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**MECHANISMS OF COMORBIDITY, CONTINUITY, AND DISCONTINUITY
IN ANXIETY-RELATED DISORDERS**

Neil McNaughton

University of Otago, NZ

Philip J. Corr

City University London, UK

for

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“Mechanisms of comorbidity, continuity, and discontinuity in psychopathology”

Correspondence address: Professor Neil McNaughton, Department of Psychology, University of Otago, Dunedin, New Zealand. Email: nmcn@psy.otago.ac.nz

Abstract

We discuss comorbidity, continuity and discontinuity of anxiety-related disorders from the perspective of a two-dimensional neuropsychology of fear (threat avoidance) and anxiety (threat approach). Pharmacological dissection of the ‘neurotic’ disorders justifies both a categorical division between fear and anxiety and a subdivision of each mapped to a hierarchy of neural modules that process different immediacies of threat. On this view, ‘anxiety’ and ‘fear’ disorders are absolutely distinct classes and so the American Psychiatric Association ‘anxiety-related disorders’ or World Health Organization ‘neurotic, stress-related and somatoform disorders’ are inappropriate conflation. Critically, each module within a hierarchy can generate normal responses, symptoms of another syndrome, or syndromal responses. We discuss the resultant possibilities for comorbid dysfunction of these modules both with each other and with some disorders not usually classified as anxiety-related. The simplest case is symptomatic fear/anxiety co-morbidity, where dysfunction in one module results in excess activity in a second, otherwise normal, module to generate symptoms and apparent co-morbidity. More complex is syndromal fear/anxiety co-morbidity, where more than one module is concurrently dysfunctional. Yet more complex are syndromal comorbidities of anxiety that go beyond the two dimensional fear/anxiety systems: Depression, SUD, and ADHD. Our account of ADHD-anxiety comorbidity entails discussion of the neuropsychology of externalizing disorders to account for the lack of anxiety comorbidity in some of these. Finally, we link the neuropsychology of disorder to personality variation, and to the development of a biomarker of variation in the anxiety system among individuals that, if extreme, may provide a means of unambiguously identifying the first of a range of anxiety syndromes. Such biomarkers are what is required if both morbidity and

comorbidity are to be approached via the Research Domain Criteria currently advocated by the National Institutes of Mental Health.

Introduction

We address comorbidity, continuity and discontinuity of anxiety-related disorders both with each other and with some disorders not usually classified as anxiety-related. Current symptom-based classifications of mental disorders emphasise discrete and unitary diagnoses. But our analysis, grounded in neuropsychology, not only expects symptoms to be mixed, even in the absence of true syndromal comorbidity, but also expects some syndromes to co-occur more often than chance, either as a result of common risk factors or by feeding off each other in a vicious pathological cycle (which can involve both physiological and psychological elements).

We distinguish three distinct ways in which anxious and fearful states can occur: normal, symptomatic, and syndromal. Consider panic as an example. In the normal case, the panic state occurs in the face of a very high level of immediate threat in the environment and is, in a general evolutionary sense, adaptive. In the symptomatic case, the external level of threat would be lower and below the normal threshold for adaptive panic; but the panic could still be seen as appropriate provided we allow for the level of (pathological, syndromal) fear or anxiety experienced. In the syndromal case, the panic response itself would be excessive in relation to the modest level of threat and of (normal) fear or anxiety – or panic would occur spontaneously as a result of epileptiform discharges in its control module that are unrelated to any fear or anxiety input.

We also categorically distinguish anxiety from fear, seeing them as functional opposites. In particular, we argue that pharmacology requires a complete separation of anxiety (involved in the approach to threat) from fear (involved in escape and the active avoidance of threat). In addition, we argue for multiple distinct disorders (that depend on the immediacy of threat) of each of fear and anxiety. On this view, ‘anxiety disorders’ and ‘fear disorders’ are classes of disorders and are absolutely distinct from each other; and the current

classes of ‘anxiety-related disorders’ (American Psychiatric Association, 2013) or ‘neurotic, stress-related and somatoform disorders’ (World Health Organization, 2010) conflate fear and anxiety inappropriately.

From our anxiety-versus-fear perspective, what are commonly seen as anxiety-related disorders include what are in our terms ‘fear’ disorders (e.g., panic disorder, OCD); while some ‘fear’ disorders (in the sense of being labelled as phobias) are better seen as anxiety disorders (e.g., social phobia, which is now often referred to as social anxiety, or agoraphobia). Diagnostic systems, such as DSM-5, not only include fear and anxiety within a single category of ‘anxiety disorders’ but entangle fear and anxiety together; for example,

“Anxiety disorders include disorders that share features of excessive fear and anxiety and related behavioural disturbances. Fear is the emotional response to real or perceived imminent threat, whereas anxiety is anticipation of future threat. Obviously these states overlap. ... Panic attacks feature prominently within the anxiety disorders as a particular type of fear response. Panic attacks are not limited to anxiety disorders but rather can be seen in other mental disorders as well.” (DSM-5, 2013, p. 826)

At the level of symptom presentation, the DSM-5 picture seems reasonable. But we believe this is a (scientific) confusion that has roots entangled deep in the psychological and psychiatric literature: Where ‘anxiety’ is often seen as a cognitively enhanced form of ‘fear’. In one sense, this is not far from our theory. Anxiety includes activation of the avoidance system and is more complex in also including activation of the approach system and, critically, in engaging mechanisms that allow conflict resolution. But, crucially, we draw attention to the functional opposition between fear and anxiety – where not only do they

represent quite distinct evolutionary adaptations but also activation of the anxiety system can suppress outputs of the fear system, such as panic (Deakin & Graeff, 1991).

However, there are also good reasons for grouping anxiety and fear disorders (and also depression) into a higher order grouping of ‘neurotic disorders’ linked to high levels of the personality trait of neuroticism (Eysenck & Eysenck, 1964; Andrews, Stewart, Morris-Yates, Holt, & Henderson, 1990; Kendler, Neale, Kessler, Heath, & Eaves, 1992a, b). Here we are close to the ICD-10 ‘neurotic, stress-related and somatoform disorders’ except for our categorical distinction between classes of fear, anxiety and depression disorder within the higher order ‘neurotic’ class. Importantly, high neuroticism is not itself a disorder. Instead a high level of neuroticism increases the risk of developing any one of a range of defensive disorders that include anxiety, fear and depression. Given the above evidence, Neuroticism may also be responsible for some of the comorbidity and shared genetic predisposing factors of defensive disorders. We leave open the question of whether ‘neurosis’ is still a useful clinical category when applied to a diffuse co-activated cluster of symptoms that do not lend themselves to distinct clinical subdivision. But there is now strong molecular genetic evidence for a general trait of neuroticism, as measured by normally distributed personality scales (Smith et al. 2015). We note below that the widespread modulation of brain systems by monoamines provides one possible substrate for such a global source of comorbidity and genetic influence.

We will use the terms ‘panic’ and ‘obsession’ to refer to states in a generally similar way to their common usage; but we will treat their pure syndromal occurrences as primary fear disorders that can result in (see below), and usually present in the clinic with, symptomatic or syndromal comorbid anxiety. According to this perspective, symptoms are a poor guide to syndromes and in many clinical cases there will be apparent comorbidity of, for example, panic disorder with anxiety disorder when only panic or anxiety is syndromal and

anxiety or panic, respectively, is symptomatic. There will also often be genuine syndromal comorbidity. Our neuropsychological perspective (see below) leads to a hierarchical, system-based, scheme that incorporates overlapping and interacting causes of different disorders and accounts for patterns of comorbidity among a range of defensive disorders.

We emphasise the links between psychology and neurobiology in psychopathology. In particular, we will look at the multiple ways that psychological and neurobiological factors can interact in generating symptoms. The clinician is faced with co-occurring symptom clusters. Our primary task, here, is to account for the specific neural modules that define continuity and discontinuity of the specific anxiety-related clinical syndromes that can generate such shared clusters. Equally important, both in terms of basic theory and clinical implications, is how anxiety-related disorders interface with a range of other types of disorder. We will argue for a range of local symptomatic and syndromal ways in which co-occurring clusters of symptoms can be produced. But we will also argue for a global level at which higher level risk factors (not pathological in and of themselves) can be common to defensive disorders and so can generate comorbidity; and we will link this to an older literature on more general classes of disorder (e.g., ‘neurosis’ and ‘hysteria’) that have modern echoes (e.g., ‘internalising’ and ‘externalising’). In addition to comorbidity among defensive disorders, we describe links to externalising disorders, such as substance use disorder (SUD) and attention deficit hyperactivity disorder (ADHD), that, on the face of it, one might not expect to be directly related to internalising disorders such as anxiety.

We also emphasise that comorbidity between two disorders can be generated in either direction. In the case of anxiety and SUD, alcohol abuse, for example, is often a form of self-medication for stress-induced anxiety. Indeed, in the past, a primary social anxiety may often have been misdiagnosed as SUD because the latter, secondary, condition was more salient (Connor, Davidson, Sutherland, & Weisler 1999). On the other hand, dependence on

sedative anti-anxiety drugs, which act via GABA_A receptors, can result from inappropriate use of these drugs as hypnotics. This dependence and resultant problems with withdrawal can then generate significant anxiety disorder.

We will discuss a number of ways in which comorbidity can result from vicious cycles. The capacity for two-way traffic between SUD and anxiety disorder that we described in the previous paragraph provides one explanation of how positive feedback between self-medication and withdrawal can sustain comorbidity of SUD (usually seen as an externalising disorder) and anxiety (as an internalising disorder). (It could be argued that SUD should not be characterised as an externalising disorder in such cases as internalising anxiety is the primary mechanism.) Positive feedback can also occur within the internalising disorders, with panic and anxiety feeding off one another. Much of this can be conditioned by the environment and, more generally, life events that people experience and construct; these can impact the settings of biological systems (Kendler, Thornton, & Gardner, 2000). Disorders, such as anxiety and depression, can also increase the incidence of disorder-enhancing life events (Harkness, Monroe, Simons, & Thase, 1999). In contrast to these external mediators of comorbidity, the paradoxical association of ADHD with anxiety disorder may result from a feedback reaction of one part of the brain to disorder in another. We explore these various issues of psychiatric comorbidity further below; but have omitted discussion of anxiety symptoms linked to more obviously neurological conditions such as epilepsy (Adamec & Young, 2000).

Pharmacological dissection of the ‘neurotic’ disorders

We have argued, so far, both for a degree of commonality among the neurotic disorders and for a need to distinguish a wide range of neurally differentiated syndromes. Before proceeding to the detailed neural model that we will use to support the remainder of our

discussion, we will cover the basic pharmacology from which the key elements of the neural model are derived. This pharmacology provides reason both to distinguish among syndromes and to see them as sharing some aspects of their control.

The ideal drug would be a ‘magic bullet’, targeting specific symptoms or a specific syndrome; but virtually all are less than specific in their effects. However, as academic researchers rather than clinicians, we can gain neurally specific information by asking what effects are not produced by a set of drugs (Table 1). Consider buspirone, a serotonergic anti-anxiety drug that targets ‘5HT_{1A}’ receptors. It improves anxiety (and depression), but not panic, and is not sedative or addictive. These differential effects show that the neural systems controlling fear (as exemplified by panic) and anxiety are somewhat independent. Buspirone also shows that an effective anti-anxiety drug need not be sedative, muscle relaxant, or addictive. We can compare buspirone with benzodiazepines and note that, at doses that treat anxiety, benzodiazepines do not generally affect panic, obsession or, importantly and unlike buspirone, depression. Taking buspirone and benzodiazepines together, then, we have reason to see anxiety systems (affected by both buspirone and benzodiazepines) as being distinct from those (unaffected by at least one of buspirone or benzodiazepines) controlling panic, obsession, depression, SUD and a wide range of side effects. As we will discuss later, we can also use experimental comparison of the effects of these classes of drug to validate potential biomarkers of anxiety disorder.

----- Table 1 about here -----

In contrast to buspirone and benzodiazepines, there are (Table 1) anti-panic drugs that show that fear systems are drug sensitive and that the lack of action on panic of some anti-anxiety drugs is not simply because panic is insensitive to drugs. Importantly, there are drugs

(such as clomipramine) that have not only anti-panic, but also anti-depressant and anti-obsessional actions, as well as treating generalised anxiety disorder. These act on monoamine systems, and have very delayed (weeks or months) development of their therapeutic effects. This suggests that they may be acting, directly or indirectly, via a system that controls a ‘neurotic disorder’ risk factor.

In order to understand the full range of these neurally distinct disorders, we require a model that accounts for the extremely varied symptom presentation in the clinic and the significant variation in the capacity of drugs to treat specific types of disorder. But we must also account for the extensive comorbidity among anxiety disorders seen in the clinic, the wide effectiveness of some of the classes of drug, and the shared neurotic predisposition to these disorders. It is to such a model that we now turn.

A two-dimensional neuropsychology of fear and anxiety

Our picture of fear, anxiety and their syndromes and symptoms has at its core the Behavioural Inhibition System (BIS) postulated by Jeffrey Gray (Gray, 1975, 1976). Gray’s BIS was defined by sensitivity to anxiolytic drugs (Gray, 1977) and its psychological nature is still being progressively determined. The BIS is distinct from, and interacts with, a Behavioural Approach System (BAS) controlling pure approach and a Fight, Flight, Freeze System (FFFS) controlling active avoidance (Gray, 1982; Gray & McNaughton, 2000). In the later versions of the model (Gray & McNaughton, 2000; McNaughton & Corr, 2004, 2008; Corr & McNaughton, 2012), fear and anxiety are absolutely distinct, functionally, chemically, structurally, and genetically. We see fear (FFFS) and anxiety (BIS) as differing in terms of a categorical dimension of ‘defensive direction’. That is, fear is a set of often concurrent reactions (e.g., autonomic activation, escape, avoidance) that have evolved to allow us to move away from danger and are sensitive to anti-panic drugs, but not anti-anxiety

drugs. In contrast, anxiety is a set of reactions (e.g., autonomic activation, risk assessment) that have evolved to allow us to move towards, or passively avoid, danger and are sensitive to anti-anxiety drugs (and also anti-panic drugs).

The ethoexperimental work of Robert and Caroline Blanchard (Blanchard & Blanchard, 1990a, b) not only provides the basis for a functional distinction between fear and anxiety but also shows that the specific fearful or anxious behaviour generated depends on ‘defensive distance’: this is a cognitive construct consisting in perceived immediacy of threat. For any individual on any particular occasion faced with a threat, it is directly related to physical distance from the threat in space or time. But for more, or less, threat-sensitive individuals a particular physical distance represents a lesser or greater, defensive distance, respectively (see Corr & Perkins, 2006).

Importantly, but not obvious from any single observation of their action, anti-anxiety drugs alter defensive distance rather than just reducing a specific behaviour: In a highly anxious individual, showing little movement towards a threat, an anti-anxiety drug will reduce defensive quiescence and allow risk assessment to start; but, a less anxious individual (at the same physical or temporal distance) will already be undertaking risk assessment and the drug will reduce risk assessment, allowing pre-threat, e.g. appetitive, behaviour to appear (Blanchard, Blanchard, Tom, & Rodgers, 1990).

----- Figure 1 about here ---

Figure 1 shows the mapping of this two-dimensional (defensive direction x defensive distance) functional picture to a corresponding neural and clinical one. A stream of structures is shown (top to bottom), one controlling fear (panic, escape and active avoidance), on the left of the figure, the other controlling anxiety (passive avoidance, risk assessment, approach

to threat), shown on the right hand side. As can be seen at the bottom of Figure 1, structures at the lowest neural level control quick and dirty responses (LeDoux, 1994) to immediate threats, and those shown at the top of Figure 1 control relatively slower, sophisticated responses to more distant threats. The BAS is not shown in the figure as our current focus is on defensive disorders. However, it has a similar hierarchical structure that can be linked functionally to ‘appetitive distance’ and that has neural levels matching those shown in Figure 1 (orbital frontal cortex, antero-dorsal cingulate cortex, central amygdala, lateral hypothalamus, but probably not representation in the PAG; see Figure 7, page 32, of McNaughton, DeYoung and Corr, in press).

An important feature of the control of these systems is the reciprocal links between modules both within and between systems (Figure 1). Each structure could operate alone, but in practice they tend to be co-activated and often interact (LeDoux, 1996). Any specific threat will activate multiple modules concurrently. These in turn, via one set of connections, will activate other adjacent modules. Higher level modules will often inhibit the outputs (but not the activations) of lower level modules. Thus, a high level of activation in an area like the amygdala that can generate a learned avoidance response will inhibit competing directed escape or undirected panic controlled by the hypothalamus and periaqueductal grey (PAG), respectively, while leaving autonomic activation, for example, intact. As noted previously, it is the combination of activation of the FFFS and the approach system that activates the BIS. Activation of the BIS, in turn, increases activation of the FFFS but not the approach system and so increases risk aversion, negative cognitive bias, and arousal. At the same time, the BIS blocks output from the PAG so that inappropriate panic/escape does not interfere with cautious approach or passive avoidance. (The inhibition of PAG output by BIS activation accounts for the otherwise surprising phenomenon of relaxation-induced panic attacks.) However, higher order mechanisms can also release panic. The periaqueductal grey (PAG)

receives direct, topographically organised, input from prefrontal cortex (Shipley, Ennis, Rizvi, & Behbehani, 1991), which allows complex threat appraisal mechanisms (including traits such as catastrophizing) to produce a panic response if a complex threat is assessed as being close/immediate.

To conceptualise the relationship between normal behaviour, symptoms and syndromes for these structures, let us, consider the PAG as the simplest case. It is thought to control all instances of panic both in humans and rodents, and consistent with this claim, in terms of symptoms, panic is much the same whatever the cause (Barlow, 2002). An extreme threat in a normal person will produce normal (potentially adaptive) panic – and ‘panic attacks’ can be mild (Marks, 1988). A weak threat in a pathologically fearful or anxious person will produce an abnormally high input to the PAG and so panic appropriate to the pathological fear or anxiety experienced (Goisman et al. 1995). Spontaneous activity in PAG (Dantendorfer et al. 1995) could generate spontaneous panic – a neurological syndrome of ‘pure panic disorder’. Pure panic disorder could also arise from excessive reaction to any one of a range of input stimuli: Hypersensitivity to blood carbon dioxide, producing a ‘suffocation false alarm’ (Klein, 1995); an exaggerated autonomic response (Gurguis, et al. 1999) to stimulant drugs; poor autonomic control (Middleton, Ashby, & Robbins, 1994); or altered central responses to, or levels of, endogenous benzodiazepines (Randall et al. 1995), orexins (Johnson et al, 2010), CCK, or monoamines (Sandford, Argyropoulos, & Nutt, 2000). We will discuss how such a syndrome of pure neurological panic disorder relates to current “Panic Disorder” diagnoses in the following sections.

A similar case can be made for obsessions and obsessive compulsive disorder (OCD), which we noted earlier is treated by our theory as a fear disorder not an anxiety disorder. As we have argued in more detail previously (Gray & McNaughton, 2000, pp 288-289, 324-326), “the repetitive checking of a toddler by a parent can seem obsessive” (p. 289)

but is actually normal and functional and would be the result of the normal activation of the anterior cingulate (or prefrontal) cortex (Rapoport, 1989). Similarly, “pathologically maintained anxiety (most likely generalised anxiety) could provide an unusually high level of input to the cingulate-basal ganglia circuitry ... [which] could then trigger any latent obsessions or compulsions” (p. 326) producing a symptomatic form of OCD. In the syndromal case, “obsession and compulsions can arise from over-activity in the cingulate-basal ganglia circuitry. Often this will give rise to avoidance behaviour (or successful checking), will not produce major increased in anxiety, and will not lead to the seeking of clinical help. ... Where the frequency of fully fledged avoidance is very high, ... or the avoidance response is in some other way blocked, then there will be conflict ... with consequent anxiety ... [particularly] in those with a neurotic introvert personality” (p326).

Simple panic, simple phobia, simple obsession, etc., would arise from pathology of specific modules (Figure 1) of the defensive systems. But the theory allows for more widespread influences. For example, structures on the right hand side of Figure 1 are coordinated by a ‘theta rhythm’ that is specifically altered by all anti-anxiety drugs with no positive or negative exceptions to date (McNaughton, Kocsis, & Hajós, 2007). This means that the entire BIS can be modulated by any endogenous anxiolytic compound and that dysfunction of this modulation would generate a disorder that would likely be diagnosed as generalised anxiety.

The theory also allows us to relate morbidity and comorbidity to the idea of ‘neurotic disorders’ that we considered above. The monoamines serotonin (5HT) and noradrenaline (NA) are a likely substrate for the general factor of neuroticism (Takano, Arakawa, Hayashi, Takahashi, Ito, & Suhara, 2007); and, as shown in Figure 1, 5HT /NA diffusely innervate most modules of the defence systems. As we noted earlier (Table 1), tricyclic drugs, clomipramine, monoamine oxidase inhibitors and specific serotonin reuptake inhibitors all

affect both anxiety and fear. However, they are also anti-depressant, and so 5HT/NA systems take us beyond the two dimensional defense system to ‘neurotic’ disorders more generally.

Our take-home message is that individual syndromes may well depend on specific structures (or receptors or uptake systems specific to those structures), but more general modulatory (and likely predisposing) influences could result in the coordinated activity of (comorbid) groups of structures.

This model predicts a number of observations: A wide range of potential syndromes (each resulting when a specific module becomes hyper- or hypo-reactive); extensive symptom overlap because of the interaction between modules (resulting in apparent comorbidity in relation to current diagnostic systems); and risk factors that modulate multiple modules, and even systems, simultaneously precipitating comorbidity.

We are focussing at a relatively low level of control, but we may well expect that, with negative reinforcement generating conditioning and cognitive elaboration, what is presented to the psychiatric diagnostician is far removed from the primary activation of the neural modules, discussed above. It is for this reason, we believe, that it is difficult to predict the efficacy of anti-panic, anti-fear, anti-depression and anti-anxiety drugs at the level of the individual patient, many of whom are prescribed a variety of medications until one seems to work. In order to determine primary causes, it is at the relatively low level of modules that we will likely want to start the scientific search and ultimately develop biomarkers (see below).

Our model also predicts that what will appear on the surface to be a single class of comorbidity can arise from two primary alternatives. The first alternative is that (primary) hyper-reactivity of one module within one of the systems controlling defense can result in excessive symptoms produced by (secondary) hyperactivity of another part that is otherwise normal. This is not co-morbidity in the classic medical sense (the co-existence of two distinct

syndromes) but, with current psychiatric diagnosis based on symptom clusters, it will currently fulfil the criteria for more than one disorder. The second alternative is that multiple modules may be (primarily) hyper-reactive. This can easily occur if two hyper-reactivities share a common risk factor or if one initial hyper-reactivity tends to result in the development of another. We believe that, often in clinical practice, the symptomatic and syndromal alternatives are intertwined; and that in many cases the same superficial symptomatology can arise from a range of different, single or multiple, primary (syndromal) causes. For example, while agoraphobia is often (Langs et al, 2000) preceded by, and appears to result from, panic attacks (and so be secondary); there is evidence (Friend & Andrews, 1990; Goisman et al 1994) that it can arise in their absence (and so be primary). Once established, the increased arousal associated with it could generate panic attacks (which would now be secondary, see also below). In the absence of some form of neuropsychological diagnostic tool (see below), it is difficult to differentiate between these possibilities.

Symptomatic fear/anxiety co-morbidities

The simplest form of co-morbidity anticipated by our perspective is more apparent than real. It involves cases where a genuine underlying hyper-reactivity of some part of a system results both directly in symptoms related to its own activity and indirectly in symptoms related to the consequent activity in other structures. This consequent activity can result from both neural connections with other parts of the same system and, more importantly for the appearance of comorbidity, from processes such as conditioning that can affect parts of other systems. We will use panic as our primary exemplar of these various effects.

First let us consider symptomatic development that proceeds from primary morbidity in the FFFS to generation of additional BIS-related symptoms. Pure physiological/neurological panic without additional complications presents rarely in the

psychiatric clinic (Shear & Maser, 1994), but is more readily measured in the general population (Joyce & Oakley-Browne, 1990) and presents in the cardiology clinic (Holt, 1990; Carter, Maddock, Zoglio, Lutrin, Jella, & Amsterdam, 1994). Despite the existence of these cases of unprovoked, uncomplicated, ‘pure panic’ attacks, current psychiatric criteria for diagnosis of ‘Panic Disorder’ require secondary avoidance or anxiety accompanying the panic. However, the occurrence of panic itself ceases to be a problem once avoidance and anxiety are treated (Franklin, 1990). We would argue, therefore, that panic disorder proper is not, by itself, a major problem; but in, e.g., a person with a neurotic personality it can engender inconvenient reactions, including increased autonomic responses that increase the incidence of panic, and then present as the current psychiatric ‘panic disorder’ entity.

----- Figure 2 about here ---

The presentation of panic as a syndrome with symptomatic comorbid anxiety is shown in Figure 2. Pathological activity (Dantendorfer et al. 1995), or re-activity (see previous section), of the periaqueductal gray produces a panic attack. This will produce consequent neural activation of other structures in the FFFS generating, for example, increased arousal via the amygdala. A panic attack that is restricted in this way should, from our point of view, be labelled ‘panic disorder’; but, unless there are additional developments, it will most likely be reported clinically as ‘irritable heart syndrome’ (Holt, 1990). If the patient accepts that the symptoms are in fact completely benign then the consequent arousal will not increase and may even decrease. However, particularly if the patient has a neurotic disposition, association of the initial aversive panic attacks with, for example, mildly threatening social situations can result in conditioned anxiety (via the BIS, right hand side of Figure 2) and so increased arousal. Increased adrenaline can then precipitate more frequent

panic attacks (Sandford et al., 2000), creating a vicious cycle that may result in presentation as what is currently diagnosed as panic disorder (if only high arousal and frequent panic attacks are present), or agoraphobia with panic (if conditioning results in avoidance of the situations that have come to elicit the panic attacks). Treatment of this avoidance, and of the negative interpretation of the panic attacks, can eliminate this vicious cycle, and result in a return to normal functioning – but with a low level of residual panic attacks remaining (Franklin, 1990) since the primary neurological cause remains.

----- Figure 3 about here ---

Such symptomatic developments can also proceed in the other direction, from primary morbidity in the BIS to generation of additional FFFS-related symptoms. If elements of the BIS are hyper-reactive (right hand side of Figure 3), this will generate a primary pathology such as Generalised Anxiety Disorder with, importantly, increased general levels of arousal. (Note that there may be a form of agoraphobia that, initially at least, presents without panic attacks. This, Social Anxiety Disorder, and dysfunctions of other parts of the BIS, could all follow this same symptomatic panic generation scenario.) As we noted in the previous paragraph, increased adrenaline will often precipitate panic attacks particularly in those with a system that is highly sensitive to its normal inputs (which need not be the case for the spontaneous panic attacks of our previous scenario). These adrenaline-induced panic attacks, which are in principle normal given the level of (pathological) anxiety being experienced, can then result in conditioned increases in the original anxiety, its accompanying arousal, and so further panic attacks.

Syndromal fear/anxiety co-morbidities

It is clear from the extensive overlap in the elements of the two scenarios we have described, that symptomatic comorbidity would be expected to be common and for the primary cause of symptoms of anxiety+panic to be difficult to determine. Coincidence will not always be the case – with both simple panic attacks and pure GAD/agoraphobia/social anxiety occurring, particularly in those who lack a neurotic personality type or a tendency to arousal-elicited panic, respectively. But a combination of symptoms is likely to be common.

A further expectation is that such symptomatic overlap can lead to a true syndromal overlap. Anxiety accompanied by panic is likely to be chronic; anxiety results in the release of stress hormones; and chronic stress is likely to result in a progressive development of sensitivity ('kindling') of the systems involved (Adamec & Shallow, 1993; Adamec, 1997; Adamec, Holmes, & Blundell, 2008; Schmidt, Abraham, Maroun, Stork, & Richter-Levin, 2013). Thus primary dysfunction of one node (with secondary increases in symptoms mediated by another node) can evolve into primary dysfunction of both nodes and so true syndromal comorbidity.

For related reasons, we would anticipate a considerable level of comorbidity of initial syndromes. Where disorder is generated by chronic stress, this can not only precipitate any one of the neurotic disorders but is likely to precipitate more than one at a time. Similarly, if the source of disorder is a genetic predisposition to anxiety (i.e., BIS activation) in general then more than one node of the system (and so more than one form of anxiety disorder) is likely to be involved simultaneously. Likewise, if there is a genetic problem with monoamine systems (potentially expressed as neuroticism or a related trait) then both the FFFS and BIS could contribute multiple disordered nodes.

----- Figure 4 about here ---

Whichever of these various routes is involved, our theory accepts that massive apparent comorbidities of its set of proposed symptom clusters will occur with potentially a range of concurrent underlying syndromes. This promiscuity creates the current complex clinical picture and emphasises the difficulty of separating symptom parallels from true syndromal comorbidities. However, while multiple positive feedback loops (Figure 4) complicate the diagnostic picture, they are also likely to provide some degree of flexibility of treatment. For example, as we have noted already, treating the neurologically normal anxiety that is consequent on abnormal panic will reduce arousal, eliminate avoidance, and reduce, even when it does not eliminate, panic attacks.

Syndromal comorbidities beyond fear/anxiety

We have already touched on the issue of syndromal comorbidities that may be consequent on, or etiologically mixed with, symptomatic comorbidities. The syndromes have been envisaged as directly involving the FFFS, BIS or both; as a result, the true comorbidities can appear continuous, with primary syndrome plus secondary symptoms shading into a pair of primary syndromes.

In the following sections, we discuss comorbidities that go beyond the FFFS and BIS systems and involve appetitive systems, one way or another. In some cases they share with FFFS/BIS syndromes chronic stress as a source of syndrome development. The three primary classes we will consider are an internalising disorder (i.e., depression) and two externalising disorders (i.e., SUD and ADHD). All three have a high probability of being comorbid with anxiety but for quite different causal reasons. We argue that a neuroscientific perspective of the type outlined above will help to shed new light on these more broad ranging comorbidities.

Anxiety and Depression

Anxiety and depression are likely to co-occur even in the absence of morbidity. There is reason (McNaughton, 1989, p 148-149), for example in the specific case of separation distress, to see an initial active anxiety response (leading to re-uniting with the parent) as being adaptive in the short term and its conversion to a risk- and resource-reducing depressed state as being equally adaptive in the long term (allowing survival until the parent's eventual return). Under more general conditions of conflict, depression may also become adaptive as a means of “communicating a need for help, signalling yielding in a hierarchy conflict, fostering disengagement from commitments to unreachable goals, and regulating patterns of investment ... [in] situations in which effort to pursue a major goal will likely result in danger, loss, bodily damage, or wasted effort” (Nesse, 2000). Thus anxious, depressive and stress responses may have co-evolved (Nesse, 1999) to solve the problems presented by both immediate (anxiety), and longer term (depression), goal conflict. On this view, it is unsurprising that the hippocampus is not only the key node of the BIS but also the main structure in the brain through which stress hormone levels are regulated (see Sapolsky, 2004; Sapolsky, Krey, & McEwen, 1984). Importantly, while acute anxiety-related responses involve increased activity in the FFFS but do not change the BAS, and so potentially solve the problem of goal conflict by withdrawal, we would argue (following Nesse) that the more chronic depression-related responses can suppress BAS activity (reducing the tendency to approach what are now seen as unreachable goals) not only via a reduction of output but via processes such as anhedonia. The argument, so far, is most clear if we see active attempts to solve a problem as leading to “danger, loss, bodily damage”. However, it has been suggested that while “some categories of defences are more proximal and symptom-focused, and result directly from ... anxious states [but] other kinds of defences operate more distally and mute anxiety by activating approach-oriented states ... [that] vary in the extent to which they ...

resolve the original discrepancy or are merely palliative” (Jonas et al, 2014). In this case, Nesses’s final alternative “wasted effort” makes it functional to suppress the BAS. Given these reasons for linking chronic functional anxiety with functional depression; it seems likely that chronic functional or dysfunctional anxiety would lead to depression with primary dysfunctional anxiety producing secondary dysfunctional depression; and chronic anxiety of both types resulting in pathological depression in stress-sensitive individuals.

The most obvious additional reason for a high comorbidity between anxiety and depression is that they share a common pre-disposing risk factor, neurotic personality. Even if their precipitating causes and neural substrates were independent, shared risk would lead us to expect co-occurrence. Potentially linked to this, serotonin (5HT) signalling is altered in anxiety and depression and may contribute to comorbidity (Deakin, 1998). Specific serotonin reuptake inhibitors (SSRIs) are now a first-line therapy in the treatment of anxiety-depression comorbidity (Kaufman & Charney 2000). 5HT_{1A} receptor ligands are effective in both disorders; but normalisation of 5HT produces distinct antidepressant and anxiolytic actions (Deakin, 1993). If quite separate 5HT systems mediate deficits in anxiety and depression, selectively, then neither would control specific comorbidity, which could nonetheless depend on more general variation in the global control of 5HT.

Anxiety and depression also appear to share precipitating causes. The triple comorbidity of PTSD+anxiety+depression occurs in about half of war veterans, this being about 3 times the rate in this population of PTSD alone or of PTSD comorbid with only one of anxiety/depression (Ginzburg, Ein-dor, & Solomon, 2010). Thus, even more so than with the other neurotic disorders, we can see anxiety and depression as linked and, therefore, often comorbid.

Anxiety, as we have noted already, is a stressor – it releases corticosterone. Stress system dysregulation appears to precipitate affective disorders (Kessler, 1997), being

moderate in primary anxiety disorder and strong in primary and comorbid major depressive disorder (Kara, Yazici, Güleç, & Ünsal, 2000). Clinical depression can be viewed as a form of dysfunctional stress response (Pariante & Miller, 2001; Pariante, 2003); and so it is unsurprising that clinical depression can be consequent on chronic anxiety (which will itself often be pathological), resulting in the two being comorbid.

Finally, we should note that there may be a distinct condition that presents symptomatically as depression co-morbid with anxiety but where both sets of symptoms are generated by a common underlying dysfunction that is more chronic and severe than those giving rise to anxiety or depression, separately, and which is accompanied by a higher suicide risk (Roy-Byrne, Stang, Wittchen, Ustun, Walters, & Kessler, 2000). Consistent with this, war veterans who “would endorse a lifetime triple comorbidity [of PTSD+anxiety+depression] are likely to have more impaired functioning (Ginzburg, Ein-dor, & Solomon, 2010, p 249).

Anxiety and SUD

Conversely to anxiety producing comorbid depression, SUD can produce comorbid anxiety. (For a more detailed version of the following discussion see McNaughton, 2008.)

Recreational use of alcohol or the regular use of barbiturates or benzodiazepines as hypnotics results in tolerance, dependence, and addiction. Tolerance, in particular, then leads to rebound anxiety upon withdrawal of the drugs. (Each of these classes of drug has its own binding site on the GABA_A receptor system; through which all produce anti-anxiety actions as well as euphoria and muscle relaxation). However, this anti-anxiety action, and the stressful nature of anxiety, gives it a capacity to generate SUD. SUD can often start with, and be substantially maintained by, self-medication particularly with alcohol. Once alcohol intake has started, the story is essentially the same as with recreational use leading to SUD. Here

again we have the potential for a vicious cycle (as when anxiety and panic feed off each other) with anxiety and SUD reinforcing each other (for detailed reviews see Stewart & Conrod, 2008). It should be emphasised that we are describing only one aspect of SUD, here, and that the causes of addiction go much deeper than a response to anxiety.

----- Figure 5 about here ---

An important point to note in relation to the self-medication story we have just presented is that SUD and the control of anxiety are linked through a complex web of endogenous interacting compounds (Figure 5). Serotonergic anti-anxiety drugs (such as buspirone or fluoxetine) impact on the neural structures that control anxiety (e.g. hippocampus and amygdala) in much the same way as GABA_A drugs, and without showing tolerance. Both classes of drug also (Figure 5) have their anti-anxiety action reduced (Meijer & de Kloet, 1994; Meijer, Van Oosten, & de Kloet, 1997) by corticosterone/cortisol (CORT). However, 5HT_{1A} drugs differ from GABA_A drugs in two important respects. The first (Figure 5) is that serotonergic drugs release CORT on initial use while GABA_A drugs inhibit it (Broadbear, Winger, & Woods, 2005) (with both classes of drug showing tolerance of their effects on CORT release). This partially explains the initial dysphoric effects of the serotonergics and euphoric effects of the GABA_A drugs. The second is that GABA_A drugs, but not serotonergics, activate opiate systems (Kostowski & Biéńkowski, 1999; Richardson, Reynolds, Cooper, & Berridge, 2005) that in turn activate dopamine systems producing rewarding and euphoriant actions that contribute to their abuse potential. We can argue, then, that the strong links between anxiety disorder and SUD relate to endogenous compounds that regulate not only anxiety but also reward systems.

Anxiety and ADHD

The final case that we will consider also likely involves complex interactions but between neural rather than chemical systems. The starting point is the observed high level of comorbidity of anxiety with ADHD (Costello, Mustillo, Erkanli, Keeler, & Angold, 2003), 30% can have comorbid anxiety disorders (Pliszka, 1998; Spencer, Biderman, & Wilens, 1999). This is, at first blush, surprising both at a superficial level and at the deeper theoretical level. At the superficial level, ADHD is thought to involve a fundamental problem of insufficient behavioural inhibition (Barkley, 1997) akin to the effect of anti-anxiety drugs. At the theoretical level, ADHD has been attributed to a fundamental hypofunction of the BIS (Quay, 1997), a system that we have argued generates anxiety. We will argue that ADHD is the result of dysfunction of both more (dopamine, white matter) and less (prefrontal but not subcortical) than the BIS as a whole. Since only prefrontal modules of the BIS are involved, this allows for comorbidity of externalizing and internalizing disorders, resulting from opposite frontal (hypoactive) and subcortical (hyperactive) BIS dysfunctions, respectively.

As is well known, ADHD involves two main types of symptom cluster: Inattentive (ADHD-IA; distractibility and difficulty focusing on tasks for a sustained period) and hyperactive/impulsive (ADHD-HI; fidgeting, excessive talking, and restlessness). These often occur together as a combined type (ADHD-CT; downgraded to combined ‘presentation’ in DSM-5). The clearest neural abnormalities (see also Table 2) are of the frontal lobe and white matter connections between the frontal lobe and subcortical regions, including the basal ganglia (Castellanos et al., 2002; Sowell, Toga, & Asarnow, 2000). “The most replicated alterations [in ADHD] . . . include significantly smaller volumes in the dorsolateral prefrontal cortex, caudate, pallidum, corpus callosum, and cerebellum” (Seidman, Valera, & Makris, 2005, p. 1263). As we have discussed in more detail elsewhere (Corr & McNaughton, 2016), several externalising disorders share these prefrontal developmental distortions and we will

discuss their differences, particularly in subcortical abnormalities, in the next section. There is dysfunction of noradrenergic systems (e.g., Plizska, 1988); and reduced dopamine in both mesocortical input to the dorsolateral prefrontal cortex and mesolimbic input to the nucleus accumbens may account for some cognitive impairments in ADHD (Sonuga-Barke, 2005) but with clear individual differences (Volkow, Wang, Newcorn, Fowler, et al., 2007a, p. 1182; see also Volkow, Wang, Newcorn, Telang, et al., 2007b).

Dysfunctional BIS activity has been implicated in ADHD (Beauchaine et al., 2001; Quay, 1997). Low BIS activity would result in reduced behavioural inhibition (i.e., a reduced capacity to inhibit prepotent goals and to resolve conflict by increased risk aversion), reduced attention (including both environmental and memory scanning), and reduced arousal. This profile of symptoms features particularly in ADHD-IA. But the neural abnormalities we have just described involve only frontal and not subcortical aspects of the BIS (see Sauder, Beauchaine, Gatzke-Kopp, Shannon, & Aylward, 2012; Stevenson & McNaughton, 2013). Conversely, there are behavioural changes that go beyond the BIS. Of particular note, is stopping in the stop signal task (SST). Impaired stopping in ADHD has been taken as evidence of BIS involvement; but SST stopping appears to depend on action rather than goal circuits (Neo, Thurlow, & McNaughton, 2011) and, critically, is insensitive to the anxiolytic drugs that define the BIS (McNaughton, Swart, Neo, Bates, & Glue, 2013). Therefore, in relation to both positive and negative features, it is difficult to see ADHD-IA simply as the low end of a BIS dimension. It is best seen as a dysfunction of prefrontal but not subcortical aspects of the BIS coupled with dysfunction of other prefrontal systems with the motivational component of the resultant phenotype being primarily BIS-.

Moving on to ADHD-CT, one idea is that it is associated with not only poor cognitive control (BIS-) but also with high positive and negative emotionality (BAS+, FFFS+; respectively). This combination of BAS+ and FFFS+ would result in the generation of a

greater tendency to make responses in the absence of conflict as well as in much higher levels of motivation under conditions of conflict (when the BAS and FFFS are equally activated). If so, all types of ADHD would show some dysfunction of the BIS. However, we cannot, as yet, rule out the possibility that in ADHD-CT the BIS is dysfunctional in relative rather than absolute terms – being activated by conflict but with insufficient power to inhibit the outputs of BAS hyperactivity.

We can see two reasons for the known ADHD neurology giving rise both to inhibitory problems and anxiety. The prefrontal components of the BIS normally process conflicts between goals that are at greater defensive distances than the subcortical components. Importantly, when they are activated they will tend to inhibit output from the subcortical components. So, if the prefrontal BIS is relatively unreactive, behavioural inhibition will be lost for distant but not close goals (allowing impulsivity free reign), and this will tend to result in situations where threats that would previously have been avoided at a distance occur at close range; and so generate anxiety via the subcortical components of the BIS. A second alternative, which is not mutually exclusive with the first, is that threats will be more likely to produce outputs via areas that normally deal with more immediate reactions and lack the inhibition that would normally be provided by slow and sophisticated systems. This will result in greater perceived immediacy of a threat than if the reactions were mediated by prefrontal components of the BIS.

A neuropsychology of externalizing disorders

Our resolution of the paradox of ADHD (an externalizing disorder) being often comorbid with internalizing anxiety disorders raises the question of why such comorbidity is not also true of other externalizing disorders with similar prefrontal neurology (that is, excluding SUD). As summarized in Table 2, and discussed in more detail by Corr & McNaughton

(2016), pathology of the BIS and FFFS combine with important hyperactivity of the behavioural approach system (BAS) to generate aspects of ADHD, phenylketonuria (PKU) conduct disorder (CD) and psychopathy – and contribute to the comorbidity of these disorders. Importantly, while the BIS is often seen to be exclusively related to internalizing disorders, we emphasize that it contributes (through under-activity) to externalizing ones. Importantly, the detailed neurology of this contribution can account not only for differences between the externalizing disorders and their comorbidity with each other but also for their pattern of comorbidity with internalizing disorders.

Dysfunctional behaviour can result from dysfunction of any one of the BAS, FFFS and BIS in isolation but will also often result from dysfunction of these and other systems acting in combination (see, e.g., Beauchaine, 2001; Beauchaine, Katkin, Strassberg, & Snarr, 2001). In conditions involving a pure excess of approach behavior, the BAS is likely to be functionally dominant. However, the BIS is often important for clinical presentation because it is involved in the regulation of goal conflict detection and resolution. BIS dysfunction causes failure of inhibition of inappropriate behaviour, which can be as important as excessive approach in generating externalizing symptoms.

The externalizing disorders shown in Table 2 appear to arise from a number of quite different proximal developmental causes. However, they ultimately converge on largely similar neural substrates (dopamine, white matter, large neutral amino acids) that alter largely similar prefrontal and temporal lobe circuits. For example, PKU has a quite distinct (point mutation) etiology from ADHD but, subject to the extent of dietary control, has a very similar final neural and behavioral phenotype; so that PKU, as a syndrome, can often be seen as comorbid with ADHD (Stevenson & McNaughton, 2013). We have argued that the differences between disorders may reflect relatively small differences in the boundaries of the systems affected. On this view there is a “topographically variable zone of neural

dysfunction” (Corr & McNaughton, 2016) with details of the individual topography of different cases accounting for common (neurally overlapping) and unique (non-overlapping) presenting features of the externalizing psychopathologies. There appears to be a common set of rostral prefrontal structures across the disorders with what appears to be a caudal progression of prefrontal and subcortical involvement. In the specific case of the BIS, as we progress from ADHD through CD to psychopathy the caudal boundary of dysfunction appears to progress from dorsolateral prefrontal cortex to the hippocampus and, then, the superior temporal gyrus and the amygdala. That is, ADHD has the least subcortical BIS dysfunction (albeit with some evidence of hippocampal disconnection) and psychopathy the most.

This topographical perspective accounts for not only many details of the individual syndromes but also for certain aspects of comorbidity. On this view, it is the combination of nominally syndrome-specific forms of damage that produces specific forms of comorbidity (e.g., ADHD + psychopathy). For example, some 60% of children with ADHD also have a diagnosis of oppositional defiant disorder and/or CD (Beauchaine et al., 2010); and approximately 70% of CD children have comorbid diagnosis of ADHD (Beauchaine et al., 2001). On the face of it, ADHD and CD would seem very different disorders. “With respect to externalising disorders in childhood, Quay suggested that ADHD and CD reflect different problems in the functioning of the BAS and the BIS. ADHD is characterised by an underactive BIS, whereas CD is associated with a BAS that dominates over the BIS: when cues for both reward and punishment are present, CD children focus on cues for reward at the expense of cues for punishment” (Matthys et al., 1998, p. 644; see also Matthys, Vanderschuren, & Schutter, 2013). But their neurologies have clear commonalities and a case with neurological abnormality overlapping both syndrome-specific zones is eminently likely. There is evidence that comorbid ADHD+CD children are prone to develop severe

externalizing disorders in adulthood (Beauchaine, Hinshaw, & Pang, 2010; Beauchaine & McNulty, 2013), including psychopathy (Greshman, Lane, & Lambros, 2000). Also, when we come to genetic loading, it is useful to think in terms of dosage: "...comorbidity between CD and the hyperactive/impulsive subtype of ADHD... represents a particularly virulent condition, characterised by a strong genetic loading, increased rates of aggression, and elevated risks of future antisocial behaviour . . . and score [high] on measures of psychopathy" (Beauchaine et al., 2001, p. 610; see also Finger et al., 2011, p. 152; Gresham, Lane, & Lambros, 2000). Our topographical view, coupled with the extent of comorbidities, would not be incompatible with a 'spectrum' view of ADHD-CD-psychopathy – with the specific presentation of any particular individual case reflecting their particular map of affected fronto-temporal areas and tracts.

Neuropsychology, personality, and biomarkers

We have presented a strongly neuropsychological view of both internalizing and externalizing disorders. We did discuss psychological factors, particularly in relation to symptomatic comorbidity, but nonetheless we could be taken to have implied that primary psychiatric disorder results from explicit neural pathology. Here, we redress the balance noting that: (a) a normally distributed long-term neurobiological sensitivity can be psychiatrically problematic at either extreme without requiring any explicit neural pathology (hence our exclusion of epilepsy earlier); (b) such sensitivities (and associated sometimes fairly gross developmental variation in neural structures) must be the fundamental substrates of personality factors, traits or facets; and, (c) a solution to the problem of diagnosing primary morbidity and, hence, syndromal comorbidity is to develop biomarkers that assess the sensitivity of the relevant neurobiological systems.

It has long been argued that establishing links between personality and disorder is vital to understanding diathesis, etiology, progression, prognosis and treatment of mental illness (e.g., Costa & Widiger, 1994; Harkness & Lilienfeld, 1997; Krueger & Tackett, 2003, 2006; Tackett, 2006; Watson, Clark, & Harkness, 1994; Widiger & Trull, 1992; Widiger, Verheul, & van den Brink, 1999). We have identified a range of neural processes the sensitivities of which could underlie long-term consistency of behavioural reactivity (i.e., ‘personality’). Either extreme of any neurobiological trait can then potentially be a risk factor for some set of disorders, the substrate of a specific disorder, or both.

Most functionally general are the monoamine and pituitary-adrenal systems. We have discussed long-term effects of serotonin, noradrenalin and stress hormones on systems controlling internalizing disorders; and briefly touched on the long-term, particularly developmental, effects of dopamine on systems controlling externalizing disorders. Chronic levels of some monoamines or hormones, system-wide, alter the reactivity of many parts of each system concurrently, giving rise to clusters of characters that define, for example, the ‘neurotic individual’. Consistent with this, anxiety disorder, in the typical population, has an estimated genetic loading of approximately 30% and this is true even with generalized anxiety, which is comorbid with other conditions, including depression (Kendler et al., 1992a,b,c). Thus, genetic vulnerability is of ‘neurotic disorders’ (including depression, but excluding simple phobia) and is not specific for any one ‘anxiety disorder’ (Andrews et al., 1990).

At the other end of the specificity spectrum, there are personality predispositions (e.g., obsessiveness, panic proneness, social anxiousness) that depend on the sensitivity of quite specific modules within the FFFS or BIS. While the reactivity of the modules concerned will depend, in concert, on monoamine inputs (and so be impacted on by ‘neuroticism’) each can have its own unique reactivity: obsessiveness depending on, e.g., the specific re-uptake

systems in the cingulate cortex that are sensitive to clomipramine but not imipramine (Rapoport, 1989); panic proneness being dependent on long term settings of a wide variety of systems we have already discussed; and social anxiety dependent on, perhaps, prefrontal monoamine oxidase. Each of these sensitivities will have its own epigenetic, genetic, and environmental (particularly developmental) contribution.

At the, intermediate, system level (FFFS/BIS), it is important to remind ourselves that anxiolytic drugs alter defensive distance and so change the level of the BIS that is in control of behaviour rather than altering any single module and, thus, any single behavior. They act like a personality factor of ‘anxiety proneness’ distinct from any ‘fear proneness’ and from any more specific proneness to panic or obsession. The anti-anxiety action of the benzodiazepines is achieved by adjusting the amplification of any subsequent effect of GABA at the GABA_A receptor but does not affect the current state of the chloride channel (Haefely, 1992). The benzodiazepine site is likely to be the target of circulating ‘anxiety-specific’ hormone-like compounds (quite distinct from stress hormones and, as noted above, likely antagonized by stress hormones). Importantly, different benzodiazepines can increase, or decrease, sensitivity to GABA. Endogenous compounds active at the ‘benzodiazepine’ receptor may, then, have a hormonal-like action (see Gray & McNaughton, 2000) controlling long term reactivity and supporting a personality factor, high levels of which could represent generalized anxiety disorder. Unlike changes in the serotonin system, changes in this system would not affect morbidity for pure OCD (i.e. presenting as a pure fear disorder uncontaminated by anxiety), panic disorder, or depression. It could affect the extent to which anxiety resulted from, and so was comorbid with, those conditions – and so impact on current DSM/ICD diagnoses. Conversely, longer term decreases in reactivity could provide vulnerability to a range of disorders of insufficient anxiety; generating some form of externalizing disorder. On this view, both extremely high and extremely low levels of anxiety

would be dysfunctional—a proposition consistent with the maintenance of a normal distribution of this trait in the general population.

In contrast to benzodiazepines, serotonergic agents achieve anti-anxiety action by binding to the 5-HT_{1A} receptor. The normal ligand for this receptor is serotonin, which is also released concurrently onto other 5-HT receptors. An endogenous, 5-HT_{1A}-specific hormone is unlikely. Changes in the 5-HT system should affect a broad range of the amazing variety of 5HT receptors (similar to effects of serotonin-selective reuptake inhibitors such as fluoxetine) or monoamines more generally (similar to effects of monoamine oxidase inhibitors) would therefore be expected to produce concurrent variation in both the FFFS (trait fear) and the BIS (trait anxiety), thus generating factors with broad-ranging effects, such as neuroticism. However, selective changes in 5HT_{1A} receptor density or sensitivity could underlie more anxiety-specific chronic effects. It should also be noted that, as discussed earlier, stress hormones may act fairly generally as antagonists of anti-anxiety hormonal actions.

Clinical and genetic data are consistent with our suggested endogenous benzodiazepine / endogenous monoamine modulation of defense systems. Statistical models of reported symptoms extract a higher order internalizing (e.g., depression and generalized anxiety disorder) factor encompassing lower order facets of ‘fear’ and ‘anxious-misery,’ which share about 50% of their variance (Krueger, 1999). There appear to be distinct risk factors for anxiety and mood disorders, on the one hand, and phobias and panic disorders, on the other (Krueger & Markon, 2006). These two risk factors are labeled ‘Distress’ and ‘Fear’, which seem to parallel BIS and FFFS sensitivities, respectively. Distress and Fear, though distinct, are strongly correlated, reflecting a more general internalizing factor that resembles a personality factor of Neuroticism (Griffith et al., 2010). Likewise, the general genetic risk for internalizing disorders breaks down ‘anxious-misery’ (i.e., depression and generalized anxiety disorder) and specific ‘fear’ (i.e., animal and situational phobia) components

(Kendler, Prescott, Myers, & Neale, 2003). So, comorbidity, continuity and discontinuity in clinical disorders would appear to be reflected in personality traits related to these disorders.

If psychiatric disorder is fundamentally an extreme of a personality trait this immediately raises a problem for diagnosis. Here, the contrast between PKU and ADHD is instructive. PKU, qua disorder, can be detected with a simple blood test (although the extent to which it generates psychiatric problems varies strongly with dietary control). ADHD, on the other hand, cannot be simply defined in terms of a point mutation or other single simple biological character. The neurotic disorders represent an even harder problem with common predisposing factors and overlapping symptom/syndrome presentations. What are required are distinct biomarkers for the syndromal basis for the presenting neurotic symptoms.

The solution to the biomarker problem, here, is to determine the sensitivity of the underlying neuropsychological systems that support both the relevant fundamental personality factor and its clinical extreme. As yet, there are no proven biomarkers of this type for any psychiatric disorder. However, the strong neuropsychological basis of the theory of the BIS has allowed development of a biomarker for BIS reactivity as a whole (McNaughton, 2014) that we are currently testing for its capacity to be the substrate of a clinical disorder. The key aspects of this biomarker are that: (1) it is a rhythmic EEG signal in the same frequency band (Shadli et al., 2015) as the rat hippocampal theta rhythm that acts as the most reliable current assay of anti-anxiety drug action (McNaughton et al., 2007); (2) it correlates with the shared variance of ‘neuroticism’ and ‘trait anxiety’ personality measures (Neo et al., 2011); and (3) it is sensitive to benzodiazepines, buspirone (McNaughton et al, 2013) and pregabalin (Shadli, McIntosh, Glue, & McNaughton, 2015), i.e., all the known classes of anti-anxiety drug that lack either anti-panic or antidepressant action. Our prediction is that this biomarker will show abnormally high values in some subgroups of, for example,

panic+anxiety symptom patients with the remainder of the, superficially similar, patients showing abnormally high values on, e.g., some future biomarker of PAG dysfunction.

From DSM to RDoC

Even the most recent update of psychiatry's primary diagnostic manual, DSM-5, is seen by, e.g., the Director of the National Institutes of Mental Health as unsatisfactory.

Unlike our definitions of ischemic heart disease, lymphoma, or AIDS, the DSM diagnoses are based on a consensus about clusters of clinical symptoms, not any objective laboratory measure. In the rest of medicine, this would be equivalent to creating diagnostic systems based on the nature of chest pain or the quality of fever. Indeed, symptom-based diagnosis, once common in other areas of medicine, has been largely replaced in the past half century as we have understood that symptoms alone rarely indicate the best choice of treatment.

Patients with mental disorders deserve better. NIMH has launched the Research Domain Criteria (RDoC) project to transform diagnosis by incorporating genetics, imaging, cognitive science, and other levels of information to lay the foundation for a new classification system. Through a series of workshops over the past 18 months, we have tried to define several major categories for a new nosology (see below). This approach began with several assumptions:

- A diagnostic approach based on the biology as well as the symptoms must not be constrained by the current DSM categories,
- Mental disorders are biological disorders involving brain circuits that implicate specific domains of cognition, emotion, or behavior,
- Each level of analysis needs to be understood across a dimension of function,

- Mapping the cognitive, circuit, and genetic aspects of mental disorders will yield new and better targets for treatment.

It became immediately clear that we cannot design a system based on biomarkers or cognitive performance because we lack the data.

Insel (2013; see also Insel et al, 2010 for a more detailed description of RDoC)

We would argue that the theoretical approach we have taken in this paper is tightly aligned with RDoC and, in that sense, provides an antidote for the generic problems of the approach taken in DSM and ICD. We do not claim that converting our preclinical theory to clinical practice is simple. However, we argue that the biomarker described in the previous section is the result of the kind of translational effort required to provide elements of a system of the RDoC type that is focused on ‘fundamental underlying mechanisms of dysfunction [and] the development of new treatments targeted to underlying pathophysiological mechanisms’ (Insel et al., 2013, p 748).

That said, the nature of our biomarker suggests that at least some psychiatric disorder as defined via RDoC will remain distinct in principle from “ischemic heart disease, lymphoma, or AIDS”. These disorders have a distinct categorical biological cause. Our biomarker reflects a continuous source of variation within the population that is best thought of as a personality trait, where extreme high and low values can each be classified as dysfunction but with no clear boundary between the functional and dysfunctional. We do not see this as a problem since physical medicine already uses drugs to treat high blood pressure in and of itself (with some arguing that reductions below ‘normal’ are therapeutic in terms of risk reduction) and a similar approach can be taken to the related continuous variables that will emerge in RDoC psychiatry.

Conclusions

We have argued here that the complex, apparently comorbid, symptom patterns of fear and anxiety disorders observed in the clinic can be accounted for by a simple two dimensional neuropsychology of fear and anxiety. Critically, any module of these defense systems can generate normal behavior, react normally but to abnormality in another module and so generate symptoms, or react abnormally producing a syndrome. Patients that are superficially similar in terms of their symptoms may then have one, or another, or both of any two fundamental disorders. We argue that diagnosis must, therefore, proceed via the use of biomarkers that detect hyper-reactivity of the various different neural modules and so allow detection of true syndromes and true comorbidity. We have provided one example of a recently developed biomarker that may achieve this for one anxiety syndrome.

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References

- Adamec, R. (1997). Transmitter systems involved in neural plasticity underlying increased anxiety and defense - implications for understanding anxiety following traumatic stress. *Neuroscience and Biobehavioral Reviews*, 21, 755-765.
- Adamec, R., Holmes, A., & Blundell, J. (2008). Vulnerability to lasting anxiogenic effects of brief exposure to predator stimuli: Sex, serotonin and other factors-relevance to PTSD. *Neuroscience and Biobehavioral Reviews*, 32, 1287-1292.
- Adamec, R., & Shallow, T. (1993). Lasting effects on rodent anxiety of a single exposure to a cat. *Physiology and Behavior*, 54, 101-109.
- Adamec, R., & Young, B. (2000). Neuroplasticity in specific limbic system circuits may mediate specific kindling induced changes in animal affect - implications for understanding anxiety associated with epilepsy. *Neuroscience & Biobehavioral Reviews*, 24, 705-723.
- American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders*, fifth edition. Arlington, VA: American Psychiatric Association.
- Andrews, G., Stewart, G., Morris-Yates, A., Holt, P., & Henderson, S. (1990). Evidence for a general neurotic syndrome. *British Journal of Psychiatry*, 157, 6-12.
- Barlow, D. H. (2002). *Anxiety and its disorders: The nature and treatment of anxiety and panic*. New York, NY: The Guilford Press.
- Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, 121, 65-94.
- Beauchaine, T. P. (2001). Vagal tone, development, and Gray's motivational theory: Toward an integrated model of autonomic nervous system functioning in psychopathology. *Development and Psychopathology*, 13, 183-214.
- Beauchaine, T. P., Hinshaw, S. P., & Pang, K. L. (2010). Comorbidity of ADHD and

- early-onset conduct disorder: Biological, environmental, and developmental mechanisms. *Clinical Psychology: Science and Practice*, 17, 327-336
- Beauchaine, T. P., Katkin, E. S., Strassberg, Z., & Snarr, J. (2001). Disinhibitory psychopathology in male adolescents: Discriminating conduct disorder from attention-deficit/hyperactivity disorder through concurrent assessment of multiple autonomic states. *Journal of Abnormal Psychology*, 110, 610-624.
- Beauchaine, T. P., & McNulty, T. (2013). Comorbidities and continuities as ontogenic processes: Toward developmental spectrum model of externalizing behavior. *Development and Psychopathology*, 25, 1505-1528.
- Blanchard, D. C., & Blanchard, R. J. (1990a). Effects of ethanol, benzodiazepines, and serotonin compounds on ethopharmacological models of anxiety. In N. McNaughton, & G. Andrews (Eds.), *Anxiety* (pp. 188-200). Dunedin, New Zealand: University of Otago Press.
- Blanchard, R. J., & Blanchard, D.C. (1990b). An ethoexperimental analysis of defense, fear and anxiety. In N. McNaughton & G. Andrews (Eds.), *Anxiety* (pp.124-133). Dunedin, New Zealand: University of Otago Press.
- Blanchard, D. C., Blanchard, R. J., Tom, P., & Rodgers, R. J. (1990c). Diazepam changes risk assessment in an anxiety/defense test battery. *Psychopharmacology (Berl)*, 101, 511-518.
- Broadbear, J. H., Winger, G., & Woods, J. H. (2005). Self-administration of methohexital, midazolam and ethanol: Effects on the pituitary-adrenal axis in rhesus monkeys. *Psychopharmacology*, 178, 83-91.
- Carter, C., Maddock, R., Zoglio, M., Lutrin, C., Jella, S., & Amsterdam, E. (1994). Panic disorder and chest pain: A study of cardiac stress scintigraphy patients. *American Journal of Cardiology*, 74, 296-298.

- Castellanos, F. X., Lee, P. P., Sharp, W., Jeffries, N. O., Greenstein, D. K., Clasen, L. S., ...Rapoport, J. L. (2002). Developmental trajectories of brain volume abnormalities in children and adolescents with ADHD. *Journal of the American Medical Association*, 288, 1740-1748.
- Connor, K. M., Davidson, J. R. T., Sutherland, S., & Weisler, R. (1999). Social phobia: Issues in assessment and management. *Epilepsia*, 40, S60-S65.
- Corr, P. J., & McNaughton, N. (2012). Neuroscience and approach/avoidance personality traits: A two stage (valuation–motivation) approach. *Neuroscience and Biobehavioral Reviews*, 36, 2339–2354.
- Corr, P. J., & McNaughton, N. (2016). Neural Mechanisms of low trait anxiety and risk for externalizing behaviour. In T. P. Beauchaine & S. P. Hinshaw (Eds.), *The Oxford handbook of externalizing spectrum disorders* (pp. 1-22). Oxford Handbooks Online: Oxford University Press.
- Corr, P. J., & Perkins A. M. (2006). The role of theory in the psychophysiology of personality: From Ivan Pavlov to Jeffrey Gray. *International Journal of Psychophysiology*, 62, 367-376.
- Costa, P., & Widiger, T. (1994). (Eds). *Personality disorders and the five-factor model of personality*. Washington, DC: American Psychological Association.
- Costello, E. J., Mustillo, S., Erkanli, A., Keeler, G., & Angold, A. (2003). Prevalence and development of psychiatric disorders in childhood and adolescence. *Archives of General Psychiatry*, 60, 837-844.
- Dantendorfer, K., Amering, M., Baischer, W., Berger, P., Steinberger, K., Windhaber, J., & Katschnig, H. (1995). Is there a pathophysiological and therapeutic link between panic disorder and epilepsy. *Acta Psychiatrica Scandanavica*, 91, 430-432.
- Deakin, J. F. W. (1993). A review of clinical efficacy of 5-HT_{1A} agonists in anxiety and

- depression. *Journal of Psychopharmacology*, 7, 283-289.
- Deakin, J. (1998). The role of serotonin in depression and anxiety. *European Psychiatry*, 13 Suppl 2, 57s-63s.
- Deakin, J. F. W., & Graeff, F. G. (1991). 5-HT and mechanisms of defence. *Journal of Psychopharmacology*, 5, 305-315.
- Eysenck, H. J., & Eysenck, S. B. G. (1964). *Eysenck Personality Inventory*. London: University of London Press.
- Finger, E. C., Marsh, A. A., Blair, K. S., Reid, M. E., Sims, C., Ng, P., Pine, D. S., & Blair, R. J. (2011). Disrupted reinforcement signaling in the orbitofrontal cortex and caudate in youths with conduct disorder or oppositional defiant disorder and a high level of psychopathic traits. *American Journal of Psychiatry*, 168, 152-162.
- Franklin, J.A. (1990). Behavioural treatment for panic disorder. In N. McNaughton & G. Andrews (Eds.), *Anxiety*. (pp. 84-91). Dunedin: University of Otago.
- Friend, P., & Andrews, G. (1990). Agoraphobia without panic attacks. In N. McNaughton & G. Andrews (Eds.), *Anxiety* (pp. 67-73). Dunedin: University of Otago Press.
- Ginzburg, K., Ein-Dor, T., & Solomon, Z. (2010). Comorbidity of posttraumatic stress disorder, anxiety and depression: A 20-year longitudinal study of war veterans. *Journal of Affective Disorders*, 123, 249-257.
- Goisman, R. M., Warshaw, M. G., Peterson, L. G., Rogers, M. P., Cuneo, P., Hunt, M. F., . . . Keller, M. B. (1994). Panic, agoraphobia, and panic disorder with agoraphobia: Data from a multicenter anxiety disorders study. *Journal of Nervous and Mental Diseases*, 182, 72-79.
- Goisman, R. M., Warshaw, M. G., Steketee, G. S., Fierman, E. J., Rogers, M. P., Goldenberg, I., Weinshenker, N. J., Vasile, R. G., & Keller, M. B. (1995). DSM-IV and the

disappearance of agoraphobia without a history of panic disorder: New data on a controversial diagnosis. *American Journal of Psychiatry*, 152, 1438-1443.

Gray, J. A. (1975). *Elements of a two-process theory of learning*. Academic Press, London.

Gray, J. A. (1976). The behavioural inhibition system: A possible substrate for anxiety. In M. P. Feldman & A. M. Broadhurst (Eds.), *Theoretical and experimental bases of behaviour modification* (pp. 3–41). London: Wiley.

Gray, J. A. (1977). Drug effects on fear and frustration: Possible limbic site of action of minor tranquilizers. In L. L. Iversen, S. D. Iversen & S. H. Snyder, (Eds.), *Handbook of psychopharmacology. Vol 8. Drugs, neurotransmitters and behavior* (pp. 433-529). New York: Plenum Press.

Gray, J. A. (1982). *The neuropsychology of anxiety: An enquiry in to the functions of the septo-hippocampal system*. Oxford: Oxford University Press.

Gray, J. A., & McNaughton, N. (2000). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system* (2nd ed.). Oxford, UK: Oxford University Press.

Gresham, F. M., Lane, K. L., & Lambros, K. M. (2000). Comorbidity of conduct problems and ADHD: Identification of fledgling psychopaths. *Journal of Emotional & Behavioral Disorders*, 8, 83-93.

Griffith, J. W., Zinbarg, R. E., Craske, M. G., Mineka, S., Rose, R. D., Waters, A. M., & Sutton, J. M. (2010). Neuroticism as a common dimension in the internalizing disorders. *Psychological Medicine*, 40, 1125-1136.

Gurguis, G. N. M., Antai-Otong, D., Vo, S. P., Blakeley, J. E., Orsulak, P. J., Petty, F., & Rush, A. J. (1999). Adrenergic receptor function in panic disorder - I. Platelet receptors: G_i protein coupling, effects of imipramine, and relationship to treatment outcome. *Neuropsychopharmacology*, 20, 162-176.

- Haefely, W. (1992). Ligands of the GABA_A receptor-associated benzodiazepine receptor. *Neuroscience Facts*, 3, 69-70.
- Harkness, A. R., & Lilienfeld, S. O. (1997). Individual differences science for treatment planning: Personality traits. *Psychological Assessment*, 9, 349-360.
- Harkness, K. L., Monroe, S. M., Simons, A. D., & Thase, M. (1999). The generation of life events in recurrent and non-recurrent depression. *Psychological Medicine*, 29, 135-144.
- Holt, P. (1990). Panic disorder: Some historical trends. In N. McNaughton & G. Andrews (Eds.), *Anxiety*. (pp. 54-65). Dunedin: University of Otago Press.
- Insel, T. (2013). Transforming Diagnosis. Retrieved February 14, 2016, from <http://www.nimh.nih.gov/about/director/2013/transforming-diagnosis.shtml>
- Insel, T., Cuthbert, B., Garvey, M. G., Heinssen, R., Pine, D. S., Quinn, K., . . . Wang, P. (2010). Research Domain Criteria (RDoC): toward a new classification framework for research on mental disorders. *American Journal of Psychiatry*, 167, 748-751.
- Johnson, P. L., Truitt, W., Fitz, S. D., Minick, P. E., Dietrich, A., Sanghani, S., . . . Shekhar, A. (2010). A key role for orexin in panic anxiety. *Nature Medicine*, 16, 111-115.
- Jonas, E., McGregor, I., Klackl, J., Agroskin, D., Fritsche, I., Holbrook, C., . . . Quirin, M. (2014). Threat and defense: From anxiety to approach. In J. M. Olson & M. P. Zanna (Eds.), *Advances in Experimental Social Psychology* (Vol. 49, pp. 219-286). Burlington: Academic Press.
- Joyce, P. R., & Oakley-Browne, M. A. (1990). The epidemiology of panic and agoraphobia. In N. McNaughton & G. Andrews (Eds.), *Anxiety* (pp. 32-38). Dunedin: University of Otago Press.
- Kara, S., Yazici, K. M., Güleç, C., & Ünsal, I. (2000). Mixed anxiety-depressive disorder and

major depressive disorder: Comparison of the severity of illness and biological variables. *Psychiatry Research*, 94, 59-66.

Kendler, K. S., Neale, M. C., Kessler, R. C., Heath, A. C., & Eaves, L. J. (1992a).

Generalized anxiety disorder in women: A population-based twin study. *Archives of General Psychiatry*, 49, 267-272.

Kendler, K. S., Neale, M. C., Kessler, R. C., Heath, A. C., & Eaves, L. J. (1992b). The

genetic epidemiology of phobias in women: The interrelationship of agoraphobia, social phobia, situational phobia and simple phobia. *Archives of General Psychiatry*, 49, 273-281.

Kendler, K. S., Neale, M. C., Kessler, R. C., Heath, A. C., & Eaves, L. J. (1992c). Major depression and generalized anxiety disorder. Same genes, (partly) different environments? *Archives of General Psychiatry*, 49, 716-722.

Kendler, K. S., Prescott, C. A., Myers, J., & Neale, M. C. (2003). The structure of genetic and environmental risk factors for common psychiatric and substance use disorders in men and women. *Archives of General Psychiatry*, 60, 929-37.

Kendler, K. S., Thornton, L. M., & Gardner, C. O. (2000). Stressful life events and previous episodes in the etiology of major depression in women: An evaluation of the "kindling" hypothesis. *American Journal of Psychiatry*, 157, 1243-1251.

Kessler, R. C. (1997). The effects of stressful life events on depression. *Annual Review of Psychology*, 48, 191-214.

Klein, D. F. (1995). Recognising panic disorder. *European Journal of Psychiatry*, 10 Suppl. 2, 61S-63S.

Krueger, R. F. (1999). The structure of common mental disorders. *Archives General Psychiatry*, 56, 921-926.

Krueger, R. F., & Markon, K. E. (2006). Reinterpreting comorbidity: A model-based

- approach to understanding and classifying psychopathology. *Annual Review of Clinical Psychology*, 2, 111-133.
- Krueger, R. F., & Tackett, J. L. (2003). Personality and psychopathology: Working toward the bigger picture. *Journal of Personality Disorders*, 17, 109-128.
- Kostowski, W., & Bienkowski, P. (1999). Discriminative stimulus effects of ethanol: Neuropharmacological characterization. *Alcohol*, 17, 63-80.
- Langs, G., Quehenberger, F., Fabisch, K., Klug, G., Fabisch, H., & Zapotoczky, H. G. (2000). The development of agoraphobia in panic disorder: A predictable process? *Journal of Affective Disorders*, 58, 43-50.
- LeDoux, J. E. (1994). Emotion, memory and the brain. *Scientific American*, 270, 50-59.
- LeDoux, J. E. (1996). *The emotional brain*. New York, NY: Simon and Schuster.
- Marks, I.M. (1988). The syndromes of anxious avoidance: Classification of phobic and obsessive-compulsive phenomena. In R. Noyes, Jr., M. Roth & G.D. Burrows (Eds.), *Handbook of Anxiety, Vol 2: Classification, etiological factors and associated disturbances*. (pp. 109-146). Elsevier Science Publishers B.V.
- Matthys, W., van Goozen, S. H., de Vries, H., Cohen-Kettenis, P. T., & van Engeland, H. (1998). The dominance of behavioural activation over behavioural inhibition in conduct disorder boys with or without attention deficit hyperactivity disorder. *Journal of Child Psychology and Psychiatry*, 39, 643-651.
- Matthys, W., Vanderschuren, L. J., & Schutter, D. J. (2013). The neurobiology of oppositional defiant disorder and conduct disorder: Altered functioning in three mental domains. *Development & Psychopathology*, 25, 193-207.
- McNaughton, N. (1989). *Biology and emotion*. Cambridge: Cambridge University Press.

- McNaughton, N. (2002). Aminergic transmitter systems. In H. D'haenen, J.A. Den Boer, H. Westenberg & P. Willner (Eds.), *Textbook of biological psychiatry*. (pp. 895-914). Chichester: John Wiley & Sons.
- McNaughton, N. (2005). *Fears and anxieties: A map of your dark side* (Vol. No. 2). Dunedin: University of Otago.
- McNaughton, N. (2008). The neurobiology of anxiety: Potential for comorbidity of anxiety and substance use disorders. In S. H. Stewart & P. J. Conrod (Eds.), *Anxiety and substance use disorders: The vicious cycle of comorbidity* (pp. 19-33). New York, NY: Springer Science+Business Media, Inc.
- McNaughton, N. (2014). Development of a theoretically-derived human anxiety syndrome biomarker. *Translational Neuroscience*, 5, 137-146.
- McNaughton, N., & Corr, P. J. (2004). A two-dimensional neuropsychology of defense: Fear/anxiety and defensive distance. *Neuroscience and Biobehavioral Reviews*, 28, 285-305.
- McNaughton, N., & Corr, P. J., (2008). RST and personality. In P. J. Corr, (Ed.), *The reinforcement theory of personality* (pp. 155-188). Cambridge, UK: Cambridge University Press.
- McNaughton, N., DeYoung, C. G., & Corr, P. J. (in press). Approach/avoidance. In J. R. Absher & J. Cloutier (Eds.), *Neuroimaging personality, social cognition and character: Traits and mental states in the brain*. London: Elsevier.
- McNaughton, N., Kocsis, B., & Hajós, M. (2007). Elicited hippocampal theta rhythm: A screen for anxiolytic and pro-cognitive drugs through changes in hippocampal function? *Behavioural Pharmacology*, 18, 329-346.

- McNaughton, N., Swart, C., Neo, P. S. H., Bates, V., & Glue, P. (2013). Anti-anxiety drugs reduce conflict-specific “theta” – a possible human anxiety-specific biomarker. *Journal of Affective Disorders*, 148, 104-111.
- Meijer, O. C., & de Kloet, E. R. (1994). Corticosterone suppresses the expression of 5-HT1A receptor mRNA in rat dentate gyrus. *European Journal of Pharmacology: Molecular Pharmacology*, 266, 255-261.
- Meijer, O. C., Van Oosten, R. V., & de Kloet, E. R. (1997). Elevated basal trough levels of corticosterone suppress hippocampal 5-hydroxytryptamine 1A receptor expression in adrenalectomized rats: Implication for the pathogenesis of depression. *Neuroscience*, 80, 419-426.
- Middleton, H.C., Ashby, M., & Robbins, T.W. (1994). Reduced plasma noradrenaline and abnormal heart rate variability in resting panic disorder patients. *Biological Psychiatry*, 36, 847-849.
- Nesse, R. M. (1999). Proximate and evolutionary studies of anxiety, stress and depression: Synergy at the interface. *Neuroscience and Biobehavioral Reviews*, 23, 895-903.
- Nesse, R. M. (2000). Is depression an adaptation? *Archives of General Psychiatry*, 57, 14-20.
- Neo, P. S. H., Thurlow, J., & McNaughton, N. (2011). Stopping, goal-conflict, trait anxiety and frontal rhythmic power in the stop-signal task. *Cognitive, Affective, and Behavioral Neuroscience*, 11, 485-493.
- Noyes, R., Jr., Burrows, G. D., Reich, J. H., Judd, F. K., Garvey, M. J., Norman, T. R., Cook, B. L., & Marriott, P. (1996). Diazepam versus alprazolam for the treatment of panic disorder. *Journal of Clinical Psychiatry*, 57, 349-355.
- Pariante, C. M., & Miller, A. H. (2001). Glucocorticoid receptors in major depression: Relevance to pathophysiology and treatment. *Biological Psychiatry*, 49, 391-404.

- Pariante, C. M. (2003). Depression, stress and the adrenal axis. *Neuro-endocrinology Briefings* 19, <http://www.neuroendo.org.uk/Topics/Stress/19Depression.aspx>
- Pliszka, S. R. (1998). Comorbidity of ADHD: An overview. *Journal of Clinical Psychiatry*, 59, 50-58.
- Quay, H. C. (1997). Inhibition and attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology*, 25, 7-13.
- Rapoport, J. L. (1989). The biology of obsessions and compulsions. *Scientific American*, 260, 63-69.
- Randall, P. K., Bremner, J. D., Krystal, J. H., Nagy, L. M., Heninger, G. R., Nicolaou, A. L., & Charney, D. S. (1995). Effects of the benzodiazepine antagonist flumazenil in PTSD. *Biological Psychiatry*, 38, 319-324.
- Rapoport, J. L. (1989). The biology of obsessions and compulsions. *Scientific American*, 260, 63-69.
- Richardson, D. K., Reynolds, S. M., Cooper, S. J., & Berridge, K. C. (2005). Endogenous opioids are necessary for benzodiazepine palatability enhancement: Naltrexone blocks diazepam-induced increase of sucrose-'liking'. *Pharmacology, Biochemistry and Behavior*, 81, 657-663.
- Rickels, K., & Rynn, M. (2002). Pharmacotherapy of generalized anxiety disorder. *Journal of Clinical Psychiatry*, 63, 9-16.
- Roy-Byrne, P. P., Stang, P., Wittchen, H. U., Ustun, B., Walters, E. E., & Kessler, R. C. (2000). Lifetime panic-depression comorbidity in the National Comorbidity Survey. Association with symptoms, impairment, course and help-seeking. *British Journal of Psychiatry*, 176, 229-235.
- Sandford, J. J., Argyropoulos, S. V., & Nutt, D. J. (2000). The psychobiology of

anxiolytic drugs: Part 1: Basic neurobiology. *Pharmacology and Therapeutics*, 88, 197-212.

Sapolsky, R. M. (2004). *Why zebras don't get ulcers* (3rd ed.). New York, NY: Henry Holt and Company.

Sapolsky, R. M., Krey, L. C., & McEwen, B. S. (1984). Glucocorticoid-sensitive hippocampal neurons are involved in terminating the adrenocortical stress response. *Proceedings of the National Academy of Sciences of the United States of America*, 81, 6174-6177.

Sauder, C., Beauchaine, T. P., Gatzke-Kopp, L. M., Shannon, K. E., & Aylward, E. (2012). Neuroanatomical correlates of heterotypic comorbidity in externalizing male adolescents. *Journal of Clinical Child and Adolescent Psychology*, 41, 346-352.

Schmidt, M. V., Abraham, W. C., Maroun, M., Stork, O., & Richter-Levin, G. (2013). Stress-induced metaplasticity: From synapses to behavior. *Neuroscience*, 250, 112-120.

Seidman, L. J., Valera, E. M., & Makris, N. (2005). Structural brain imaging of attention-deficit/hyperactivity disorder. *Biological Psychiatry*, 57, 1263-1272.

Shadli, S. M., McIntosh, J., Glue, P., & McNaughton, N. (2015). An improved human anxiety process biomarker: Characterisation of frequency band, personality, and pharmacology. *Translational Psychiatry*, 5, e699.

Shear, M. K., & Maser, J. D. (1994). Standardized assessment for panic disorder research: A conference report. *Archives of General Psychiatry*, 51, 346-354.

Shibley, M. T., Ennis, M., Rizvi, T. A., & Behbehani, M. M. (1991). Topographical specificity of forebrain inputs to the midbrain periaqueductal gray: Evidence for discrete longitudinally organized input columns. In A. Depaulis & R. Bandler (eds.), *The midbrain periaqueductal gray matter*. (pp. 417-448). New York, NY: Plenum Press.

Smith, D. J., Escott-Price, V., Davies, G., Bailey, M. E. S., Colodro, L. C., Ward, J.,...

O'Donovan, M. (2015). Genome-wide analysis of over 106,000 individuals identifies 9 neuroticism-associated loci. *BioRxiv*.

<http://biorxiv.org/content/biorxiv/early/2015/11/25/032417.full.pdf>

Sonuga-Barke, E. J. S. (2005). Causal models of attention-deficit/hyperactivity disorder:

From common simple deficits to multiple developmental pathways. *Biological Psychiatry*, 57, 1231-1238.

Sowell, E. R., Toga, A. W., & Asarnow, R. (2000). Brain abnormalities observed in childhood-onset schizophrenia: A review of the structural magnetic resonance imaging literature. *Mental Retardation and Developmental Disabilities Research Reviews*, 6, 180-185.

Spencer, T., Biederman, J., & Wilens, T. (1999). Attention-deficit/hyperactivity disorder and comorbidity. *Pediatric Clinics of North America*, 46, 915-927.

Stein, D. J., Hollander, E., Mullen, L. S., DeCaria, C. M., & Liebowitz, M. R. (1992). Comparison of clomipramine, alprazolam and placebo in the treatment of obsessive-compulsive disorder. *Human Psychopharmacology*, 7, 389-395.

Stein, D. J., Vythilingum, B., & Seedat, S. (2004). Pharmacotherapy of phobias. In M. Maj (ed.), *Evidence and experience in psychiatry*. Vol. 7. phobias. Chichester: John Wiley & Sons, Ltd.

Stevens, J. C., & Pollack, M. H. (2005). Benzodiazepines in clinical practice: Consideration of their long-term use and alternative agents. *Journal of Clinical Psychiatry*, 66, 21-27.

Stevenson, M., & McNaughton, N. (2013). A comparison of phenylketonuria with attention deficit hyperactivity disorder: Do markedly different aetiologies deliver common phenotypes? *Brain Research Bulletin*, 99, 63-83.

- Stewart, S. H., & Conrod, P. J. (eds.) (2008). *Anxiety and substance use disorders: The vicious cycle of comorbidity*. New York: Springer Science+Business Media, Inc.
- Swoboda, K. J., & Jenike, M. A. (1995). Frontal abnormalities in a patient with obsessive-compulsive disorder: The role of structural lesions in obsessive-compulsive behavior. *Neurology*, 45, 2130-2134.
- Tackett, J. L. (2006). Evaluating models of the personality-psychopathology relationship in children and adolescents. *Clinical Psychology Review*, 26, 584-599.
- Takano, A., Arakawa, R., Hayashi, M., Takahashi, H., Ito, H., & Suhara, T. (2007). Relationship between neuroticism personality trait and serotonin transporter binding. *Biological psychiatry*, 62, 588-592.
- Volkow, N. D., Wang, G-J., Newcorn, J., Fowler, J. S., Telang, F., Solanto, M. V., . . . Pradhan, K. (2007a). Brain dopamine transporter levels in treatment and drug naive adults with ADHD. *NeuroImage*, 34, 1182-1190.
- Volkow, N. D., Wang, G-J., Newcorn, J., Telang, F., Solanto, M. V., Fowler, J. S., . . . Swanson, J. M. (2007b). Depressed dopamine activity in caudate and preliminary evidence of limbic involvement in adults with attention-deficit/hyperactivity disorder. *Archives of General Psychiatry*, 64, 932-940.
- Watson, D., Clark, L. A., & Harkness, A. R. (1994). Structure of personality and their relevance to psychopathology. *Journal of Abnormal Psychology*, 103, 18-31.
- Westenberg, H. G. M. (1999). Facing the challenge of social anxiety disorder. *European Neuropsychopharmacology*, 9, S93-S99
- Widiger, T. A., & Trull, T. J. (1992). Personality and psychopathology: An application of the five-factor model. *Journal of Personality*, 60, 363-393.
- Widiger, T. A., Verheul, R., & van den Brink, W. (1999). Personality and psychopathology. In L. A. Pervin & O. P. John (eds.), *Handbook of personality: Theory and research*

(pp. 347-366). New York: Guilford Press.

World Health Organization (2010). International statistical classification of diseases and related health problems (10th Revision). Available from:

<http://apps.who.int/classifications/icd10/browse/2010/en>

Table 1: Relative effectiveness of drugs in treating different aspects of neurotic disorder (Gray & McNaughton, 2000; McNaughton, 2002; Stein, Vythilingum, & Seedat, 2004; Stevens & Pollack, 2005; Westenberg, 1999; Stein, Hollander, Mullen, DeCaria, & Liebowitz, 1992; Rickels & Rynn, 2002). Simple phobia is included for comparison as a fear/anxiety-related disorder that is not linked to neurotic personality. Abuse potential is included to emphasise the fact that antianxiety efficacy, per se, is not linked to abuse. Different patterns of response in the table can be attributed to the variation in receptor occupancy or interaction by particular drugs in different parts of the brain. No drug or drug class produces a specific limited effect (despite the omission of side effects from the table) but the variation in relative effectiveness across the different aspects of neurotic disorder argues for distinct neural control of each. Table and text from McNaughton (2008).

Symbols: 0, no effect; – reduction; —, extensive reduction; +, increase; (), small or discrepant effects.

	<u>'antianxiety'</u>		<u>'antidepressant'</u>				
	BDZ₁	BUS	BDZ₂	IMI	CMI	MAOI	SSRI
<i>Simple Phobia</i>	0	?	?	0	?	(-)	(-)
Generalized Anxiety	–	–	–	–	–	?	–
Social Anxiety	–	(-)	(-)	0	(-)	–	–
Unipolar Depression	0	–	–	–	–	–	–
Atypical Depression	0	?	?	(-)	?	–	?
Panic Attacks	0	0	–	–	—	–	–
Obsessions/Compulsions	0	(-)	0	(-)	—	(-)	—
<i>Abuse potential</i>	+	0	+	0	0	0	0

BDZ₁ early benzodiazepines, e.g., chlordiazepoxide (Librium) and diazepam (Valium) administered at typical antianxiety doses. Other sedative antianxiety drugs (barbiturates, meprobamate) have similar effects.

BDZ₂ later high potency benzodiazepines, e.g. alprazolam (Xanax). The antipanic effect is achieved at higher doses and this has also been reported with equivalent high doses for BDZ₁ (Noyes Jr. et al. 1996).

BUS Buspirone (BuSpar) and related 5HT_{1A} agonists.

CMI Clomipramine (Anafranil).

IMI imipramine (Tofranil) and other tricyclic antidepressants, but excluding clomipramine

MAOI Monoamine Oxidase Inhibitors, e.g. phenelzine (Nardil).

SSRI Selective Serotonin Reuptake Inhibitors, e.g. fluoxetine (Prozac).

Table 2. A tentative summary of relations between motivational phenotype and neural source. Note that, with the exception of the amygdala and hippocampus, affected subcortical areas have been omitted, as have the posterior cingulate and the cerebellum. Subtypes of both ADHD and psychopathy (PSYC) have been assigned the same structural values (gray areas) because there is insufficient data to delineate their neural differences. Involvement of an area is indicated for major dysfunction (--), dysfunction (-), minor dysfunction or disconnection (*), no reported involvement (0), and hyperactivity (+). ADHD-IA, ADHD inattentive subtype; ADHD-CT, ADHD combined subtype; PKU, phenylketonuria; PSYC-1, primary psychopathy; PSYC-2, secondary psychopathy; ACC, anterior cingulate cortex; BAS, behavioral approach system; BIS, behavioral inhibition system; DLPFC, dorsolateral prefrontal cortex; FFFS, fight-flight-freeze system; MIFG, medial or inferior frontal gyrus; OFC, orbital frontal cortex; STG, superior temporal gyrus. Table and legend taken from Corr & McNaughton (2016).

Diagnosis		ADHD-IA	ADHD-CT	PKU	CD	PSYC-1	PSYC-2
Phenotype	BAS	0	+	as ADHD	+	0	+
	FFFS	0	+	as ADHD	0	-	0
	BIS	-	-	as ADHD	*	--	--
BAS Structures	OFC	0	0	0	-	-	-
FFFS structures	ACC	-	-	-	--	--	--
	amygdala	0	0	0	-	--	--
BIS structures	DLPFC	-	-	-	*	-	-
	Temporal	-	-	-	-	-	-
	STG	0	0	0	-	-	-
	hippocampus	*	*	-	-	-	-
Other structures	White matter	-	-	-	0	+	+
	insula	0	0	0	-	-	-
	MIFG	-	-	-	0	-	-
	Parietal	-	-	-	--	0	0

Figure 1: The 2D defence system (direction x distance), updated from McNaughton and Corr (2004). Brain area in capitals, normal function lower case, nominal disorder (closest current diagnosis) in italics. Note the reciprocal (excitatory and inhibitory) connections between levels and systems. The stippled oval represents areas that show RSA (see text), which is modulated by 5HT_{1A} and BDZ receptor agonists. Dashed lines = 5HT/NA modulation. 5HT = 5-hydroxytryptamine /serotonin; 5HT_{1A} = 5HT_{1A} receptors; BDZ = benzodiazepine receptors; NA = noradrenaline; OCD = obsessive compulsive disorder; PAG = periaqueductal grey; PFC = (pre) frontal cortex; RSA = rhythmical slow activity. Figure and legend from McNaughton (2014).

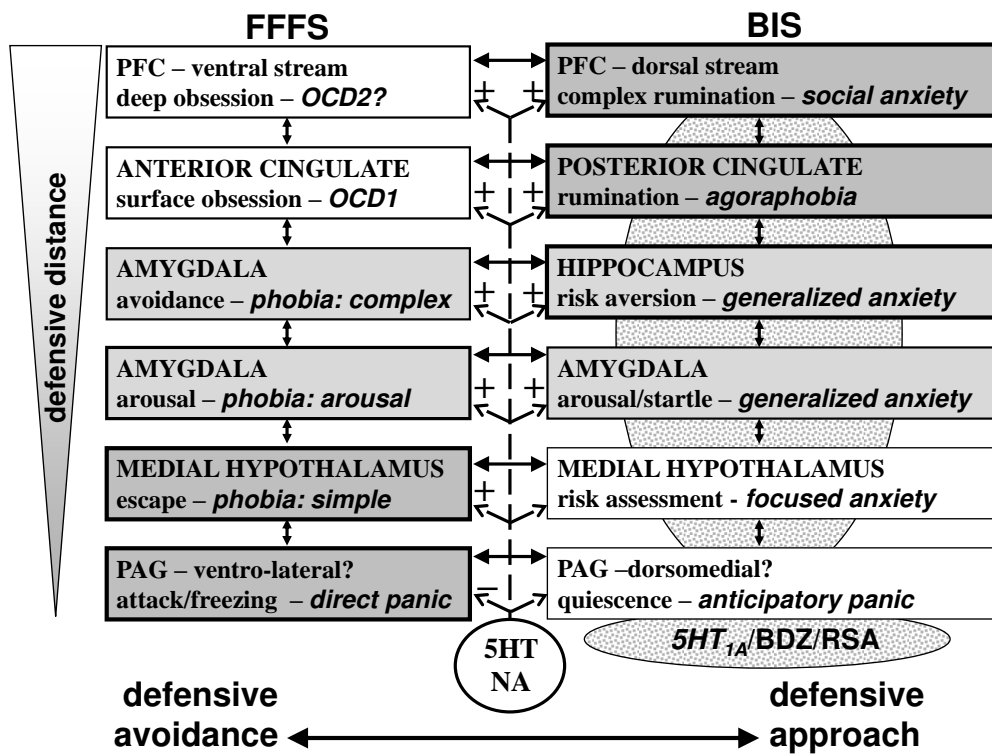


Figure 2: Panic as a syndrome with symptomatic comorbid anxiety. Lower levels of the Flight, Fight Freeze (FFFS) system (bottom left) produce spontaneous activity (or hyper-reactivity) of the periaqueductal gray (PAG) generating pathological panic attacks. Active avoidance and arousal are increased via existing ascending neural connections of the FFFS (solid outline filled grey arrows, width indicates degree of activation, simple black double headed arrows show available connections). Coincidence of the occurrence of the panic attack with distinctive or threatening environmental circumstances can result – particularly in neurotic introverts – in the learning of anticipatory anxiety (dashed outline filled grey arrow), mediated by the hippocampus and amygdala, and the normal spread of neural activity through the Behavioural Inhibition System (BIS). Thus abnormal panic produces fear and anxiety that are normal given the level of perceived threat generated by the panic. Note that this implies that a treatment such as cognitive behavioural therapy could modify the anxiety, and considerably reduce the incidence and increase the tolerability of panic attacks, while leaving a primary, neurological, incidence of panic intact. Figure modified and updated from McNaughton (2005).

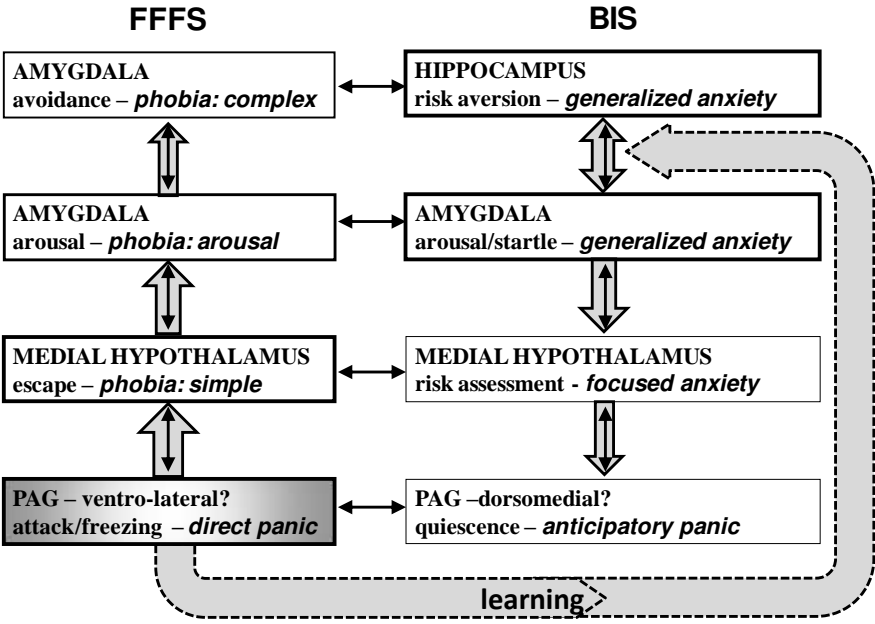


Figure 3: Symptomatic comorbid panic with syndromal anxiety disorder. Abbreviations and symbols as in Figure 2. Upper levels of the BIS (top right), show abnormal spontaneous activity (or hyper-reactivity) of the hippocampus, amygdala, or both, generating pathological generalised anxiety. Other aspects of anxiety are increased via existing descending neural connections (solid outline filled grey arrows) of the BIS (and also ascending connections, not shown). Increased peripheral arousal, e.g. levels of adrenaline, activates the PAG (dashed outline filled grey arrow) and generates panic attacks – particularly in panic prone individuals; and also produces a normal spread of neural activity through the FFFS. Thus abnormal anxiety produces panic and fear that are normal given the level of perceived anticipatory threat generated by the pathological anxiety. Figure modified and updated from McNaughton (2005).

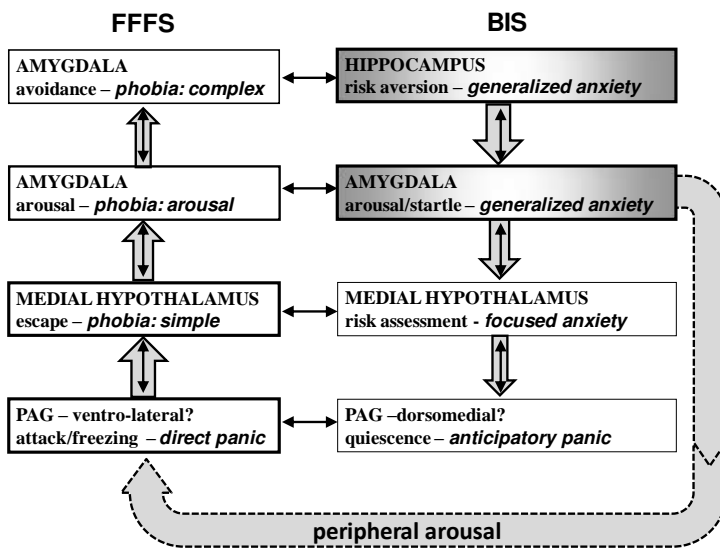


Figure 4: Syndromal comorbidity and positive feedback between anxiety and panic. Abbreviations and symbols as in Figure 2. Genetic and or environmental predisposing factors (particularly those linked to neuroticism) can result in pathological activity in both the PAG, generating panic, and in the hippocampus and amygdala, generating anxiety. These can concurrently reinforce each other through the state feedback mechanisms detailed in Figure 2 and 3 (dashed outline filled grey double headed arrow) – resulting in positive feedback. Repetitive or chronic activation of either or both if the FFFS and BIS (and particularly the resultant release of stress hormones, see Figure 5) can result in a progressive sensitisation of the other system (‘kindling’) and this can also generate longer-term trait positive feedback (circular arrows). Not only does this imply that symptomatic comorbidity can result in trait comorbidity but it implies that therapeutic intervention at any one of the main links in these positive feedback circuits can produce some improvement. Figure modified and updated from McNaughton (2005).

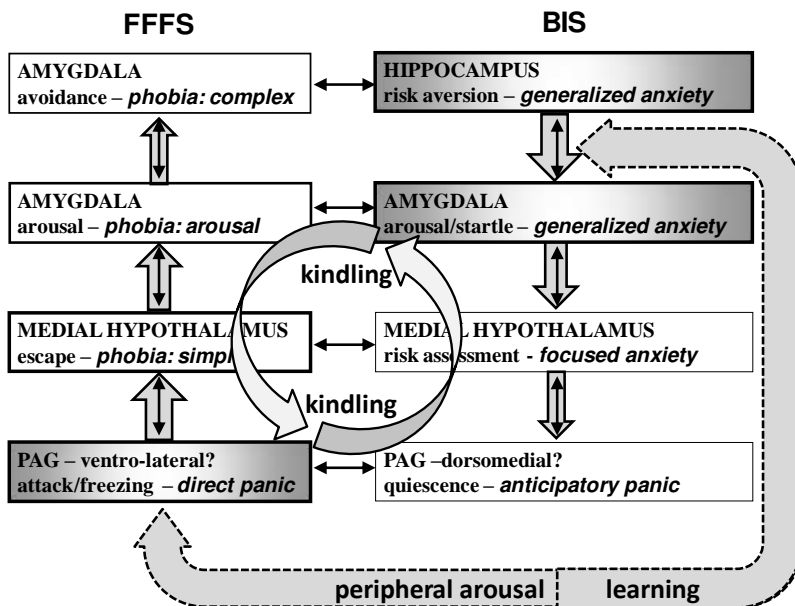


Figure 5: Pathways for comorbidity beyond the FFFS and BIS. A selection of sources of potential interaction between the FFFS/BIS – primarily the amygdala (AMYG) and hippocampus (HIP) and other systems are shown. Solid lines represent net excitatory connections, dashed lines represent net inhibitory connections. Of most immediate relevance to the long term trait changes of Figure 4 are the interactions with the stress system. Anxiety is a stressor, releasing corticosterone/cortisol (CORT) via activation of the paraventricular nucleus (PVN), release of corticotrophin releasing factor (CRF) and adrenocorticotrophic hormone (ACTH). Importantly, negative feedback control of the release of CORT is achieved by its action on HIP and its connection with PVN. High levels of CORT can damage the hippocampus, reduce this feedback inhibition, and so result in progressive increases in CORT. Continuously high CORT can then result in depression (see text) as well as other problems. CORT will also reduce the effects of endogenous anxiolytic action mediated by 5HT_{1A} and GABA_A (particular benzodiazepine site) receptors. At least in the short term, 5HT_{1A} activation release CORT but benzodiazepine activation inhibits it. (Both of these effects show tolerance.) The GABA_A system is particularly important for comorbidity as it not only reduces anxiety (without tolerance) but also produces muscle relaxation, euphoria, and rewarding effects via endogenous opiate systems (OPI) that cause the release of dopamine (DA). These effects show tolerance and lead to addiction. Thus use of anxiolytics can lead to substance use disorder (SUD) and, via tolerance and withdrawal, SUD can result in anxiety disorder (see text).

