts include, but are not limited to, aliphatic, alicyclic or aromatic organic amines such as methylamine, trimethylamine and picoline, alkylammonias or ammonia. The selection of the appropriate salt will be known to a person skilled in the art.

[0046] The term "treating" or "treatment," as used herein and as is well understood in the art, means an approach for obtaining beneficial or desired results, including, for example, clinical results. Beneficial or desired clinical results can include, but are not

limited to, alleviation or amelioration of one or more symptoms or conditions, diminishment of extent of disorder, stabilized (i.e., not worsening) state of disorder, delay or slowing of disorder progression, amelioration or palliation of the disorder, diminishment of the reoccurrence of the disorder, and remission (whether partial or total), whether detectable or undetectable. Treatment methods comprise administering to a subject a therapeutically effective amount of one or more of the compounds of the application and optionally consists of a single administration, or alternatively comprises a series of administrations. For example, the compounds of the application are administered at least once a week. However, in another embodiment, the compounds are administered to the subject from about one time per three weeks, or about one time per week to about once daily for a given treatment. In another embodiment, the compounds are administered 2, 3, 4, 5 or 6 times daily. The length of the treatment period depends on a variety of factors, such as the severity of the disease, the age of the patient, the concentration, the activity of the compounds of the application, and/or a combination thereof. It will also be appreciated that the effective dosage of the compound used for the treatment or prophylaxis may increase or decrease over the course of a particular treatment or prophylaxis regime. Changes in dosage may result and become apparent by standard diagnostic assays known in the art. In some instances, chronic administration is required. For example, the compounds are administered to the subject in an amount and for a duration, sufficient to treat the patient.

[0047] As used herein, the term “effective amount” or “therapeutically effective amount” means an amount effective, at dosages and for periods of time necessary to achieve the desired result. For example in the context of treating a disease, disorder or condition characterized by or associated with an over-abundance of $\alpha5GABA_A$ receptors on neuronal surfaces, an effective amount is an amount that, for example, reduces $\alpha5GABA_A$ receptor accumulation on neuronal surfaces compared to the $\alpha5GABA_A$ receptor accumulation without administration of the compound. Effective amounts can vary according to factors such as the stage or state of the disorder, age, sex and/or weight of the subject. The amount of a given compound that will correspond to such an amount will vary depending upon various factors, such as the given compound, the pharmaceutical formulation, the route of administration, the type of condition, disease or

disorder, the identity of the subject being treated, and the like, but can nevertheless be routinely determined by one skilled in the art.

[0048] The term "administered" as used herein means administration of a therapeutically effective dose of a compound or composition of the application to a cell either in cell culture or in a subject.

[0049] The term "executive function," as used herein, refers to regulation or control of cognitive processes, such as, but not limited to working memory, reasoning, problem solving, planning, plan execution and task execution. Impairment of executive function associated with various cognitive and mood disorders. A "mood disorder" is a psychological disorder characterized by the elevation or lowering of a person's mood. Examples of mood disorders include, but are not limited to, depression and bipolar disorder.

[0050] The term "amino acid" refers to naturally occurring and non-naturally occurring amino acids, as well as amino acid analogs and amino acid mimetics that possess similar structural, chemical and/or functional characteristics to the naturally occurring amino acids. Naturally encoded amino acids are the 20 common amino acids (alanine, arginine, asparagine, aspartic acid, cysteine, glutamine, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tryptophan, tyrosine, and valine) and pyrrolysine and selenocysteine. Reference to an amino acid includes, for example, naturally occurring proteogenic L-amino acids as well as D-amino acids. Standard single letter or three letter notations have been used as follows:

A – Ala – alanine
C – Cys – cysteine
D – Asp – aspartic acid
E – Glu – glutamic acid
F – Phe – phenylalanine
G – Gly – glycine
H – His – histidine
I – Ile – Isoleucine

K – Lys – lysine

L – Leu – leucine

M – Met – methionine

N – Asn – asparagine

O – Pyl – pyrrolysine

P – Pro – proline

Q – Gln – glutamine

R – Arg – arginine

S – Ser – serine

T – Thr – threonine

U – Sec – selenocysteine

V – Val – valine

W – Trp – tryptophan

Y – Tyr – tyrosine.

[0051] The expression "amino acid analogs" as used herein, including in reference to non-naturally occurring amino acids and to modified naturally occurring amino acids, refers to compounds that have the same basic chemical structure as a naturally occurring amino acid, i.e., a carbon that is bound to a hydrogen, a carboxyl group, an amino group, and an R group, and includes, for example, homoserine, norleucine, methionine sulfoxide and methionine methyl sulfonium. Such analogs have modified R groups (such as, norleucine) or modified peptide backbones, but retain the same basic chemical structure as a naturally occurring amino acid. Amino acid analogs include chemically modified amino acids such as amino acid variants and derivatives; naturally occurring non-proteogenic amino acids such as β-alanine, ornithine, etc.; and chemically synthesized compounds having properties known in the art to be characteristic of amino acids. Examples of non-naturally occurring amino acids include, but are not limited to, α-methyl amino acids (e.g., α-methyl alanine), D-amino acids, histidine-like amino acids (e.g., 2-amino-histidine, β-hydroxy-histidine, homohistidine, α-fluoromethyl-histidine and α-methyl-histidine), amino acids having an extra methylene in the side chain ("homo" amino acids), and amino acids in which a carboxylic acid functional group in the side chain is replaced with a sulfonic acid group (e.g., cysteic acid). The incorporation of amino acid analogs, such as non-natural amino acids, including synthetic

non-native amino acids or substituted amino acids, may be advantageous in a number of different ways.

[0052] The terms "polypeptide," "peptide" and "protein" refer to a polymer or oligomer of amino acid residues. The terms apply to naturally occurring amino acid polymers as well as amino acid polymers in which one or more amino acid residues are a non-naturally encoded amino acid. As used herein, the terms encompass amino acid chains of any length, including full length proteins, wherein the amino acid residues are linked by covalent peptide bonds. The polypeptides, peptides and proteins are written using standard sequence notation, with the nitrogen terminus being on the left and the carboxy terminus on the right.

[0053] The term "conservative amino acid substitutions" refers to all substitutions wherein the substituted amino acid has similar structural, chemical and/or functional properties with the corresponding amino acid in the reference sequence. By way of example, conservative amino acid substitutions involve substitution of one aliphatic or hydrophobic amino acid, e.g., alanine, valine, leucine, isoleucine, methionine, phenylalanine, or tryptophan with another; substitution of one hydroxyl-containing amino acid, e.g., serine and threonine, with another; substitution of one acidic residue, e.g., glutamic acid or aspartic acid, with another; replacement of one amide-containing residue, e.g., asparagine and glutamine, with another; replacement of one aromatic residue, e.g., phenylalanine and tyrosine, with another; replacement of one basic residue, e.g., lysine, arginine and histidine, with another; and replacement of one small amino acid, e.g., alanine, serine, threonine, and glycine, with another. Conservative substitution tables providing functionally similar amino acids are known to those of ordinary skill in the art. Peptides comprising one or more conservative amino acid substitution are referred to herein as "conservative variants".

[0054] As used herein, the term "small molecule biomimetic" refers to a non-peptide compound that mimics the activity of a peptide, such as a non-peptide compound that mimics the inhibitory activity of the inhibitory peptide of the present application.

Compounds, Compositions and Methods of the Application

[0055] The present application provides an inhibitory compound, such as a peptide or a small molecule, and methods for using the inhibitory compound in the treatment, diagnosis or monitoring of cognitive and mood disorders, which are typically associated with memory loss and/or loss of executive function. In one example, the inhibitory compound is an inhibitory peptide that mimics the N-terminal sequence of the intracellular loop of α5 subunit, where a number of proteins, including scaffold proteins, signaling molecules and kinases, bind and generate a response. Consequently, the inhibitory peptide can also block intracellular signaling transduction.

[0056] Also provided are compositions and methods for treating a disorder associated with memory loss or loss of executive function. The therapeutic method comprises the step of inhibiting binding of radixin to α5GABA$_A$ receptors, for example, by administration of the presently described inhibitory compound or peptide.

[0057] The inhibitory compound and use thereof, as described herein, is efficacious and selective in the treatment of conditions characterized by or associated with memory and/or executive function loss or impairment, since the inhibitory compound preferentially reduces the number of "excess" receptors that occur under pathological conditions. The inhibitory compound (e.g., the inhibitory peptide) differs from currently employed pharmaceutical compounds or NAMs in terms of working mechanism; it inhibits α5GABA$_A$ receptor function through blocking the receptor trafficking and cell surface expression rather than via a non-specific binding or inhibitory effect.

[0058] Inhibitory Agent

[0059] The inhibitory agent, or compound, of the present application attenuates α5GABA$_A$ receptor function by interfering with the excessive trafficking of α5GABA$_A$ receptors to the cell surface that occurs under pathological conditions. More specifically, the present inhibitory agent, which can be an inhibitory peptide, targets and interferes with the signaling pathways that traffic receptors to the surface of neurons or maintain the receptors in the plasma membrane. This approach is effective since cell-surface trafficking is increased during a variety of pathological conditions, such as sepsis or after exposure to anesthetic drugs. The approach of using inhibitory peptides has been

successfully used by others for a variety of other neurological and non-neurological disorders (Aarts et al., 2002; Fan et al., 2014; Leite et al., 2015), however, this approach has not been previously applied to attenuate $\alpha5GABA_A$ receptor function.

[0060] Radixin, a scaffolding protein located primarily at extra-synaptic sites of synapses, recruits and stabilizes $\alpha5GABA_A$ receptors to the plasma membrane of the dendrites and the soma of neurons (Figure 1B). Immunoimaging studies have shown that radixin and $\alpha5GABA_A$ receptors co-localize. Also, studies that use pharmacological and genetic strategies to disrupt the interaction between radixin and $\alpha5GABA_A$ receptors show a reduction in the tonic current that $\alpha5GABA_A$ receptors generate (Loebrich et al, 2006; Hausrat et al., 2015). However, prior to the present studies utilizing the exemplary inhibitory peptide, there had been no demonstration or contemplation of any therapeutic benefit associated with such a disruption.

[0061] A specific binding domain on α5 subunit associates with radixin. As shown in Figure 1A, this domain on the α5 subunit is a 16 amino-acid sequence located at positions 342 to 357 of the second intracellular loop (Loebrich et al, 2006). The radixin-binding domain of $\alpha5GABA_A$ receptors is identical in man, mouse, rat, cow, dog, and monkey and shares 93% amino acid identity with the corresponding domain bird and fish (Loebrich et al, 2006). The present inventors have now designed and synthesized a specific inhibitory peptide that mimics the amino acid binding sequence of this α5 subunit (Figure 1, Table 1). An aspect of the present application, therefore, is an agent, such as a peptide, that interferes with this binding of α5 subunit and thereby prevents the binding of $\alpha5GABA_A$ receptors to radixin on cell plasma membrane. Administration of this inhibitory agent to a subject reduces the number of $\alpha5GABA_A$ receptors that are expressed on the cell surface and/or interferes with $\alpha5GABA_A$ receptor cluster formation and, consequently improves memory performance and/or executive function.

[0062] According to a particular aspect of this application, the inhibitory compound or agent is an antibody or antibody fragment that either binds to radixin or to the specific binding domain on the α5 subunit that associates with radixin, thereby disrupts, inhibits or eliminates the binding of radixin to $\alpha5GABA_A$ receptors.

[0063] In another aspect of the present application, the inhibitory compound or agent is an inhibitory peptide that either binds to radixin or to the specific binding domain on the

α5 subunit that associates with radixin, thereby disrupts, inhibits or eliminates the binding of radixin to α5GABA$_A$ receptors. In the examples provided below, an inhibitory peptide that specifically targeted the α5 subunit binding domain on radixin was used to interfere with this interaction and, thereby prevent cell surface expression of α5GABA$_A$ receptors. As would be readily appreciated by a worker skilled in the art, a peptide that binds to the reciprocal motif on the α5 subunit (i.e., the site where radixin binds to α5 subunits) will have a similar inhibitory affect.

[0064] According to a particular aspect of this application, the inhibitory compound or agent is an inhibitory peptide comprising a region that disrupts, inhibits or eliminates the binding of radixin to α5GABA$_A$ receptors. In one embodiment, the inhibitory agent comprises an eight amino acid peptide having the sequence of SEQ ID NO:4 (AWDGKKAL), or a conservative variant thereof. Alternatively, the inhibitory agent comprises a ten amino acid peptide having the sequence of SEQ ID NO:3 (GWAWDGKKAL), or a conservative variant thereof. In another alternative, the inhibitory agent comprises a twelve amino acid peptide having the sequence of SEQ ID NO:2 (KRGWAWDGKKAL). In another alternative, the inhibitory agent comprises a sixteen amino acid peptide having the sequence of SEQ ID NO:1 (NYFTKRGWAWDGKKAL).

[0065] The peptides disclosed herein can include peptides comprising an amino acid sequence having at least 80%, at least 85%, at least 90%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99% of sequence homology with the peptide of SEQ ID NO:4 or a fragment thereof. In accordance with one embodiment, the inhibitory peptide comprises one or more amino acid analogue. In another embodiment, the peptide comprises a peptidomimetic. Examples of different amino analogues and peptidomimetics that can be included in the peptides and methods and compositions of the present application are enumerated above. The amino acid subunits are, in certain embodiments, linked by peptide bonds. In other embodiments, two or more amino acid subunits are linked by another type of bond, e.g. ester, ether, etc. In certain embodiments, peptidomimetics or amino acid analogues are incorporated into the peptide in order to reduce or eliminate proteolytic enzyme or protease susceptibility and improve stability of the peptide *in vivo*. In an alternative embodiment, the peptide is cyclized (between side

chains or the termini of the peptide), again to reduce susceptibility to proteolytic enzymes or proteases and to improve stability. The incorporation of peptidomimetics or amino acid analogues, and/or the cyclization of the peptide is performed such that it does not reduce or significantly reduce the inhibitory effect of the peptide.

[0066] The peptides disclosed herein can be produced using conventional methods of peptide synthesis. Alternatively, the peptides can be produced using conventional methods of recombinant technology using nucleic acids that can express the inhibitory peptides from appropriate vectors and host cells, as are well known to workers skilled in the art.

[0067] Optionally the inhibitory peptide is beneficially modified by methods known to enhance passage of the molecule across cellular membranes and/or across the blood-brain barrier. For example, in one embodiment the peptide additionally comprises a polypeptide portion that facilitates transport of the peptide across cellular membranes. For example, the inhibitory peptide can comprise a cell-penetrating peptide (CPP), protein transduction domain (PTD), spontaneous membrane translocating peptide (SMTP) or the like. Examples of such peptide sequences are well known to those of skill in the art (see, for example, Bechara et al, 2013 and Macchi et al, 2015) and selection of the appropriate sequence can be made readily based on various factors, such as, for example, target tissue or cell type, type of subject, delivery composition and overall length of the inhibitory peptide.

[0068] Examples of sequences and transporters that are useful in facilitating transport of the peptide across cellular membranes are Antennapedia sequences, TAT, HIV-Tat, Penetratin, Antp-3A (Antp mutant), Buforin II, Transportan, MAP (model amphipathic peptide), K-FGF, Ku70, Prion, pVEC, Pep-1, SynB1, Pep-7, HN-1, BGSC (Bis-Guanidinium-Spermidine-Cholesterol, and BGTC (Bis-Guanidinium-Tren-Cholesterol). These can be included as part of the inhibitory peptide, or can be formulated for administration together with the inhibitory peptide.

[0069] In some embodiments, the inhibitory peptide can be used for diagnostic purposes. For example, the peptide can be used as a binding peptide in assays to identify over or under expression of $\alpha 5GABA_A$ receptors, and/or to identify the over or under expression of radixin, and/or to explore association of radixin with $\alpha 5GABA_A$ receptors. In some

examples of such diagnostic uses, the inhibitory peptide will additionally comprise a label or signal molecule useful for visualization of the peptide using imaging technologies. Selection of the appropriate label or signal molecule will depend on the imaging method and technology employed in the diagnostic method. The label can be, for example, a peptide sequence for binding by an antibody in an immunoassay, or a coloured molecule in the case of a colourimetric assay.

[0070] The present application further provides a diagnostic kit comprising a peptide comprising an amino acid sequence of SEQ ID NO:4, SEQ ID NO:3, SEQ ID NO:2, SEQ ID NO:1, a conservative variant of SEQ ID NO:4, SEQ ID NO:3, SEQ ID NO:2, or SEQ ID NO:1, or a peptide including an amino acid sequence having a sequence homology of 80% or greater to the amino acid sequence of SEQ ID NO:4; and instructions for use in a diagnostic assay or method.

[0071] In an alternative embodiment, the inhibitory peptide is used and/or adapted for use as an antigen for the production of antibodies, or antibody fragments, specific for the α5 subunit of $\alpha5GABA_A$ receptors. As would be appreciated by a worker skilled in the art, such antibodies have particular utility as inhibitory agents, since they will function similarly to the present inhibitory peptide by masking or targeting the intracellular loop of the α5 subunit. Such antibodies will also have utility in binding methods or assays used to detect or quantify or visualize $\alpha5GABA_A$ receptors.

[0072] According to a particular aspect of this application, the inhibitory compound or agent is a small molecule biomimetic of the inhibitory peptide of the present application (as described above). In particular, the present application further provides a small molecule biomimetic that binds to radixin or to the specific binding domain on the α5 subunit that associates with radixin, thereby disrupting, inhibiting, or eliminating the binding of radixin to the $\alpha5GABA_A$ receptors.

[0073] Therapeutic Methods and Compositions

[0074] In accordance with another aspect, there is provided a method of treating a cognitive or mood disorder characterized by or associated with memory and/or executive function loss. The method comprises the step of administering to a subject an inhibitory agent to reduce $\alpha5GABA_A$ receptor expression by inhibiting association of radixin with the $\alpha5GABA_A$ receptor. In a particular example of this method, the inhibitor agent is an

inhibitory peptide, such as a peptide comprising the sequence of SEQ ID NO:4, SEQ ID NO:3, SEQ ID NO:2 or SEQ ID NO:1.

[0075] Examples of cognitive or mood disorders treatable using the present method and compositions include, but are not limited to, cognitive deficits after surgery and/or anesthesia (Zurek et al, 2014; Zurek et al, 2012 and Saab et al, 2010), stroke (Clarkson et al, 2010), Alzheimer's Disease (Jo et al, 2014 and Wu et al, 2014), stress (Fischell et al, 2015), sepsis-associated encephalopathy (Serantes et al, 2006), Down syndrome (Mohler, 2012; Braudeau et al, 2011; Martinez-Cue et al, 2014; and Potier et al, 2014), schizophrenia (Asai et al, 2008; Craddock et al, 2005; Papadimitriou et al, 2001; Papadimitriou et al, 1998; and Gill et al, 2011), anxiety (Botta et al, 2015) and autism (Fatemi et al, 2010 and Mendez et al, 2013).

[0076] Also provided herein is the use of the present inhibitory agent in a method for preventing inflammation-induced dysfunctions or for modulation of the benzodiazepine-recognition domain of the $\alpha5GABA_A$ receptor, for preventing $\alpha5GABA_A$ receptor-related deficits after anesthesia and surgery or surgery or brain trauma, or acquired neurodegenerative disorders such as Alzheimer's disease. In another embodiment, there is provided the use of the present inhibitory agent in a method for treating side effects, such as memory deficits, associated with the use of certain GABAergic drugs, such as those that cause an allosteric up-regulation of the GABA receptor.

[0077] In the studies summarized in the following examples, the efficacy of the exemplary inhibitory peptide was demonstrated with behavioral deficits and biochemical and electrophysiological changes related to increased $\alpha5GABA_A$ receptor function induced by a general anesthetic, etomidate. The injectable anesthetic etomidate (which increases the tonic current and thereby causes cognitive deficits) was selected for these studies. However, it is known that etomidate is only one of many drugs that increase $GABA_A$ receptor function. For example, the inhaled anesthetics sevoflurane and isoflurane, as well as the injectable anesthetic propofol and benzodiazepine midazolam similarly cause the sustained increase in tonic current. It is further known that inflammation also causes an increase in tonic current. The results provided in the Examples provide evidence that other anesthetic drugs such as desflurane and future anesthetics and benzodiazepines that increase $GABA_A$ receptor function will also cause

cognitive deficits that can be treated with the inhibitory agent of the present application (e.g., an inhibitory peptide). Thus, the cognitive and mood deficits that are caused by these anesthetics, benzodiazepines and other drugs that increase $GABA_A$ receptor function can be prevented and treated with the inhibitory peptide. In summary, data provided in the Examples below provide the first evidence that these drugs that allosterically increase $GABA_A$ receptor activity, trigger a sustained increase in tonic current in neurons (as occurs with etomidate). Thus, cognitive and mood deficits cause by these drugs can be prevented and treated by the peptide.

[0078] The inhibitory agent of the present application can be administered in any manner that is medically acceptable. This can include injections, by parenteral routes such as intravenous, intravascular, intraarterial, subcutaneous, intramuscular, intratumor, intraperitoneal, intraventricular, intraepidural, intracranial, intranasal or others as well as nasal, or topical. Slow release administration is also specifically included in the invention, by such means as depot injections or erodible implants.

[0079] In one embodiment, the administration is parenteral injection, preferably intravenous, subcutaneous, intramuscular, intracranial or intraperitoneal. It is possible for the inhibitory agents of the present application to be administered as the raw chemical (e.g., the peptide alone), it is generally preferred for them to be administered in the form of a pharmaceutical formulation. The pharmaceutical formulations can be prepared by conventional techniques, such as as described in Allen LV, Jr. Remington: The Science and Practice of Pharmacy. 22nd ed. London, UK: Pharmaceutical Press; 2012.

[0080] The term "pharmaceutically acceptable carrier" means one or more organic or inorganic ingredients, natural or synthetic, with which the inhibitory agent (e.g., inhibitory peptide) is combined to facilitate its application. A suitable carrier includes sterile saline although other aqueous and non-aqueous isotonic sterile solutions and sterile suspensions that are pharmaceutically acceptable are known to those of ordinary skill in the art.

[0081] The inhibitory agents of the present application can be formulated for parenteral administration and can be presented in unit dose form in ampoules, pre-filled syringes, small volume infusion or in multi-dose containers, optionally with an added preservative. The compositions can take such forms as suspensions, solutions, or emulsions in oily or

aqueous vehicles, for example solutions in aqueous polyethylene glycol. Examples of oily or non-aqueous carriers, diluents, solvents or vehicles include propylene glycol, polyethylene glycol, vegetable oils (e.g., olive oil), and injectable organic esters (e.g., ethyl oleate), and can contain agents such as preserving, wetting, emulsifying or suspending, stabilizing and/or dispersing agents. Alternatively, the active ingredient can be in powder form, obtained by aseptic isolation of sterile solid or by lyophilisation from solution for constitution before use with a suitable vehicle, e.g., sterile, pyrogen-free water.

[0082] An "effective amount" refers to that amount that is capable of ameliorating or delaying progression of the cognitive or mood disorder. An effective amount can be determined on an individual basis and will be based, in part, on consideration of the symptoms to be treated and results sought. An effective amount can be determined by one of ordinary skill in the art employing such factors and using no more than routine experimentation.

[0083] In one aspect of the present application, there is provided a composition comprising an inhibitory agent as described above, which is optionally an inhibitory peptide comprising the sequence of SEQ ID NO:4, SEQ ID NO:3, SEQ ID NO:2, SEQ ID NO:1, any conservative variant thereof, or a sequence having at least 80% homology with SEQ ID NO:1. The composition can comprise a synthetic or isolated peptide as described herein, an isolated nucleic acid for expression of the inhibitory peptide as described herein, an expression vector encoding an inhibitory peptide as described herein, or a cell line expressing inhibitory peptides as described herein.

[0084] In one embodiment, there is provided a kit comprising a peptide comprising an amino acid sequence of SEQ ID NO:4, SEQ ID NO:3, SEQ ID NO:2, SEQ ID NO:1, a conservative variant of SEQ ID NO:4, SEQ ID NO:3, SEQ ID NO:2, or SEQ ID NO:1, or a peptide including an amino acid sequence having a sequence homology of 80% or greater to the amino acid sequence of SEQ ID NO:4; and instructions for at least one of administration dose, administration route, administration frequency, and indication of the peptide or composition.

[0085] In one embodiment the pharmaceutical composition or kit comprises the inhibitory agent (e.g., inhibitory peptide) as a pharmaceutical ingredient in combination

with another composition for the treatment of cognitive or mood disorders, or for the prophylactic treatment of a subject facing the risk of developing a cognitive or mood disorder.

[0086] In one embodiment the inhibitory agent (e.g., inhibitory peptide) or composition is for the treatment of cognitive or mood disorders, or for the prophylactic treatment of a mammal facing the risk of developing a cognitive or mood disorder, and is combined with another pharmaceutical agent or composition for the treatment or prophylaxis of cognitive or mood disorders.

[0087] In particular, in one embodiment, the pharmaceutical composition further comprises a second active ingredient for treatment of cognitive or mood disorders, or for the prophylactic treatment of a subject facing the risk of developing a cognitive or mood disorder. In a related embodiment, the pharmaceutical composition further comprises a second active ingredient for improving memory function, for treating inflammation-induced dysfunctions or for modulation of the benzodiazepine-recognition domain of the $\alpha5GABA_A$ receptor, for preventing $\alpha5GABA_A$ receptor-related deficits after anesthesia and surgery or surgery or brain trauma, or acquired neurodegenerative disorders such as Alzheimer's disease.

[0088] Examples of ingredients that can be used as a second active ingredient to be administered before, during or after administration of the present inhibitory agent include, but are not limited to MRK-016, L-655,708, α5IA; RO4938581, RG-1662, PWZ-029, TB-21007 and pyridazine and others (Milic et al. (2013), Savic et al (2008)).

[0089] As would be appreciated by those of skill in the art, the additional two or more active ingredients can be administered to a subject in combination with the presently provided inhibitory agent (e.g., inhibitory peptide) in the same composition or in a separate composition(s). When administered in a separate composition(s), the administration can be simultaneous with administration of the presently provided inhibitory agent (e.g., inhibitory peptide) or they can be administered at different times.

[0090] To gain a better understanding of the invention described herein, the following examples are set forth. It should be understood that these examples are for illustrative purposes only. Therefore, they should not limit the scope of this invention in any way.

EXAMPLES

[0091] Experimental Animals

[0092] All experimental procedures were approved by the Animal Care Committee of the University of Toronto (Toronto, Ontario, Canada). Adult mice (C57BL/6, 2-4 month old, male) and pregnant Swiss White mice were purchased from Charles River (Wilmington, MA, USA). Some adult mice (C57BL/6J x SvEv129, 2-4 month old, male) were also used and housed in the animal care facility of the University of Toronto. For *in vivo* experiments, the mice were treated with sedating doses of etomidate (8 mg/kg, i.p., single injection). Propylene glycol 35% (v/v) was used as the vehicle control as it is the solvent system for etomidate. To prevent potential hypoxia during the treatment, each mouse was placed in an air-tight acrylic chamber (27 cm x 10 cm x 10 cm) that was flushed with supplemental oxygen and medical air (70 % air, 30 % O_2) delivered at a flow of 1 L/min. The concentration of O_2 and CO_2 in the chamber were continuously monitored with a commercial gas analyzer (Datex Ohmeda, *Mississa*uga, Ontari, Canada). To prevent hypothermia, the temperature of the chamber was maintained at 35 C° with a heating blanket.

[0093] Synthesis of the Inhibitory Peptides

[0094] The inhibitory peptides were synthesized by BioMatik (Cambridge, ON, Canada). The sequences are confirmed by Mass Spectral analysis, and the purity of these peptides is over 95% as examined by HPLC.

[0095] Use of Etomidate

[0096] The prototypic injectable general anesthetic etomidate was studied in these examples. This drug is widely used in clinical practice, and is the most selective positive allosteric modulator of $GABA_A$Rs among the various intravenous and inhaled anesthetics (Forman 2011, Belelli et al. 1997). Also, etomidate causes minimal adverse hemodynamic effects (Forman (2011)). Thus, hemodynamic factors do not confound the interpretations of behavioral studies. Etomidate also offers the ease of injectable administration. For *in vitro* studies, a clinically-relevant concentration of etomidate (1 μM) was applied to the cell cultures. For *in vivo* studies, etomidate (8 mg/kg) was

injected intraperitoneally (i.p.) at a sedative dose in a warmed and oxygenated environment.

[0097] The *in vitro* studies provided in the following Examples, also used etomidate to treat the astrocytes and neurons for *in vitro* studies. To extend these key findings to another major class of anesthetic, evidence that other anesthetics and a benzodiazepine increased in the tonic current in hippocampal neurons was obtained. Etomidate does not cause hemodynamic instability and is rapidly metabolized and eliminated. In addition, etomidate triggers the memory deficits by activating similar pathways to those activated by inflammatory processes. Thus, etomidate-induced memory loss is a model of cognitive deficits associated with inflammation resulting from disease or surgery. Other general anesthetics, including, for example, sevoflurane, isoflurane, propofol and sedative benzodiazepines, have now been found to increase the memory blocking tonic conductance *in vitro* (see Figure 16). Thus, these additional anesthetics also cause memory deficits that can be prevented and treated with the inhibitory agent (e.g., inhibitory peptide) of the present application.

[0098] EXAMPLE 1: Immunoprecipitation and Western Blotting Studies to Demonstrate Disruption of α5 Subunit-Radixin Interaction

[0099] In this example, it was demonstrated, using co-immunoprecipitation (Co-IP) and Western blot (WB) analysis, that the inhibitory peptide prevented coupling between $\alpha5GABA_A$ receptors and radixin.

[00100] The experiments used tissue lysate prepared from the hippocampus of adult mice (C57BL/6J x SvEv, 2-4 month old, male). Hippocampal tissue was homogenized in ice-cold RIPA buffer (20 mM Tris-HCL, pH 7.5, 150 mM NaCl, 1 mM Na2EDTA, 1 mM EGTA, 1% NP-40, 1% sodium deoxycholate, 2.5 mM sodium pyrophosphate, 1 mM β – glycerophosphate) supplemented with 1 mM sodium orthovanadate and 1% protease inhibitor cocktail and 1% phosphatase inhibitor cocktail (Roche Diagnostics, GmbH, Manheim Germany). The tissue lysate was subsequently spun at 14,000 rpm for 30 min with the Microfuge 22R Centrifuge (Beckman CoulterTM, Brea, California, US). The supernatant was collected and frozen at -20 C°. The next day, the supernatant, after thawing, was re- centrifuged at 14,000 rpm for another 30 min to clear the potential

undissolved or pellet substances. After spinning twice, the supernatant was collected for subsequent experiments.

[00101] For the immunoprecipitation experiment, the tissue lysate containing 500 mg protein (in 250 µl) was incubated with 20 µM (20 µl) of either the inhibitory peptide (SEQ ID NO:1) or scramble peptide (SEQ ID NO:5) without TAT sequence. One hour following the incubation, the antibodies (2 – 4 µg) against either α5 subunit (cat# sc-31417, Santa Cruz Biotechnology, Inc., 10410 Finnell St. Dallas, TX, 75220, USA) or radixin (cat# ab91312, Abcam Inc., c/o 913860, PO Box 4090 Stn A, Toronto, ON M5W 0E9), or 4 µg of non-specific IgG protein (cat# sc-2028, Santa Cruz Biotechnology, Inc., 10410 Finnell St. Dallas, TX, 75220, USA), were added to the lysate solution. After gently shaking overnight at 4°C, the immune complexes were precipitated with protein A/G plus-agarose beads (Santa Cruz Biotechnology, Inc., 10410 Finnell St. Dallas, TX, 75220, USA). Forty microliters of the A/G plus agarose beads were added to the immune complex solution and shaking gently for 2 h at 4°C. After spin with the microcentrifuge (Eppendorf Mini-Spin Plus, Marshall Scientific, 424 Route 125, Brentwood, NH 03833, USA), the immunoprecipitates were washed four times with ice-cold PBS, then resuspended in 2× Laemmli sample loading buffer containing 5% β – mercaptomethanol, and boiled for 5 min. These samples were subjected to Western blot experiment.

[00102] For Western blot, 40 µg (5 – 10 µl of tissue lysate) proteins or 10 µl of immunoprecipitates were separated by SDS–PAGE (10 % acrylamide/bisacrylamide) and transferred at 4 C° to the nitrocellulose membrane (BioTraceTM NT, Pall Corporation, 8780 Ely Rd, Pensacola, FL 32514, USA). The blotting analysis was performed by repeated stripping and successive probing with antibodies: anti-α5 (1:1000, cat# 846-GA5C, PhosphoSolutions Inc., 12635 East Montview Blvd., Aurora, CO 80045-7337, USA), anti-radixin (1:1000, cat# sc-6408, Santa Cruz Biotechnology, Inc., 10410 Finnell St. Dallas, TX, 75220, USA) and anti-pThr564-radixin (1:800, cat# 3141, Cell Signaling Technology, New England Biolabs Ltd., 9 Carlow Court, Unit 3, Whitby, ON L1N 9T7, Canada). Other antibodies, including anti-gephyrin (cat# sc – 25311), anti - GABAA receptor α1 (cat# sc- 7348) and α2 (cat# sc – 133602) subunits (Santa Cruz Biotechnology, Inc., 10410 Finnell St. Dallas, TX, 75220, USA) and anti β – actin (cat#

A00730, GenScript, 860 Centennial Ave., Piscataway, NJ 08854, USA) were used. These results were analyzed with Molecular Imager (ChemiDocTMXRS+, BioRad Inc.).

[00103] The data showed that the inhibitory peptide reduced the association between α5 subunit and radixin whereas the scramble peptide did not reduce this association (Figure 2). These results show that the inhibitory peptide specifically disrupted the interaction of radixin with α5 subunit *in vitro* whereas the scramble peptide had no significant effect.

[00104] EXAMPLE 2: Immunoprecipitation and Western Blotting Studies to Demonstrate Selectivity of Inhibitory Peptide

[00105] In order to further demonstrate the specificity and selectivity of the inhibitory peptide, the immunoprecipitates from Example 1 were probed by WB using anti-gephyrin, anti-$GABA_A$ receptor α1 and α2 subunits (Santa Cruz Biotechnology) and anti β-actin (GenScript, Piscataway, NJ, USA) antibodies.

[00106] In the hippocampus, CA1 region in particular, α1 and α2 subunit containing $GABA_A$ receptors are highly expressed and are largely located at synaptic sites where they bind and interact with the scaffolding protein, gephyrin (Tyagarajan, et al., 2014). This interaction with gephyrin regulates the synaptic plasticity. The α5 subunit, via the intracellular loop might also associate with gephyrin (Brady et al., 2015; Hausrat et al., 2015). Therefore, the ability of the inhibitory peptide to alter the interaction between gephyrin and $GABA_A$ receptor containing α1, α2 and α5 subunits was studied with Co-IP and WB assays. The immunoprecipitates from Example 1 were probed by WB using anti-gephyrin, anti-$GABA_A$ receptor α1, α2 and α5 subunit (Santa Cruz Biotechnology) antibodiesThe results showed that the inhibitory peptide did not interfere with gephyrin and α5 subunit interaction (Figure 3), and did not have any effects on α1 and α2 subunit containing $GABA_A$ receptors in the hippocampal tissue (Figure 4).

[00107] The results showed that the inhibitory peptide selectively and specifically targets the interaction between α5$GABA_A$ receptors and radixin.

[00108] EXAMPLE 3: Modification of Inhibitory Peptide for Cell Transport

[00109] The inhibitory peptide was modified to incorporate a peptide to facilitate penetration of the cell membrane. Both the inhibitory peptide and the scramble peptide

were fused to an 11 – mer HIV-1 Tat sequence of protein transduction domain (Table 1), as described previously (Aarts et al., 2002; Fan et al., 2014).

[00110] Synthesis of the peptides was performed as described above.

Table 1: Peptide Sequences

Peptide	**Sequence***
α5 Inhibitory Peptide	NYFTKRGWAWDGKKAL (SEQ ID NO:1)
α5 Scramble Peptide	TYFGRKNALWKAWKGD (SEQ ID NO:5)
TAT – α5 Inhibitory Peptide	*YGRKKRRQRRR*NYFTKRGWAWDGKKAL (SEQ ID NO:6)
TAT – α5 Scramble Peptide	*YGRKKRRQRRR*TYFGRKNALWKAWKGD (SEQ ID NO:7)

* The amino acids shown in italics are the TAT sequence

[00111] EXAMPLE 4: Toxicity Study

[00112] The toxicity of the fused TAT- inhibitory peptides synthesized in Example 3 was studied by treating primary hippocampal neurons that were grown in dissociated cell culture with a serial concentration of the TAT-inhibitory peptide.

[00113] Primary Cell Cultures

[00114] Primary cultures of hippocampal neurons were prepared from Swiss White mice (Charles River, Montreal, Canada). Briefly, fetal pups (embryonic day 18) were removed from maternal mice that had been sacrificed by cervical dislocation. The hippocampi of each fetus were collected and placed on an ice-cooled culture dish. Neurons were then dissociated by mechanical trituration with a Pasteur pipette (tip diameter 150–200 μm) and plated on 35-mm culture dishes. The culture dishes were coated with collagen or poly-D-lysine (Sigma-Aldrich, Oakville, Canada). The density of neurons per culture dish was approximately 1×10^6 cells. Two hours later, the medium was changed to a neurobasal medium supplemented with 2% B27 and 1% GlutaMAX (Life Technologies, Waltham, USA). The medium was changed every 3 days.

[00115] MTT Assay

[00116] After 24 hrs incubation with the fused peptides, cell survival was examined using the MTT assay, which measures the mitochondrial metabolism of 3-(4, 5-dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide (MTT) in the neurons.

[00117] Mitochondrial metabolism of 3-(4, 5-dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide (MTT) was used as an index of mitochondrial viability or cell viability. MTT solution was added to each well containing cultured hippocampal neurons at a final concentration of 5 µg/ml. The cells were incubated with MTT solution for 2 h at 37°C. Following the incubation, the medium containing MTT was removed, and 500 µl of DMSO was added to dissolve the intracellular purple formazan metabolite. The intensity of color was assessed using a microplate reader (Synergy-MX, BioTek Instrument Inc., Winooski, VT, USA) at a wavelength of 590 nm.

[00118] The results of the MTT assay are shown in Figure 5. Based on these *in vitro* studies, the peptides fused with TAT sequence are safe under the concentration of 3 µM for cultured hippocampal neurons. Furthermore, the toxicity levels observed from the inhibitory peptide and from the scramble peptides were similar, suggesting that the lack of toxicity that was observed was not sequence specific.

[00119] EXAMPLE 5: Receptor Cell Surface ELISA Assay in Cell Culture Model

[00120] A culture model was developed which replicated the pathological increase in the number of $\alpha5GABA_A$ receptors expressed on the surface of neurons as observed in various mood and cognitive disorders typically characterized or associated with memory and/or executive function loss.

[00121] This model was described in a recently published report that showed the general anesthetic, etomidate significantly augmented $\alpha5GABA_A$ receptor cell-surface expression as evidenced by an increase in $\alpha5GABA_A$ receptor – generated tonic conductance recorded 24 hrs after the treatment and an increase in protein levels in studies that used surface biotinylation and Western blotting. Noticeably, only neurons co-cultured with astrocytes or incubated with medium collected from astrocytes were able to produce the increase of tonic conductance (Zurek, et al., 2014).

[00122] This experimental cell culture model was used to test the effects of the inhibitory peptide on an overexpression of $\alpha5GABA_A$ receptors on the surface of neurons. The medium from astrocytes that were treated with etomidate (1 µM, 1 hr) (conditioned medium) was collected, and the medium bathing cultured hippocampal neurons was exchanged with the astrocyte-conditioned medium. The cells were incubated at 37°C, 5% CO_2 with the peptide or scramble peptide (2 µM). After 24 hrs incubation,

the cells were used for receptor cell-surface ELISA assay. The cells were fixed in 4% paraformaldehyde for 20 min in the presence (permeabilized) or absence (non-permeabilized) of 1% Triton-X100. The cells, after 3 times wash with cold PBS and blocked with 5% bovine album solution, were incubated with a α5 antibody (Santa Cruz Biotech Inc.,) at 4°C overnight. The next day the cells were thoroughly washed with PBS and incubated with the horseradish peroxidase (HRP) – conjugated secondary antibody for 2 hrs. With HRP substrate added and color developed in the medium, the results were determined with microplate reader.

[00123] The cell surface expression of α5 subunit was presented as the ratio of the colorimetric reading under non-permeabilized conditions to those permeabilized conditions. Consistent with the previous report, etomidate increases $\alpha5GABA_A$ receptor surface expression. This increase was blocked by the specific peptide, but not the scramble peptide (Figure 6A). The results also verified that the peptide is membrane permeable.

[00124] In addition, the effects of the inhibitory peptide on $\alpha5GABA_A$ receptor expression or trafficking under basal conditions were studied. Similarly, neurons were treated with the peptide but without exposure to etomidate. The results showed the inhibitory peptide does not alter baseline of $\alpha5GABA_A$ receptors expression either in total or the cell surface level under the non-pathological condition (Figure 6B). These results showed that the peptide does not interfere with $GABA_A$ receptor normal function, which makes this inhibitor peptide (or other inhibitory agent, such as a peptidomimetic or related small molecule) particularly attractive as therapeutic agents, since it provides a benefit in pathological conditions without disturbing normal function.

[00125] For astrocyte culture, cortical astrocytes were isolated from embryonic day 18 (E18) mouse embryos. Cells were allowed to grow to confluence in MEM and 10% fetal bovine serum (FBS; Life Technologies, Grand Island, New York) for 14 d. Cells were then enzymatically dissociated with trypsin–EDTA (0.05%; Life Technologies, Grand Island, New York), and passaged three times to obtain a nearly pure astrocytic culture. Astrocytes were then plated at a density of 25,000 cells per dish.

[00126] EXAMPLE 6: Inhibitory Peptides of Varying Length

[00127] The minimal amino acid sequence required for the inhibitory peptide to reduce $\alpha5GABA_A$ receptor cell-surface expression was determined.

[00128] The peptide was truncated from either the N-terminus or C-terminus; the two truncated peptides were named α5pΔN4 and α5pΔC4, respectively (Table 2).

Table 2: Truncated Peptide Sequences

Peptide	**Sequence***
α5 Inhibitory Peptide	^{342}NYFTKRGWAWDGKKAL^{357} (SEQ ID NO:1)
α5pΔN4	^{346}KRGWAWDGKKAL^{357} (SEQ ID NO:2)
α5pΔC4	^{342}NYFTKRGWAWDG^{353} (SEQ ID NO:8)

* The superscript numbers indicate the position of the peptide sequence within the amino acid sequence of the native α5 subunit.

[00129] An ELISA assay was performed in which hippocampal neurons were incubated with conditioned medium that contained α5 peptide and the N- and C-terminal truncated peptides (2 μM, each). After 24 hrs incubation, the cells were collected for α5 subunit cell surface expression analysis with ELISA assay. The neurons treated with the truncated peptides revealed that the α5pΔN4 (C – terminal portion maintained) peptide retains the inhibitory function, but α5pΔC4 (N-terminal portion maintained) lost the inhibitory function (Figure 7). Based on this result, the α5pΔN4 peptide was further truncated from its N-terminus by deleting 2 amino acids cut-down each step (Table 3).

Table 3: N-terminal Truncated Peptides

Peptide	**Sequence***
α5pΔN4	^{346}KRGWAWDGKKAL^{357} (SEQ ID NO:2)
α5p-C10 (c10)	^{348}GWAWDGKKAL^{357} (SEQ ID NO:3)
α5p-C8 (c8)	^{350}AWDGKKAL^{357} (SEQ ID NO:4)
α5p-C6 (c6)	^{352}DGKKAL^{357} (SEQ ID NO:9)
α5p-C4 (c4)	^{354}KKAL^{357} (SEQ ID NO:10)

* The superscript numbers indicate the position of the peptide sequence within the amino acid sequence of the native α5 subunit.

[00130] Cultured neurons were incubated for 24 hrs with the conditional medium that contained each of the truncated peptides (2 μM). The expression of a5 subunit was analyzed with ELISA assay as described above.

[00131] As shown in Figure 8, the 8 amino acid sequence of the inhibitory peptide was necessary or the minimal required for the peptide to block α5GABA$_A$ receptor trafficking and cell surface expression. However, as would be appreciated by those of skill in the art, conservative variants of this peptide will have a similar inhibitory activity. C10 and C8 peptides prevented the etomidate-induced α5GABA$_A$ receptor surface expression, but C6 and C4 peptides did not

[00132] EXAMPLE 7: Whole-cell Voltage-clamp Recordings

[00133] If the peptide reduces α5GABA$_A$ receptors on the cell surface expression, it may be anticipated that it may reduce the GABA$_A$ receptor mediated tonic current in hippocampal neurons. Figures 9A and 9B show the results of testing the effects of inhibitory peptide on the amplitude of the GABA$_A$ receptor-mediated tonic current in neurons grown in astrocyte – neuronal cell co-cultures. Note that the sustained increase in GABA$_A$ receptor mediated - tonic current that is triggered by general anesthetics occurs only when neurons are grown in co-culture with astrocytes, but not when neurons are cultured alone. The hippocampal neurons that were co-cultured with cortical astrocytes were treated with etomidate, vehicle, etomidate plus inhibitory peptide, or etomidate plus the scramble peptide. The tonic current was measured using standard

whole cell recording methods. The results showed that etomidate caused an increase in the amplitude of the tonic current, measured 24h after the drug treatment. Co-treatment with inhibitory peptide, but not the scramble peptide, reversed the increase in tonic current.

[00134] For astrocyte-neuron coculture, astrocyte cell suspension was placed over hippocampal neurons cultured at 7 d in neurobasal media. Astrocytes were monitored visually to ensure survival and confluence for the duration of the experiment. The neurons were maintained in culture for 14–20 days before use. At this point in time, hippocampal neurons become appropriately polarized, develop extensive axonal and dendritic arbors and form numerous, functional synaptic connections with one another, which resemble mature hippocampal neurons *in vivo*. Culture dishes were prepared from at least two different mice for each experiment, and a maximum of two cells were recorded from each dish.

[00135] Whole-cell currents were recorded under voltage-clamp (–60 mV) conditions using an Axopatch 200A amplifier (Molecular Devices, Sunnyvale, CA, USA) controlled with pClamp 9.0 software (Molecular Devices) via a Digidata 1322 interface (Molecular Devices). Patch pipettes with open-tip resistances of 2–3 MΩ were pulled from thin-walled borosilicate glass capillary tubes. Extracellular recording solution contained (in mM): 140 NaCl, 2 $CaCl_2$, 1 $MgCl_2$, 5.4 KCl, 25 N-2-hydroxy-ethylpiperazine-N'-2-ethanesulphonic acid (HEPES), 28 glucose (pH 7.4, 320–330 mOsm). Intracellular solution contained (in mM): 140 CsCl, 10 HEPES, 11 EGTA, 4 MgATP, 2 $MgCl_2$, 1 $CaCl_2$, 2 TEA and 4 MgATP (pH 7.3 with CsOH, 285–295 mOsm). A computer-controlled, multibarrelled perfusion system (SF-77B, Warner Instruments, Hamden, USA) was used to apply the extracellular solution to neurons. 6-Cyano-7-nitroquinoxaline-2,3-dione (CNQX, 10 μM) and (2R)-amino-5-phosphonovaleric acid (APV, 20 μM) were added to the extracellular solution to block ionotropic glutamate receptors. Tetrodotoxin (0.2 μM) was also added to the extracellular solution to block voltage-dependent sodium channels.

[00136] Etomidate (1 μM) or vehicle solution was used to treat the culture dish for 1 h. The media was then removed and replaced with fresh culture media. For some etomidate-treated dishes, the inhibitory peptide or scramble peptide was co-treated with etomidate

for 1 h. The media was then removed and replaced with fresh culture media containing the peptide or the scramble peptide. Recordings were performed 24 h later. To measure the amplitude of the tonic current, exogenous GABA (0.5 μM) was added to the extracellular solution and the change in holding current was measured during application of bicuculline (20 μM). GABA (0.5 μM) is similar to physiological levels of extracellular GABA that occur *in vivo*.

[00137] EXAMPLE 8: Reduction of $\alpha5GABA_A$ Receptor Expression

[00138] We next asked whether injection of inhibitory peptide, when administered to mice *in vivo* by I.P. injection, reduced the level of $\alpha5GABA_A$ receptors expressed in the hippocampus. To test whether the peptide reduces $\alpha5GABA_A$ receptor cell-surface expression *in vivo*, we took advantage of a mouse model that we developed recently (Zurek, et al., 2014), in which up-regulation of $\alpha5GABA_A$ receptor cell surface expression causes memory deficits. Adult mice (22 – 25 g) were treated with etomidate (8 mg/kg, i.p.), and sacrificed 24 hrs later according to a protocol approved by the Animal Care Committee of the University of Toronto. The hippocampi were collected and subject to experiments. We first measured the level of radixin phosphorylation, because radixin phosphorylation is required for the recruitment of $\alpha5GABA_A$ receptors to extrasynaptic sites of the neurons (Loebrich et al., 2006; Hausrat et al., 2015). The antibody against threonine at 564 of radixin, which is specific for radixin phosphorylation involving $\alpha5GABA_A$ receptor extra-synaptic trafficking, was used for these studies (Choii et al., 2015; Hausrat et al., 2015). The results showed that treatment with etomidate increases radixin phosphorylation but does not alter total radixin protein level (Figure 10), suggesting that etomidate increases $\alpha5GABA_A$ receptor cell surface expression via enhancing radixin phosphorylation. We next examined whether the inhibitory peptide prevented $\alpha5GABA_A$ receptor from trafficking to surface membrane *in vivo* by studying *ex vivo* brain slices. We administrated the peptide or scramble peptide (20 mg/kg, i.p.) to adult mice (male) then examined α5 subunit on cell surface expression using the surface biotinylation assay, which specifically labeled proteins expressed on the cell surface. The results showed that the peptide selectively prevented the expression of $\alpha5GABA_A$ receptors on the cell surface expression (Figure 11A), but did not change $\alpha5GABA_A$ total protein production (Figure 11B).

[00139] EXAMPLE 9: Novel object recognition task – use of peptide to prevent memory impairment

[00140] The NOR task is a widely used model for investigation into memory alterations (Antunes and Biala 2012). This test is sensitive enough to detect alteration in animal behavior, and has been employed to evaluate the influence of clinically used drugs in animals' memory and recognition. For example, animals that were exposed to cocaine in prenatal period displayed a preference for the novel object when tested later (Schindler et al. 2010). Another psychostimulant drug, methamphetamine decreased the novelty index significantly in adult rats (Herring et al. 2008), and can produce a profound, persistent, and selective deficit for both short- and long-term retention in the NOR task (Schroder et al 2003). Other drugs, such as lidocaine (Hammond et al 2004), ketamine (Goulart et al.2010), caffeine (Botton et al. 2010), neuroactive steroids (Nanfaro et al. 2010), and hormones (Walf et al.2009 and Aubele et al. 2008) can also alter NOR task which are consistent with the effects of these drugs on learning and memory in humans. In summary, the NOR task is a validated tool to test the pharmacological effects of a drug, to understand the cognitive profile of a clinical disorder with the aim of developing a targeted therapeutic (Antunes and Biala 2012) .

[00141] Furthermore, α5GABA$_A$ receptors are expressed in high levels in the hippocampus where they effectively disrupt some forms of memory performance. For example, it has been previously shown that an increase in receptor function impairs performance in the novel object recognition task ("NOR", Zurek et al., 2014 JCI). Therefore, the NOR task was selected to determine whether the exemplary inhibitory peptide altered cognitive performance in terms of both preventing and treating memory deficit. The NOR task is a well-validated and widely used behavioral assay that is used to study declarative and recognition memory in laboratory animals and humans. For example, drugs such as caffeine, ampakines, nicotine, which were found to improve performance using the NOR test in rodents, are known to also improve cognition in humans (Costa et al. 2008 and Borota et al. 2014, Damgaard et al. 2010, Ingvar et al. 1997, Tian et al. 2015, Heishman et al. 2010). These studies show that the NOR studies in animals may be used to predict the utility of the drug for changing human cognitive

behaviors. Here, we showed the inhibitory peptide both prevented and treated (reversed) memory deficits triggered by a previous exposure to the general anesthetic etomidate.

[00142] The novel object recognition task involves the presentation of two identical objects for visual inspection (in the case of humans and non-human primates) and exploration in the case of rodents. After a delay, one of the original objects is presented together with a new (novel) object. Humans and animals normally spend time more time looking at (or in the case of mice, exploring) the novel object. Indeed, the test relies on the innate preference of humans and animals for novelty. The inspection or interaction time differs only if the familiar object is recognized. Otherwise, the subject spends an equal amount of time inspecting both objects. Time spent observing (or interacting) the novel object and the familiar object is used as a surrogate measure of the memory for the familiar object. Scores are high if the previously presented (familiar) object is recognized and more time was spent with the novel object whereas scores are low if there is no recall and interaction times resulted from random chance encounters with the both objects.

[00143] In the present study mice were handled two times a day, 5 min each before start of behavioral experiments. Object recognition was assessed in a circle opaque chamber with the diameter of 38.5 cm in a regular lit room. Each mouse was habituated to the chamber for 5 min since day 3. During the training phase, the mouse was allowed to explore two identical objects for 5 min. The mouse was then returned to its home cage for a retention period of 1 h. The mouse was reintroduced to the training context and presented with one familiar object and one novel object for 5 min. Movement and interaction with the objects was recorded with a video camera that was mounted above the chamber. The exploratory behavior and mouse activity was analyzed blindly by a person with a good training and the software EthoVision, XT v11.5 provided by the Noldus Information Tech Inc., (Leesburg VA, USA). Exploratory behavior was defined as sniffing, licking, or touching the object while facing the object. Memory was assessed by measuring the novelty preference ratio (i.e., the ratio of time spent exploring the novel object to the time spent exploring both objects). Mice that exhibited a preference ratio greater than the value of chance (0.5) were deemed to have remembered the familiar object. Animals that did not interact for a minimum of 1 s with each object during the test

period were excluded. Total interaction time with both objects was compared between groups to determine whether the treatments affected locomotor activity or exploration during the testing phase.

[00144] Specifically, we studied whether the use of the inhibitory peptide with etomidate prevented etomidate-induced memory deficits (attributed to the increase in cell surface expression of $\alpha5GABA_A$ receptors). As shown in Figure 12, the mice (2 months old, male) were treated (i.p.) with Etom (8 mg/kg), or Etom plus α5 peptide (20 mg/kg). Saline and 35% propylene glycol were used as the vehicle control. NOR was conducted the next day. The results shows that the peptide could prevent the etomidate – induced memory deficits (Figure 13). The etomidate-treated mice showed no preference for the novel object whereas the etomidate-treated mice who also received the peptide showed preference for the novel object. This difference was not due to the effect of the peptide on locomotion or general behavior of the mice, as the peptide did not impair the ability to move (Table 4) and the body state (Table 5) of the mice.

Table 4: Mouse Movement comparison

Treatment	Total Distance (CM)	Velocity (cm/s)		
		Minimum	Maximum	Mean
Veh	1599±236	0.0042±0.002	43.8±7.7	5.3±0.8
+Pep	1402±100	0.0040±0.003	39.5±4.9	4.7±0.3
P value	0.165	0.165	0.925	0.355

Table 5: Mice remained healthy during the studies as evidenced by the Mouse Body State Comparison

Treatment	Body Elongation State (s)			Body Angle State (s)		Rotation
	Stretched	Normal (%)	Contracted (%)	Straight (%)	Bent (%)	Frequency
Veh	0	236±55 (79%)	64±55 (21%)	258±47(96%)	10±5 (4%)	4.8±1.9
+Pep	0	252±66 (84%)	48±66 (16%)	269±45(98%)	6±3 (2%)	5.5±1.7
P (Veh vs +Pep)		P>0.05	P>0.05	P>0.05	P>0.05	P>0.05

[00145] EXAMPLE 10: Novel object recognition task – use of peptide to treat memory impairment

[00146] We next tested whether the peptide was effective at reversing memory deficits as they were established. As described above and in previous studies, treatment with etomidate induces memory deficits. Control mice received no etomidate. We studied whether treating mice that had etomidate-induced memory deficits with the peptide restored memory performance. The experimental protocol is shown in Figure 14. Adult male mice were first treated with etomidate (to induce memory loss). The following day, subgroups of mice were treated with the inhibitory peptide, saline or the scramble peptide 4 hrs before behavioral testing, using the NOR test as described in Example 9. The inhibitory peptide but not the scramble peptide reversed the memory deficits in etomidate-treated mice (Figure 15). The Etom+Sal group showed no preference for the novel object. Similarly the group who received the scramble peptide also showed no preference for the novel object. However, the group who received the peptide showed preference for the novel object.

[00147] Statistical Analyses

[00148] Results are presented as mean ± SEM. Significance was determined using a Student's t-test or ANOVA with *post hoc* tests to determine differences among more than two groups. Differences were considered significant at $P<0.05$.

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[00213] Heishman SJ, et al.: Meta-analysis of the acute effects of nicotine and smoking on human performance. Psychopharmacology (Berl) 2010; 210:453-69.

[00214] All publications, patents and patent applications mentioned in this Specification are indicative of the level of skill of those skilled in the art to which this invention pertains and are herein incorporated by reference to the same extent as if each individual publication, patent, or patent applications was specifically and individually indicated to be incorporated by reference.

[00215] Although the present invention has been described with reference to specific features and embodiments thereof, it is evident that various modifications and combinations can be made thereto without departing from the invention. The specification and drawings are, accordingly, to be regarded simply as an illustration of the invention as defined by the appended claims, and are contemplated to cover any and all modifications, variations, combinations or equivalents that fall within the scope of the present invention.

CLAIMS

1. An inhibitory compound that interrupts binding of radixin to α5GABA$_A$ receptors.

2. The inhibitory compound of claim 1, wherein the inhibitory compound is an antibody, a peptide, a peptidomimetic or a small molecule.

3. The inhibitory compound of claim 1 or 2, wherein the inhibitory compound is an isolated or synthetic peptide that binds to an α5 subunit binding domain on radixin or that binds to a radixin binding domain on an α5GABA$_A$ receptor.

4. The inhibitory compound of claim 3, which is an isolated or synthetic peptide comprising the sequence of SEQ ID NO:4, a conservative variant thereof or a sequence having at least 80% homology with SEQ ID NO:4.

5. The inhibitory compound of claim 4, wherein the peptide is s 8 to 50, or 8 to 40, or 8 to 20 amino acids in length.

6. The inhibitory compound of claim 4 or 5, which comprises the sequence of SEQ ID NO:3, SEQ ID NO:2, SEQ ID NO:1, or a conservative variant thereof.

7. The inhibitory compound of any one of claims 3 – 6, which additionally comprises a cell permeation peptide that facilitates transport of the peptide across cell membranes, such as a cell-penetrating peptide (CPP), protein transduction domain (PTD), spontaneous membrane translocating peptide (SMTP) or the like.

8. The inhibitory compound of any one of claims 1 – 7, for use in the treatment of a cognitive or mood disorder characterized or associated with impairment of memory or executive function or both.

9. A method for treatment or prevention of a cognitive or mood disorder characterized or associated with impairment of memory or executive function or both in a subject, wherein said method comprises administering to the subject an agent that interrupts binding of radixin to α5GABA$_A$ receptors.

10. The method of claim 9, wherein the cognitive or mood disorder is a cognitive and memory deficit caused by anaesthesia, surgery, inflammation or trauma, Alzheimer's

disease, stroke, stress, sepsis-associated encephalopathy, Down syndrome, schizophrenia, anxiety or autisim.

11. The method of claim 9 or 10, wherein the agent is an antibody, a peptide, a peptidomimetic or a small molecule.

12. The method of claim 9 or 10, wherein the agent is a peptide that binds to an α5 subunit binding domain on radixin or that binds to a radixin binding domain on an $\alpha5GABA_A$ receptor.

13. The method of claim 12, wherein the agent is a peptide comprising the sequence of SEQ ID NO:4, a conservative variant thereof or a sequence having at least 80% homology with SEQ ID NO:4.

14. The method of claim 13, wherein the peptide is s 8 to 50, or 8 to 40, or 8 to 20 amino acids in length.

15. The method of claim 13 or 14, wherein the peptide comprises SEQ ID NO:3, SEQ ID NO:2, SEQ ID NO:1, or a conservative variant thereof.

16. The method of any one of claims 12 – 15, wherein the peptide additionally comprises a cell permeation peptide that facilitates transport of the peptide across cell membranes, such as a cell-penetrating peptide (CPP), protein transduction domain (PTD), spontaneous membrane translocating peptide (SMTP) or the like.

17. The method of any one of claims 9 – 16, wherein the agent is administered with a second pharmaceutically active agent.

18. A method for improving memory or executive function or both in a subject, wherein said method comprises administering to the subject an agent that interrupts binding of radixin to $\alpha5GABA_A$ receptors.

19. The method of claim 18, wherein the agent is an antibody, a peptide, a peptidomimetic or a small molecule.

20. The method of claim 19, wherein the agent is a peptide that binds to an α5 subunit binding domain on radixin or that binds to a radixin binding domain on an $\alpha5GABA_A$ receptor.

21. The method of claim 20, wherein the agent is a peptide comprising the sequence of SEQ ID NO:4, a conservative variant thereof or a sequence having at least 80% homology with SEQ ID NO:4 .

22. The method of claim 21, wherein the peptide is s 8 to 50, or 8 to 40, or 8 to 20 amino acids in length.

23. The method of claim 21 or 22, wherein the peptide comprises SEQ ID NO:2, SEQ ID NO:3, SEQ ID NO:4, or a conservative variant thereof.

24. The method of any one of claims 20 – 23, wherein the peptide additionally comprises a cell permeation peptide that facilitates transport of the peptide across cell membranes, such as a cell-penetrating peptide (CPP), protein transduction domain (PTD), spontaneous membrane translocating peptide (SMTP) or the like.

25. The method of any one of claims 18 – 24, wherein the agent is administered with a second pharmaceutically active agent.

26. A pharmaceutical composition for use in (i) treating or preventing a cognitive or mood disorder characterized or associated with impairment of memory or executive function or both; or (ii) improving memory or executive function or both, said composition comprising an inhibitory agent and a pharmaceutically acceptable carrier or excipient, wherein the inhibitory agent interferes with binding of radixin to α5GABA$_A$ receptors.

27. The pharmaceutical composition of claim 26, wherein the inhibitory agent is an

antibody, a peptide, a peptidomimetic or a small molecule.

28. The pharmaceutical composition of claim 27, wherein the inhibitor agent is a peptide that binds to an α5 subunit binding domain on radixin or that binds to a radixin binding domain on an α5GABA$_A$ receptor.

29. The pharmaceutical composition of claim 28, wherein the inhibitory agent is a peptide comprising the sequence of SEQ ID NO: 4, a conservative variant thereof or a sequence having at least 80% homology with SEQ ID NO:4 .

30. The pharmaceutical composition of claim 29, wherein the peptide is 8 to 50, or 8 to 40 or 8 to 20 amino acids in length.

31. The pharmaceutical composition of claim 29 or 30, wherein the peptide comprises SEQ ID NO:3, SEQ ID NO:2, SEQ ID NO:1, or a conservative variant thereof.

32. The pharmaceutical composition of any one of claims 28 – 31, wherein the peptide additionally comprises a cell permeation peptide that facilitates transport of the peptide across cell membranes, such as a cell-penetrating peptide (CPP), protein transduction domain (PTD), spontaneous membrane translocating peptide (SMTP) or the like.

33. The pharmaceutical composition of any one of claims 26 – 32, wherein the composition additionally comprises a second pharmaceutically active agent.

34. The pharmaceutical composition of any one of claims 26 – 33, wherein the composition is formulated for enteral, topical, nasal or parenteral administration or as part of a sustained release implant, patch or the like.

35. A pharmaceutical composition comprising a peptide comprising the sequence of SEQ ID NO: 4, a conservative variant thereof or a sequence having at least 80% homology with SEQ ID NO:4 .

36. The pharmaceutical composition of claim 35, wherein the peptide is 8 to 50, or 8 to 40 or 8 to 20 amino acids in length.

37. The pharmaceutical composition of claim 35 or 36, wherein the peptide comprises SEQ ID NO:3, SEQ ID NO:2, SEQ ID NO:1, or a conservative variant thereof.

38. The pharmaceutical composition of any one of claims 35 – 37, wherein the peptide additionally comprises a cell permeation peptide that facilitates transport of the peptide across cell membranes, such as a cell-penetrating peptide (CPP), protein transduction domain (PTD), spontaneous membrane translocating peptide (SMTP) or the like.

39. The pharmaceutical composition of any one of claims 35 – 38, wherein the composition additionally comprises a second pharmaceutically active agent.

40. The pharmaceutical composition of any one of claims 35 – 39, wherein the composition is formulated for enteral, topical, nasal or parenteral administration or as part of a sustained release implant, patch or the like.

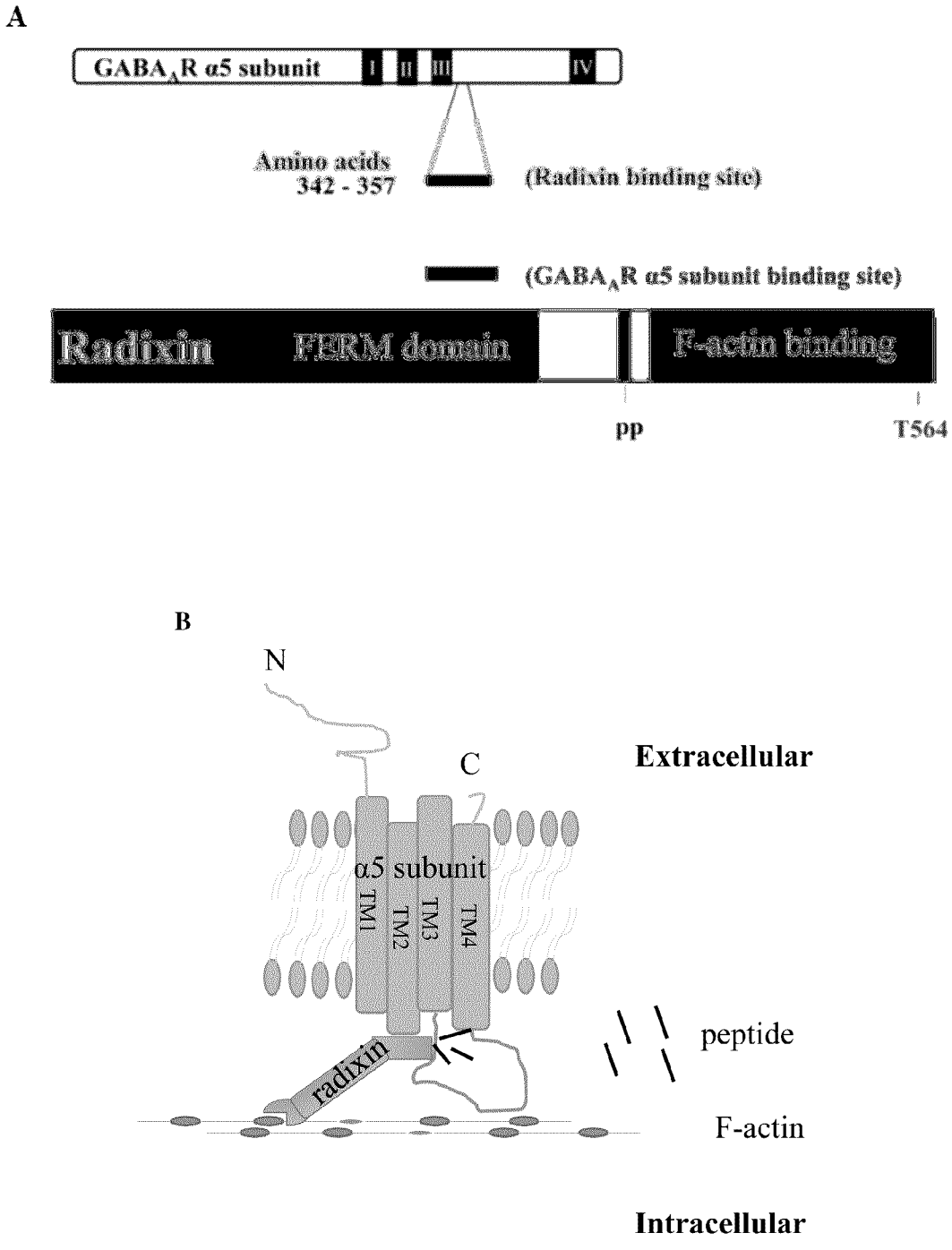
A
GABA$_A$R α5 subunit
I
II
III
IV
Amino acids
342 - 357
(Radixin binding site)
(GABA$_A$R α5 subunit binding site)
Radixin
FERM domain
F-actin binding
pp
T564
B
N
C
Extracellular
α5 subunit
TM1
TM2
TM3
TM4
peptide
radixin
F-actin
Intracellular

FIGURE 1

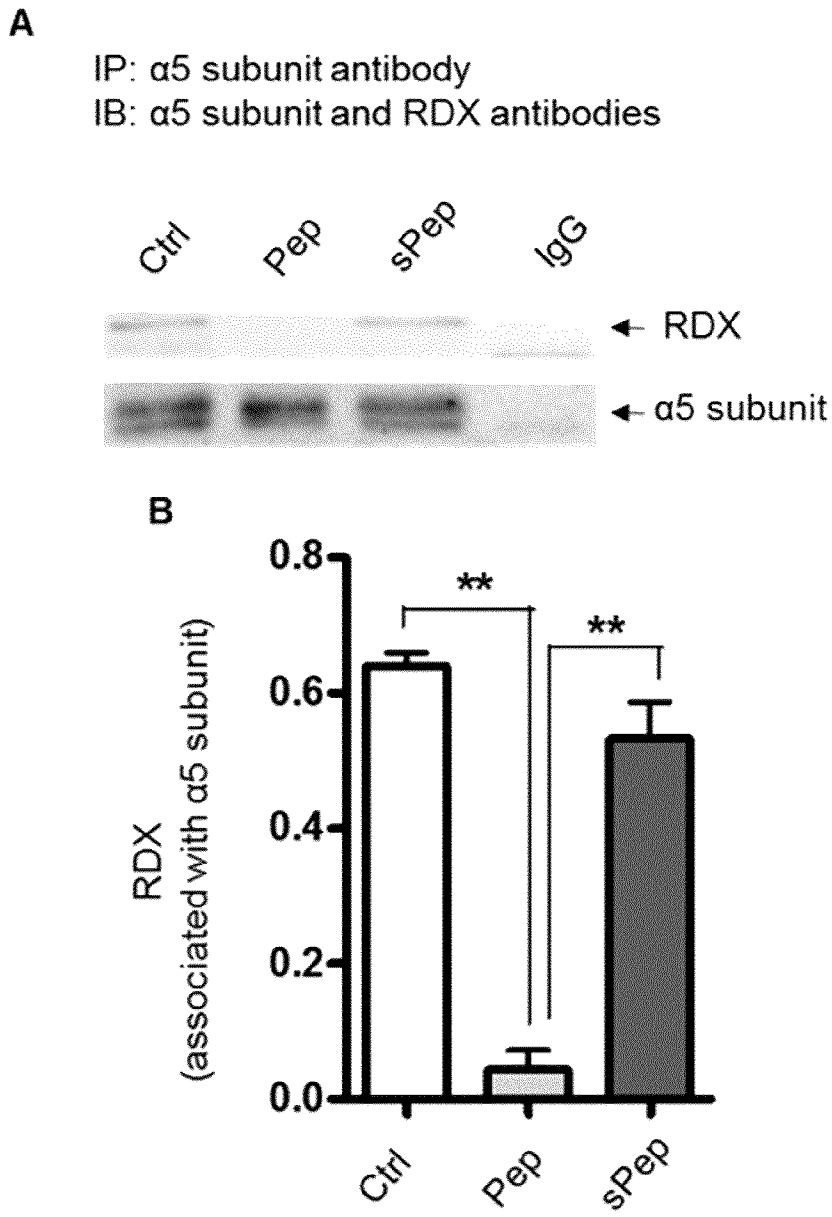
A
IP: α5 subunit antibody
IB: α5 subunit and RDX antibodies
Ctrl
Pep
sPep
IgG
RDX
α5 subunit
B
RDX (associated with α5 subunit)
0.8
0.6
0.4
0.2
0.0
**
**
Ctrl
Pep
sPep

FIGURE 2

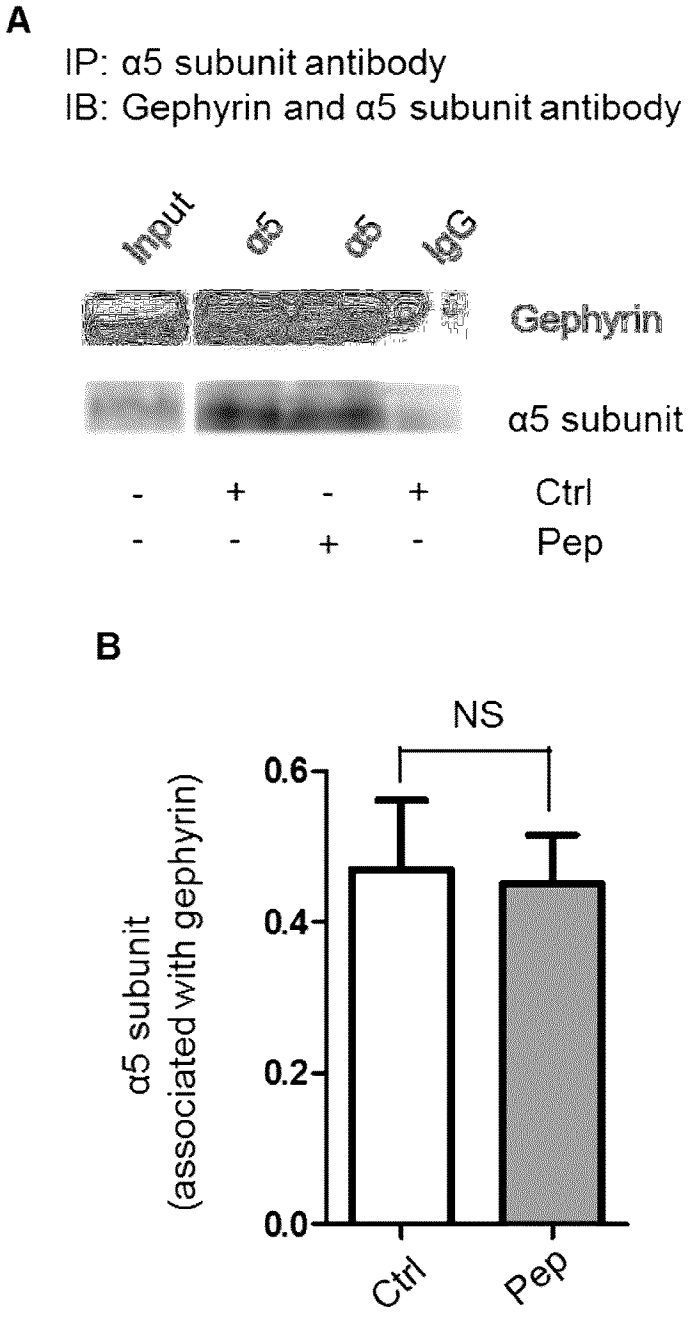
A
IP: α5 subunit antibody
IB: Gephyrin and α5 subunit antibody
Input
α5
α5
IgG
Gephyrin
α5 subunit
- + - +
Ctrl
- - + -
Pep
B
NS
α5 subunit (associated with gephyrin)
0.6
0.4
0.2
0.0
Ctrl
Pep

FIGURE 3

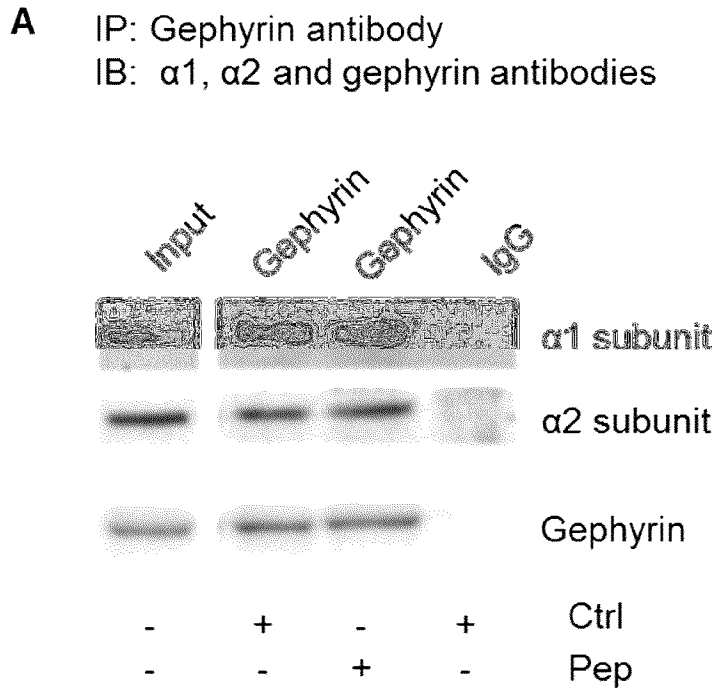
A
IP: Gephyrin antibody
IB: α1, α2 and gephyrin antibodies
Input
Gephyrin
Gephyrin
IgG
α1 subunit
α2 subunit
Gephyrin
- + - + Ctrl
- - + - Pep
B
Associated GABA$_A$ receptor subunits (normalized to gephyrin)
Ctrl
Pep
0.4
0.3
0.2
0.1
0.0
NS
NS
α1 subunit
α2 subunit

FIGURE 4

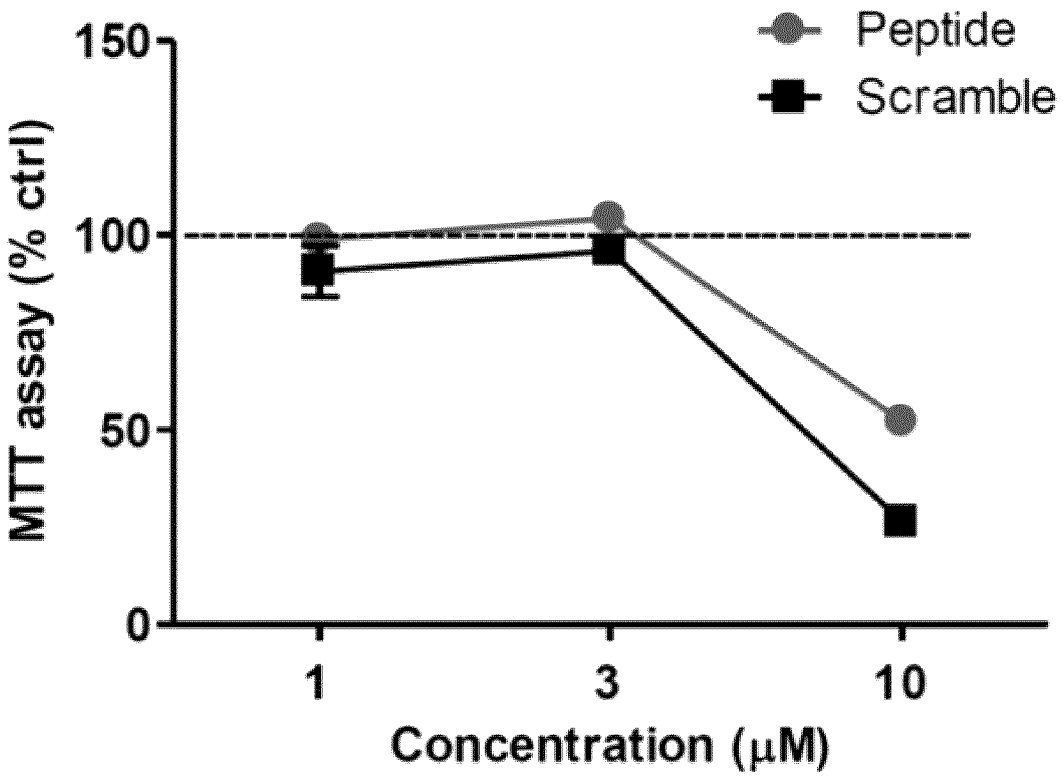
Peptide
Scramble
150
100
50
0
MTT assay (% ctrl)
1
3
10
Concentration (μM)

FIGURE 5

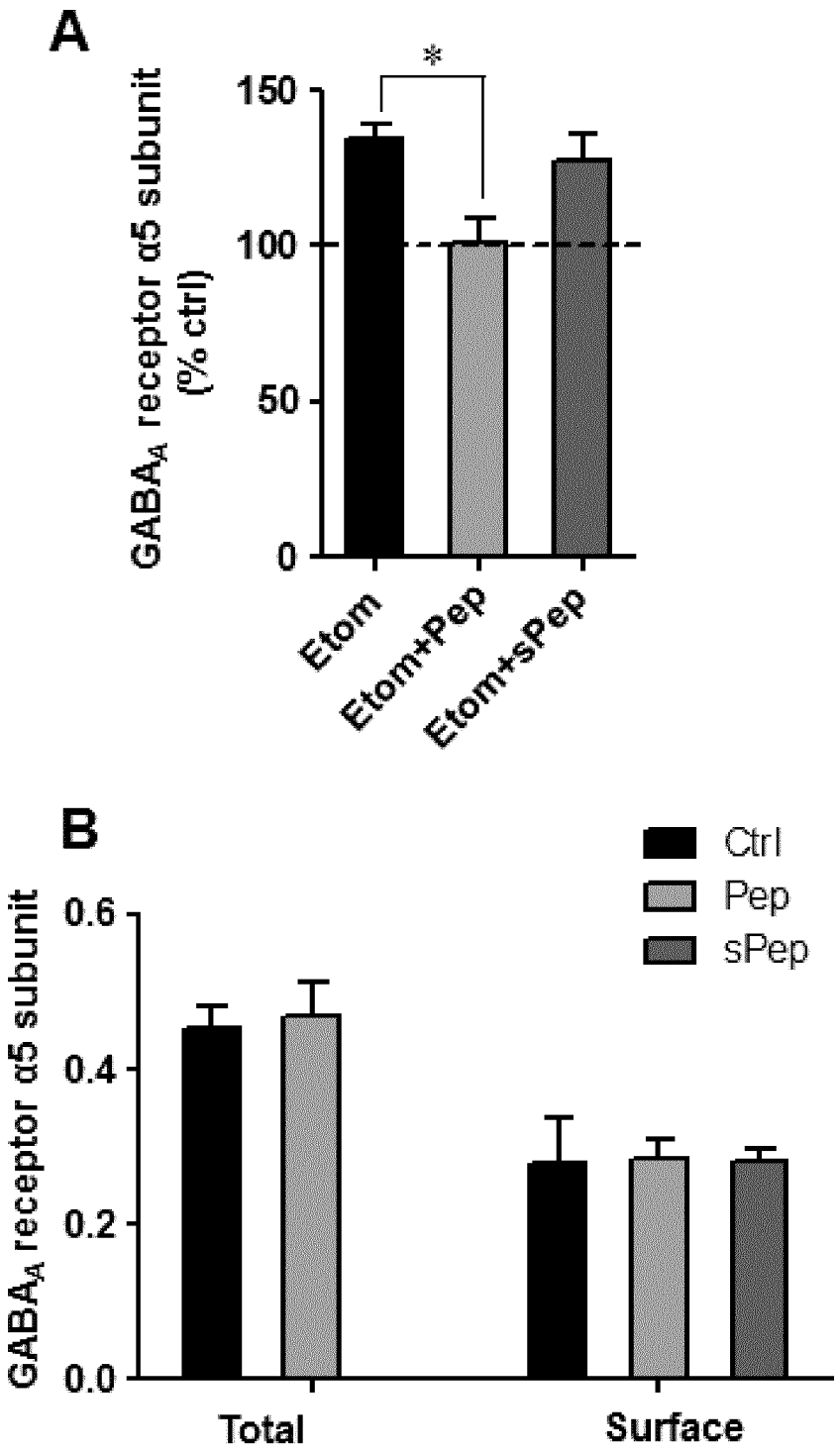
A
*
150
100
50
0
GABA$_A$ receptor α5 subunit (% ctrl)
Etom
Etom+Pep
Etom+sPep
B
Ctrl
Pep
sPep
0.6
0.4
0.2
0.0
GABA$_A$ receptor α5 subunit
Total
Surface

FIGURE 6

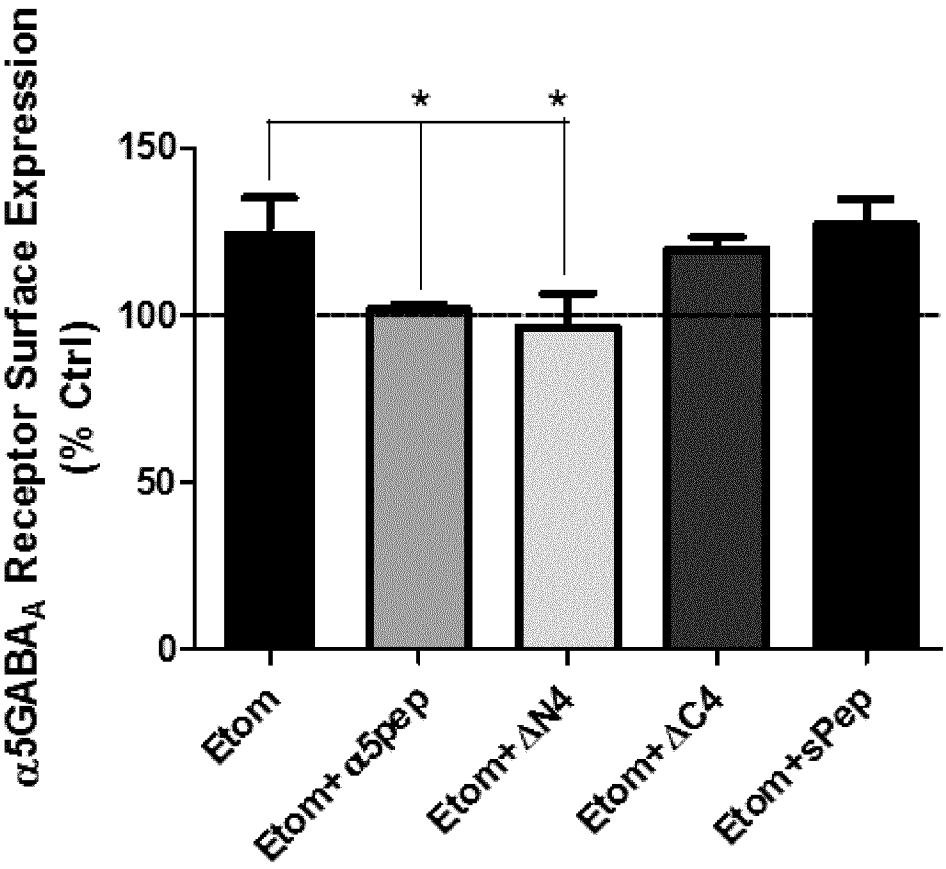
α5GABA$_A$ Receptor Surface Expression
(% Ctrl)
150
100
50
0
*
*
Etom
Etom+α5pep
Etom+ΔN4
Etom+ΔC4
Etom+sPep

FIGURE 7

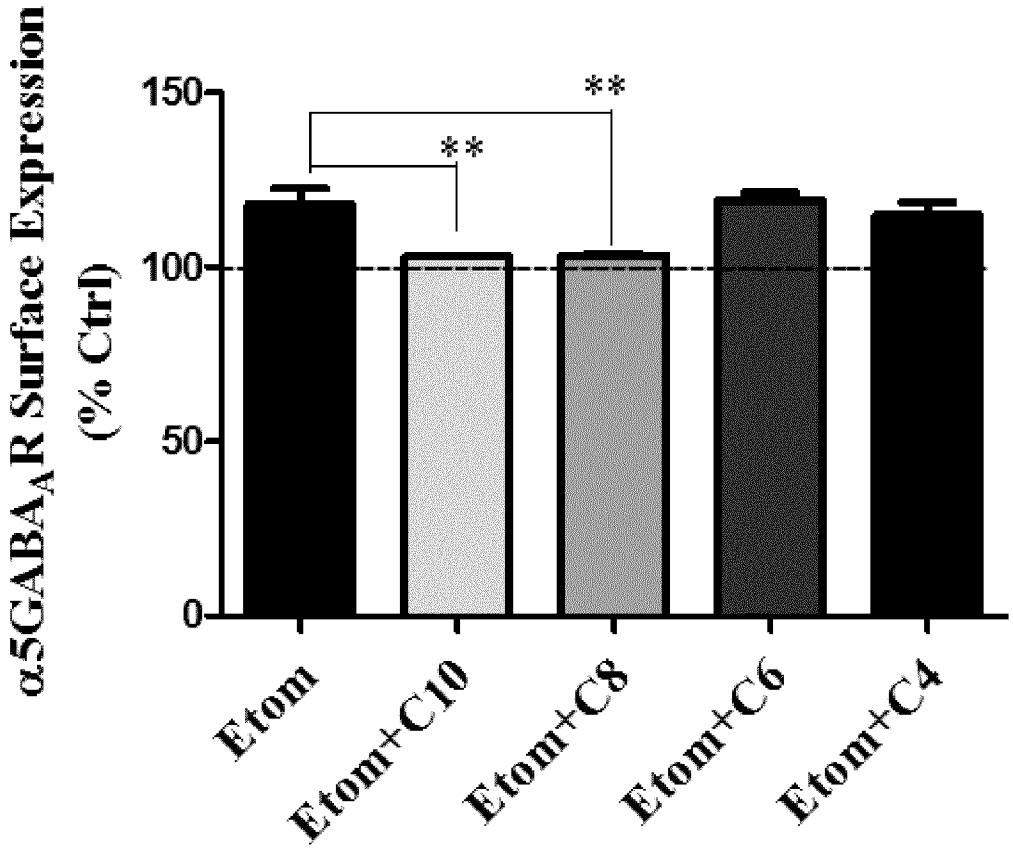
α5GABA$_A$R Surface Expression
(% Ctrl)
150
100
50
0
**
**
Etom
Etom+C10
Etom+C8
Etom+C6
Etom+C4

FIGURE 8

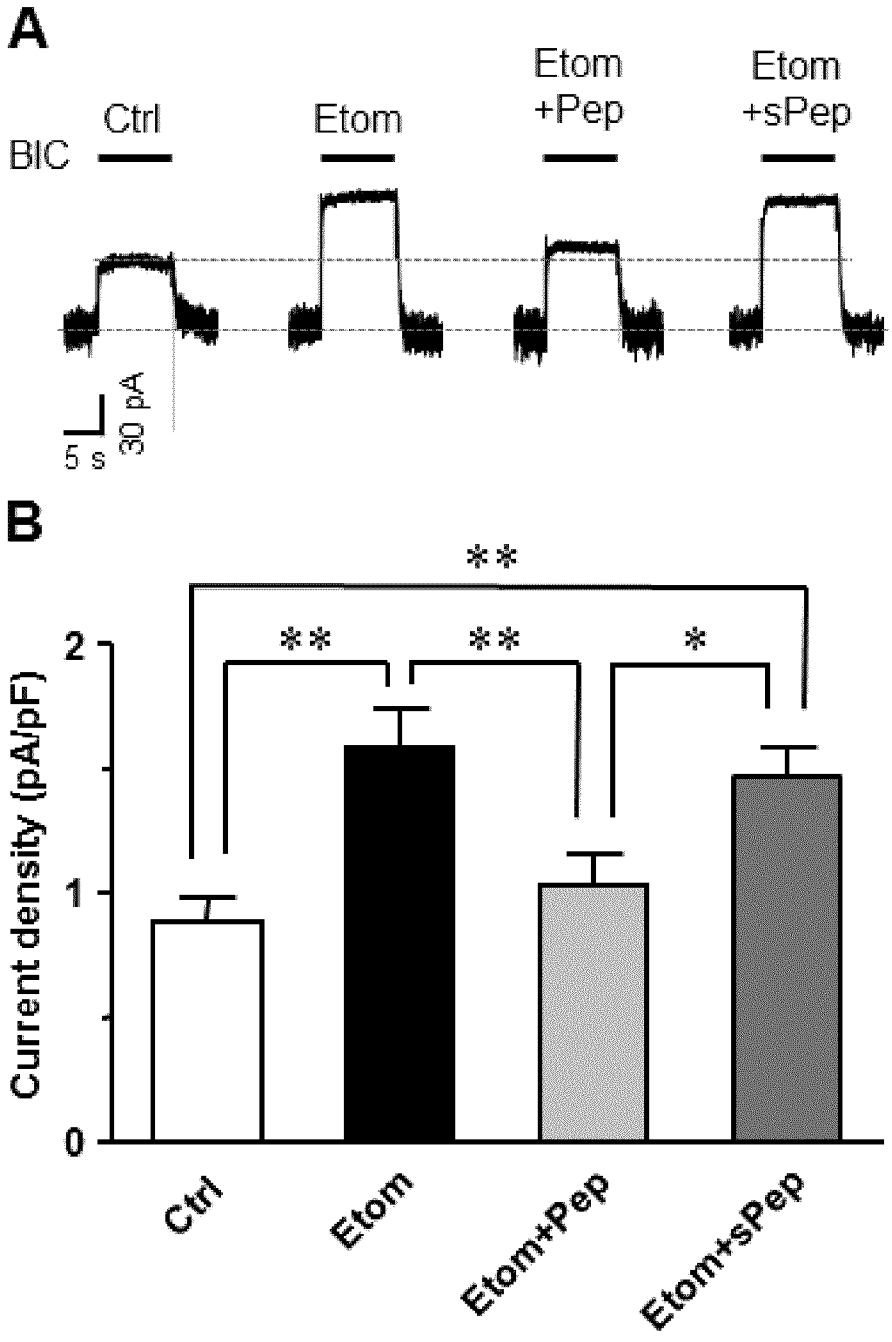
A
Ctrl
Etom
Etom +Pep
Etom +sPep
BIC
30 pA
5 s
B
**
**
**
*
Current density (pA/pF)
2
1
0
Ctrl
Etom
Etom+Pep
Etom+sPep

Figure 9

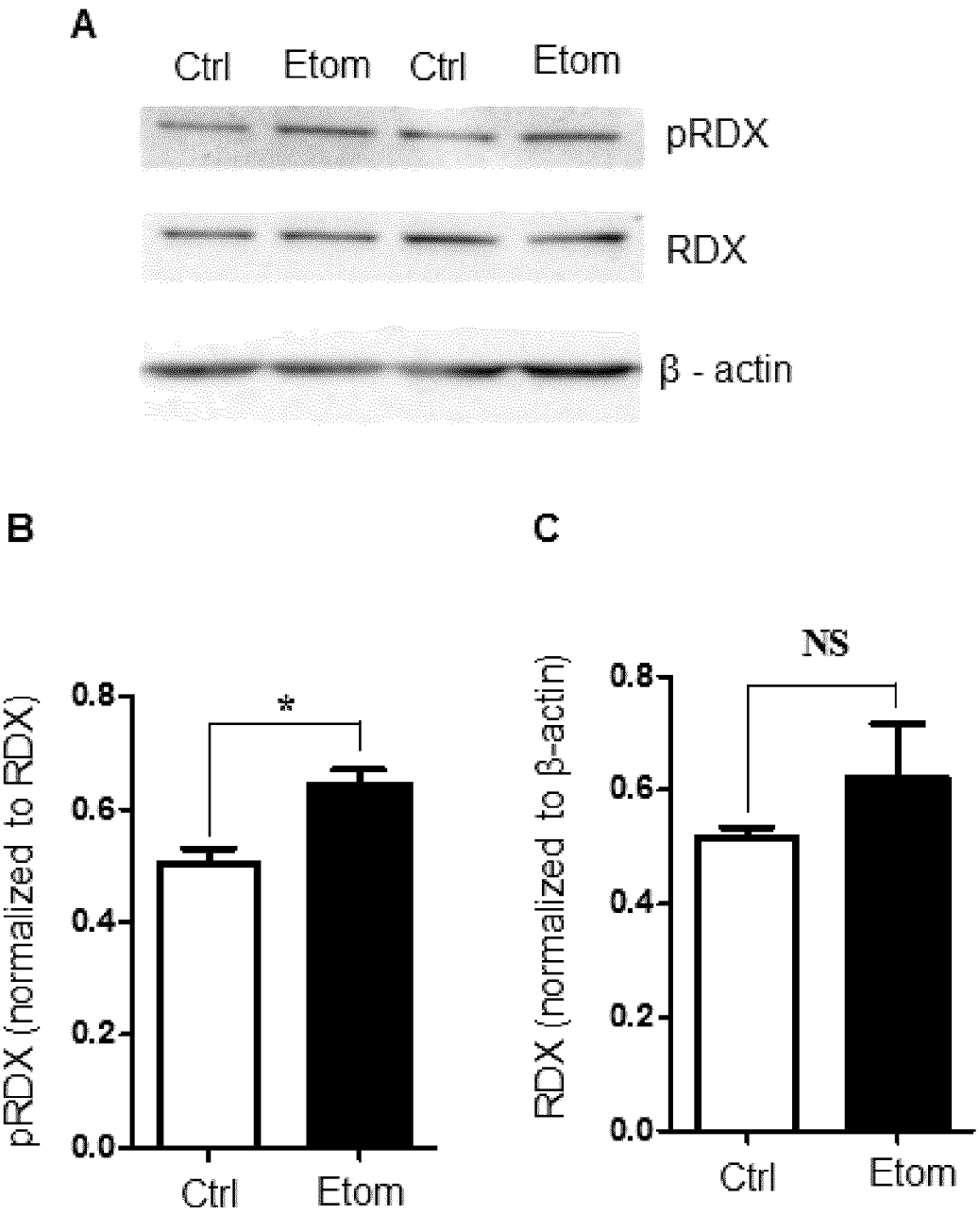
A
Ctrl
Etom
Ctrl
Etom
pRDX
RDX
β - actin
B
pRDX (normalized to RDX)
0.8
0.6
0.4
0.2
0.0
*
Ctrl
Etom
C
RDX (normalized to β-actin)
NS
0.8
0.6
0.4
0.2
0.0
Ctrl
Etom

FIGURE 10

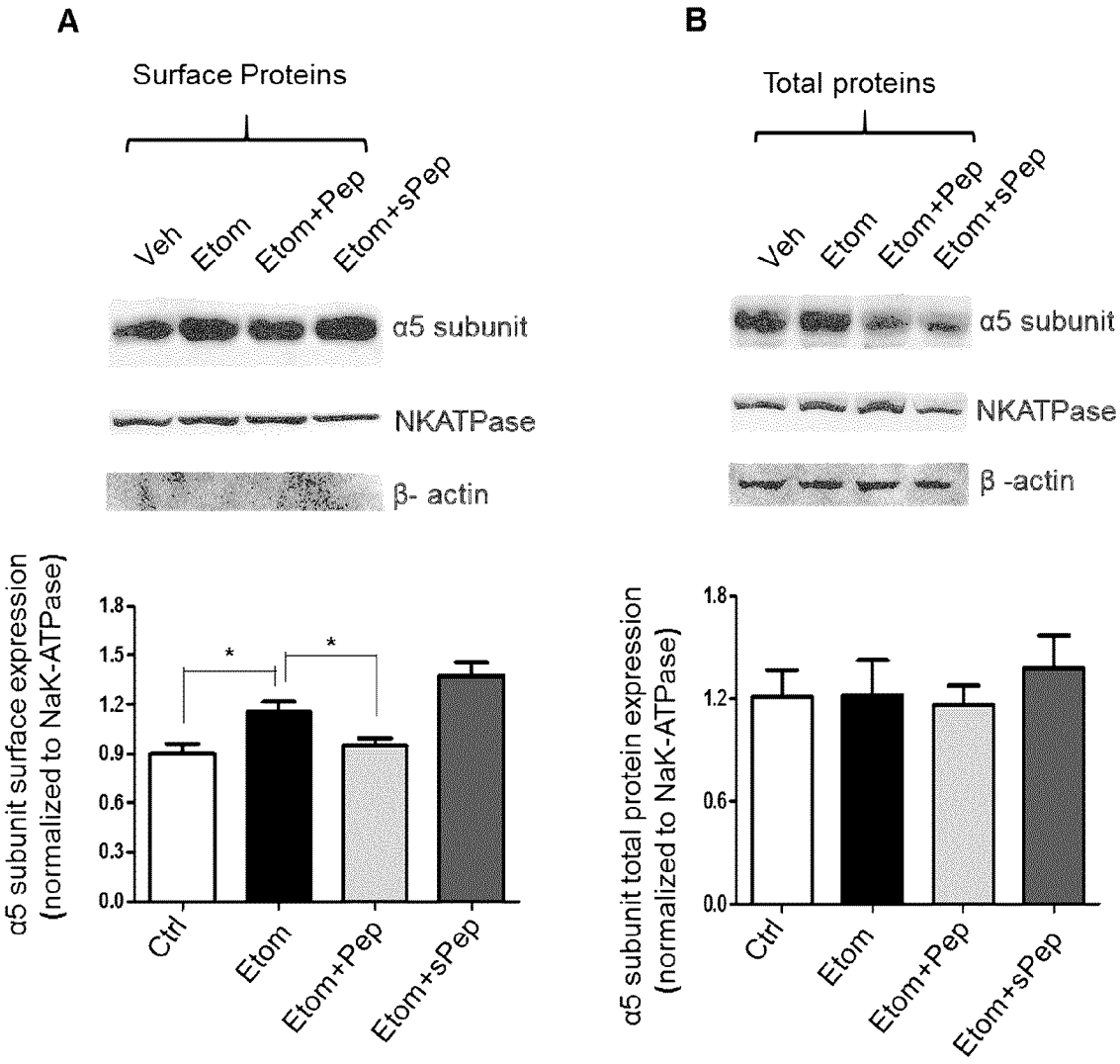
A
Surface Proteins
Veh
Etom
Etom+Pep
Etom+sPep
α5 subunit
NKATPase
β- actin
α5 subunit surface expression (normalized to NaK-ATPase)
1.8
1.5
1.2
0.9
0.6
0.3
0.0
*
*
Ctrl
Etom
Etom+Pep
Etom+sPep
B
Total proteins
Veh
Etom
Etom+Pep
Etom+sPep
α5 subunit
NKATPase
β -actin
α5 subunit total protein expression (normalized to NaK-ATPase)
1.8
1.2
0.6
0.0
Ctrl
Etom
Etom+Pep
Etom+sPep

FIGURE 11

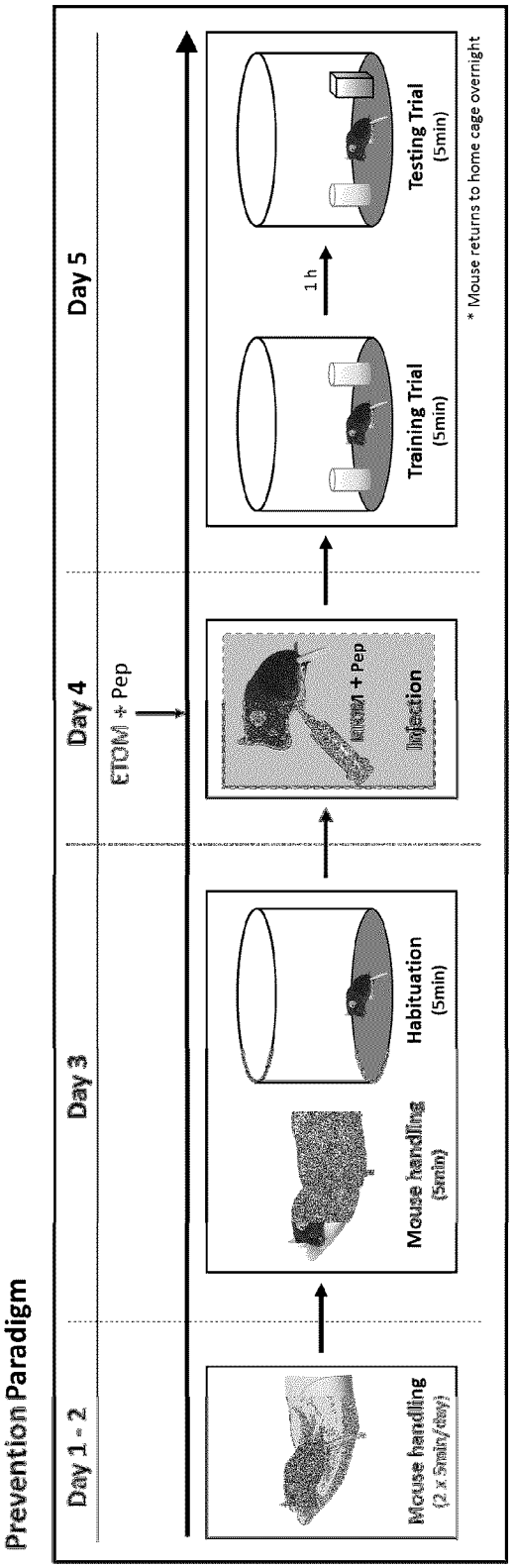
Prevention Paradigm
Day 1 - 2
Day 3
Day 4
Day 5
Mouse handling
(2 x 5min/day)
Mouse handling
(5min)
Habituation
(5min)
ETOM + Pep
Injection
1 h
Training Trial
(5min)
Testing Trial
(5min)
* Mouse returns to home cage overnight

Figure 12

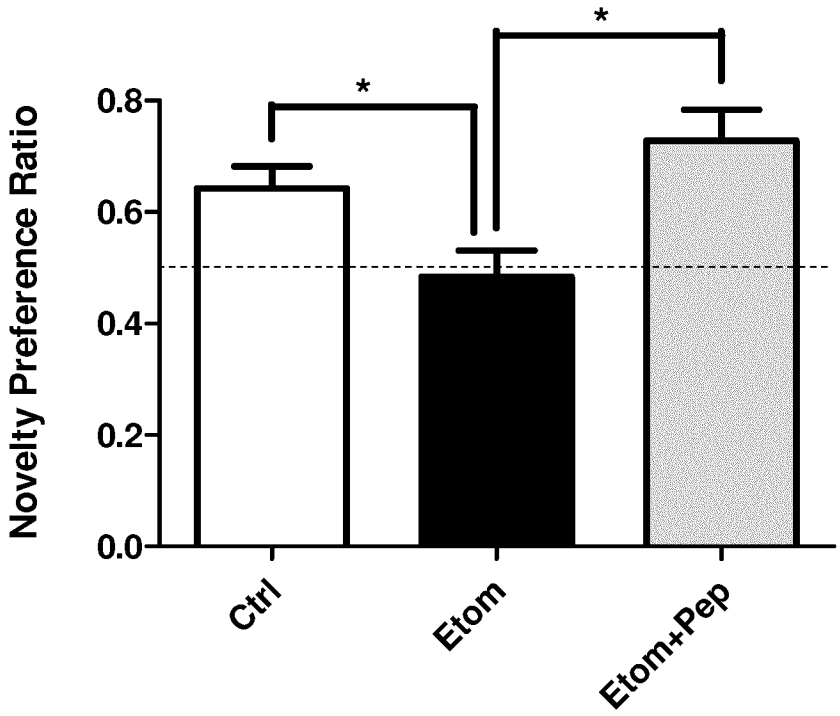

Figure 13

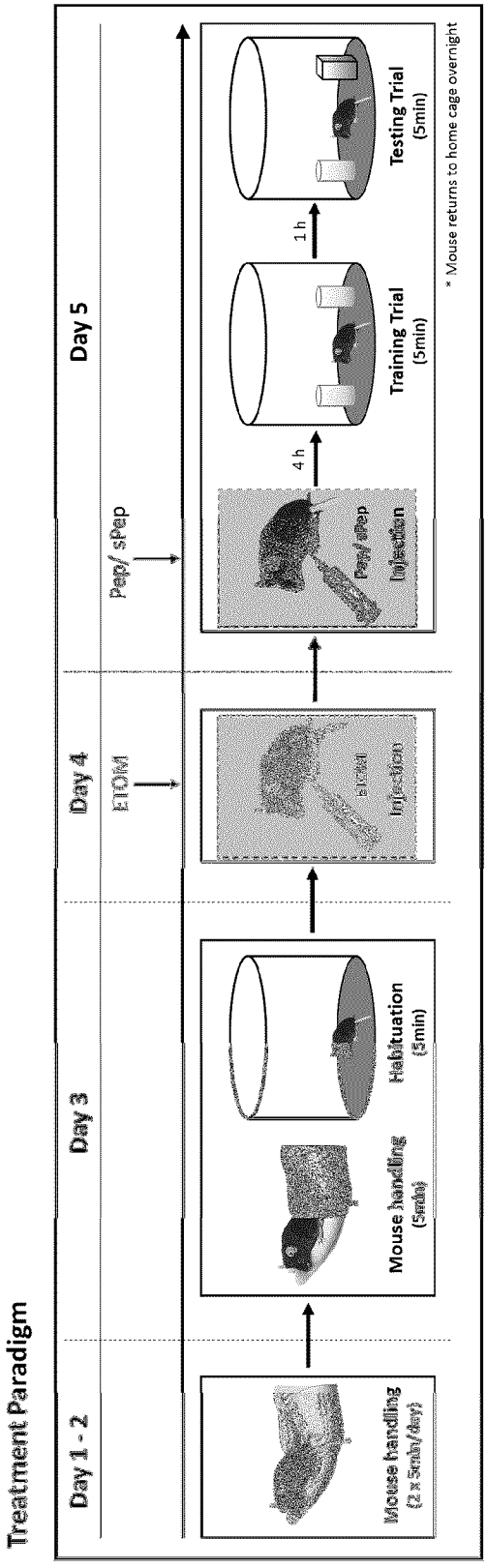
Treatment Paradigm
Day 1 - 2
Day 3
Day 4
Day 5
Mouse handling
(2 x 5min/day)
Mouse handling
(5min)
Habituation
(5min)
EtOH
Injection
Pep/ sPep
Injection
4 h
1 h
Training Trial
(5min)
Testing Trial
(5min)
* Mouse returns to home cage overnight

Figure 14

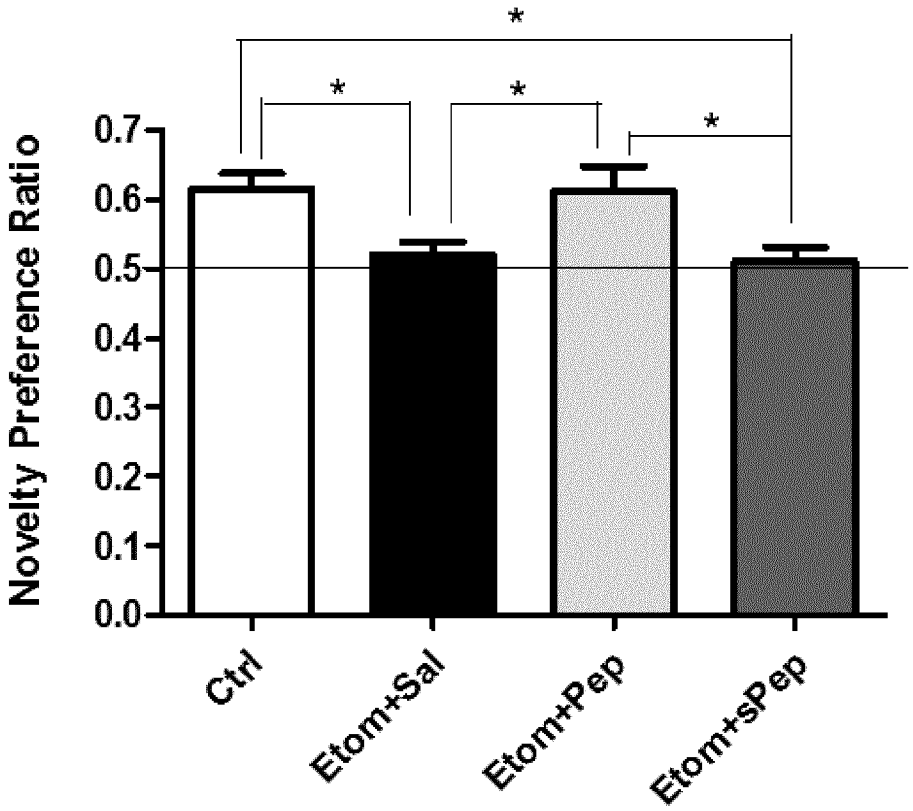
*
*
*
*
Novelty Preference Ratio
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Ctrl
Etom+Sal
Etom+Pep
Etom+sPep

Figure 15

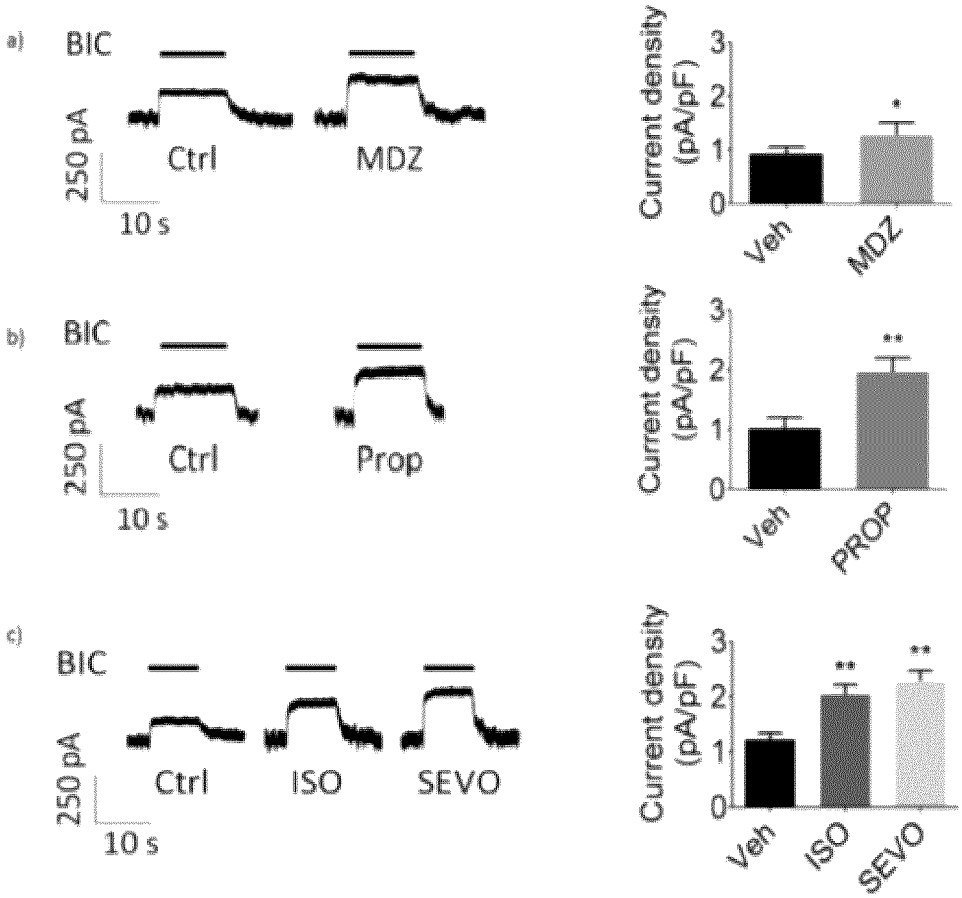
a)
BIC
250 pA
Ctrl
MDZ
10 s
Current density (pA/pF)
Veh
MDZ
b)
BIC
250 pA
Ctrl
Prop
10 s
Current density (pA/pF)
Veh
PROP
c)
BIC
250 pA
Ctrl
ISO
SEVO
10 s
Current density (pA/pF)
Veh
ISO
SEVO

Figure 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2016/051496

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***C07K 7/06*** (2006.01), ***A61K 38/08*** (2006.01), ***A61K 38/10*** (2006.01), ***A61K 38/17*** (2006.01), ***A61K 39/395*** (2006.01), ***A61P 25/00*** (2006.01), ***C07K 14/47*** (2006.01), ***C07K 16/18*** (2006.01), ***C07K 16/28*** (2006.01), ***C07K 7/08*** (2006.01), *C07K 14/705* (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: ***C07K 7/06*** (2006.01), ***A61K 38/08*** (2006.01), ***A61K 38/10*** (2006.01), ***A61K 38/17*** (2006.01), ***A61K 39/395*** (2006.01), ***A61P 25/00*** (2006.01), ***C07K 14/47*** (2006.01), ***C07K 16/18*** (2006.01), ***C07K 16/28*** (2006.01), ***C07K 7/08*** (2006.01), ***C07K 14/705*** (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Electronic databases: Questel Orbit, Google Patents, Canadian Patent Database, Pubmed-NCBI.
Search Terms:α5GABA$_A$, radixin, inhibitor, peptide, GABA, α51A, memory, L-655,708, SEQ IDNOs: 1-4

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO/2013/040142 A2 (BREMEL & HOMA) 21 March 2013 (21-03-2013)	1-6, 35-37, 39, 40
A	HAUSRAT et al., Nature Communications, 20 April 2015 (20-04-2015), Vol. 6:6872	1-40

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 03 March 2017 (03-03-2017)	Date of mailing of the international search report 03 April 2017 (03-04-2017)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 819-953-2476	Authorized officer Joel Karwatsky (819) 576-2121

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2016/051496

Box No. I **Nucleotide and/or amino acid sequence(s) (Continuation of item 1.c of the first sheet)**

1. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of a sequence listing:

a. ☑ forming part of the international application as filed:

☑ in the form of an Annex C/ST.25 text file.

☐ on paper or in the form of an image file.

b. ☐ furnished together with the international application under PCT Rule 13*ter*.1(a) for the purposes of international search only in the form of an Annex C/ST.25 text file.

c. ☐ furnished subsequent to the international filing date for the purposes of international search only:

☐ in the form of an Annex C/ST.25 text file (Rule 13*ter*.1(a)).

☐ on paper or in the form of an image file (Rule 13*ter*.1(b) and Administrative Instructions, Section 713).

2. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

3. Additional comments:

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2016/051496

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☑ Claim Nos.: 9-25
because they relate to subject matter not required to be searched by this Authority, namely:

Claims 9-25 are directed to a method for treatment of the human or animal body by surgery or therapy, which the International Searching Authority is not required to search under PCT Rule 39.1(iv). However, this Authority has carried out a search based on the alleged effect or purpose/use of the product defined in claims 9-25.

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2016/051496

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
WO2013040142A2	21 March 2013 (21-03-2013)	WO2013040142A2	21 March 2013 (21-03-2013)
		WO2013040142A3	13 February 2014 (13-02-2014)
		EP2550529A1	30 January 2013 (30-01-2013)
		EP2550529A4	02 November 2016 (02-11-2016)
		EP2771349A2	03 September 2014 (03-09-2014)
		EP2771349A4	17 June 2015 (17-06-2015)
		US2013330335A1	12 December 2013 (12-12-2013)
		US2017039314A1	09 February 2017 (09-02-2017)
		WO2011119484A1	29 September 2011 (29-09-2011)