Capturing the Dynamics of a Psychiatric Illness: A System Dynamics Translation of the Contemporary Biological and Psychological Conceptualization of Panic Disorder (PD)

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The present study undertakes a partial system dynamics (SD) translation of the contemporary biological and psychological conceptualizations of panic disorder (PD). It makes explicit the dynamic processes implicit in the narrative presentations in the literature. It serves as a facilitator for the discussion about PD for it provides an easy-to-understand and illustrative language for commoners to understand, and researchers of different fields to critically examine, the biological, psychological, social and cognitive aspects of PD.

Keywords: system dynamics, biological, psychological, panic disorder (PD), dynamic processes, facilitator, social, cognitive

1. Introduction

This section defines panic disorder (PD), discusses its prevalence and significance and the types of panic attacks associated with PD. Then it outlines the context of the present study and, finally, highlights the *dynamic* problem and the research goal.

1.1 What is *Panic Disorder*?

Panic disorder is classified as a form of anxiety disorder: a broad category of psychological disorder in which anxiety is a prominent feature (Rachman and De Silva 2004, 7; Berman 2005, 6). According to Rachman and De Silva (2004, 5-6), in the widely used and comprehensive classification of psychological disorders set out by the American Psychiatric Association (APA), the defining features of PD are:

1. A person has repeatedly experienced unexpected panic attacks: the discrete episode of intense sensation of fear or discomfort.

2. At least, one of the panic attacks was followed by persistent worry, lasting a month or more, of having another panic attack or by a significant change in the lifestyle or behaviour related to the panic attacks.

3. During the attacks, at least four of the following sensations develop abruptly and reach a peak within 10 minutes: shortness of breath or smothering, dizziness or faintness, pounding heart (palpitations), trembling or shaking, feeling of choking, sweating, stomach distress or nausea, feeling that one's surroundings or oneself are not quite real (derealization), feeling of being detached from oneself (depersonalization), feeling of numbness or tingling (paresthesias), hot flushes or chills, chest pain or discomfort, fear of dying and fear of losing control or going crazy.

4. These attacks are not directly caused by a drug or a general medical condition.

Most panic attacks last for less than 30 minutes (American Psychological Association 2005). In PD, panic attacks may occur as often as daily or several times per week (Rachman and De Silva 2004, 6) depending upon the severity of the disorder. PD patients often have these attacks with an increasing frequency (Wehrenberg and Prinz 2007, 55).

1.2 Prevalence and Significance:

PD is largely disabling and associated with functional morbidity and reduced quality of life. It is

costly for individuals as well as society as evident from the increased use of health-care, absenteeism and reduced productivity. (Roy-Byrne, Craske and Stein 2006, 1023) Approximately 15 out of 1000 people in the general population develop PD at some point in their lives. The size of the problem is nearly the same throughout the world and no ethnic differences have been found. (Rachman and De Silva 2004, 23)

According to the National Institute of Mental Health (2008), PD affects about 6 million American adults and is twice as common in women than men. PD is rarely diagnosed or uncommon in children (Wehrenberg and Prinz 2007, 53; Rachman and De Silva 2004, 26) but begins to strike more frequently in late adolescence or early adulthood (National Institute of Mental Health, 2008). According to Bouton, Mineka and Barlow (2001), PD is more likely to strike the individuals between their mid-teens and 40 years of age. The comorbidity of PD with other anxiety and depressive disorders is so high that as many as 55% of PD patients also have one or more of such disorders (Barlow and Durand 2005).

1.3 Types of Panic Attacks associated with PD:

All panic attacks are not necessarily indicative of PD. In PD, the panicky sensations are unprovoked, unexplained and often occur from an unforeseen source, whereas in a panic attack (without the presence of PD), one is keenly aware of the source of one's fearful sensations, for example, heights, snakes or spiders (Roy-Byrne, Craske and Stein 2006, 1023). In addition, to be diagnosed with PD, after a panic attack, the patient must worry for, at least, one month either about having another attack, or that the attack is symptomatic of a larger problem, or make some noteworthy changes in her behaviour, such as avoiding certain people or places (Whalen and McKinney 2007, 12-3). PD with avoidance of certain people or places gives rise to a special classification of the ailment called "PD with agoraphobia". Barlow and Durand, as per DSMV-IV[1], describe three basic types of panic attacks: situationally bound, unexpected and situationally predisposed[2]. The unexpected and situationally predisposed attacks commonly relate to PD whereas situationally bound attacks are common in specific or social phobia (Barlow and Durand 2002, 113-15).

1.4 Context of the Present Study:

The present study focuses on the panic attacks which are indicative of PD without agoraphobia. There are a number of theories which explain why PD occurs, including psychological and biological ones (Salkovskis 1998). The psychological theories relate PD to the environment and personality traits (Psyber Square 1999), for instance, a history of childhood separation anxiety (LeDoux 1998, 258). Whereas, the biological theories relate it to the human anatomy and brain chemistry. Most practising psychotherapists, however, view PD as an outcome of both, the human anatomy and psychology (Psyber Square 1999).

The present study considers the biological as well as psychological and cognitive aspects of PD. It

1 *"The DSMV-IV* (IV depicts edition) *is a reference book containing the classification of mental disorders used by most psychiatrists, psychologists, social workers and other mental health professionals."* (Berman 2005, 2)

2 *"If you know you are afraid of high places or of driving over long bridges, you might have a panic attack in these situations but not anywhere else; this is a situationally bound (cued) panic attack. By contrast, you might experience unexpected (uncued) panic attacks. The third type of panic attack, the situationally predisposed, is in between. You are more likely, but not inevitably, to have an attack where you have had one before, for example, in a large mall. If you don't know whether it will happen today, and it does, the attack is situationally predisposed."* (Barlow and Durand 2002, 114)

is centred around the malfunctioning s*tress response system* of the brain and the "conditioning[3] theory". The former is modelled as the main structure responsible for PD and then the biological, psychological and cognitive causes of this malfunctioning are addressed as proposed by most of the modern researchers.

1.5 Dynamic Problem:

The dynamic problem under consideration is the presence of abrupt (usually peaking within a minute), unreasonable and unnecessary discrete episodes of intense feeling of fear or anxiety, in an individual, which take a while until they drop back to their initial level (Rachman and De Silva 2004, 1, 5; Wehrenberg and Prinz 2007, 59-61; Berman 2005, 6). Fig. 1 illustrates the pattern of these fear episodes (or panic attacks) over time. On the Y-axis, 0 to 5 is supposed to be the normal fear level (no significant fear, anxiety or discomfort present); 5 to 10 high and above that, so extreme that it may be labelled as "panic". In PD, the panic attacks may occur as often as daily or several times per week (Rachman and De Silva 2004, 6). These attacks usually occur with an increasing frequency (Wehrenberg and Prinz 2007, 55). If PD is left untreated, the panic attacks may become chronic (Rachman and De Silva 2004, 27) and last for years (Federal Citizen Information Center, Pueblo, Colorado).

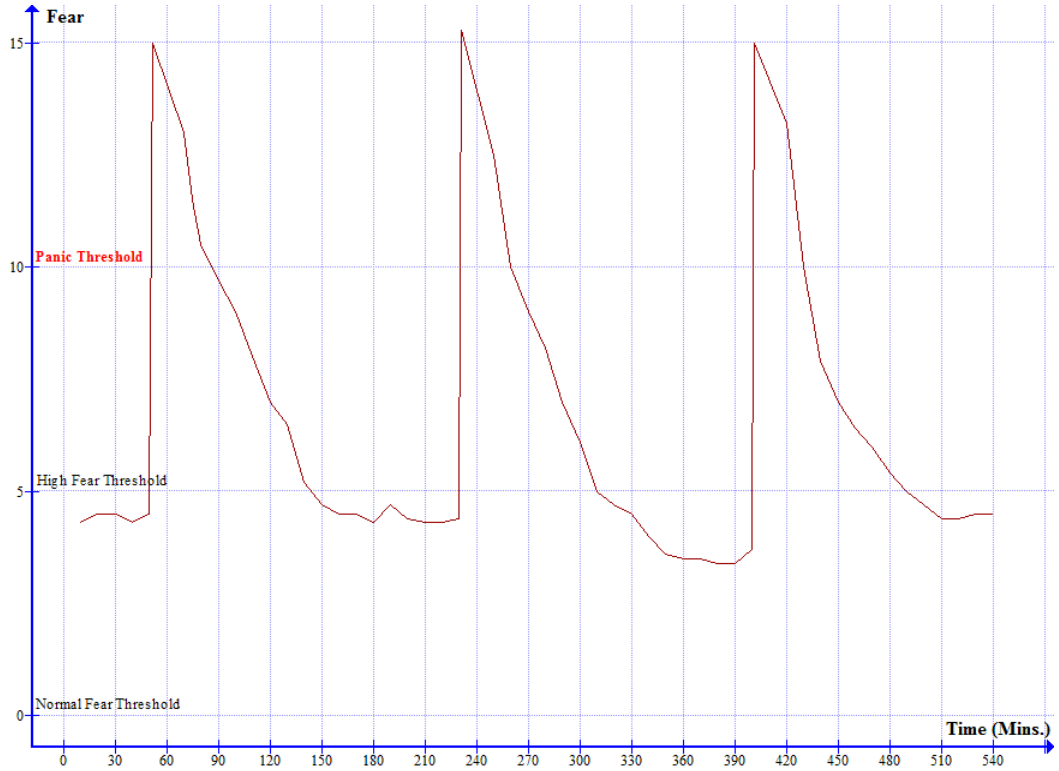

Fig. 1: A Self-Drawn Reference Mode[4] Showing Panic Attacks Over Time Using the *Feeling of Fear* Symptom

Feeling of fear and other cognitive symptoms of panic develop in response to physical symptoms of racing heart, choking, stomach distress and/or trembling etc. (Wehrenberg and Prinz 2007, 55), therefore, the sensations of intense fear are directly proportional to the physical symptoms of a

3 It is a process in which the conditioned stimulus (e.g., the smell of coffee) is paired with and precedes the unconditioned stimulus (the panic attack) until the conditioned stimulus alone is sufficient to elicit the response (the panic disorder) (Dictionary Reference 2008).

4 A set of graphs and other descriptive data showing the development of the problem over time (Sterman 2000, 90).

panic attack. What it implies is that first the heart rate, for example, will exhibit the same behaviour pattern as shown in Fig. 1 and then the feelings of fear will follow it. Therefore, the *fear* on the y-axis (Fig. 1) may also be interchanged with the *average heart rate* or any other physical symptom of a panic attack.

1.6 Research Goal:

The literature in biology and psychology contains theories for the occurrence of the problematic panic behaviour pattern shown in Fig. 1. The research goal of the present effort is to synthesize the predominant biological and psychological theories of PD[5] and provide a ground to further translate them into a system dynamics (SD) simulation model. The whole effort is expected to:

- Make explicit the dynamic processes implicit in the narrative presentations of the contemporary PD theories which would make it easy to visualize and understand them.

- Help form a bridge between abnormal psychology, psychiatry, biological psychology etc. and SD. This may encourage other researchers to apply SD methods to a wide range of interesting brain-based behaviours some of which are highlighted in this study.

- Provide a common, easy-to-understand and illustrative language (the SD translations) to further understand and critically examine the biological, psychological and cognitive conceptualizations of PD.

2. Research Method: System Dynamics Translation

A full *system dynamics (SD) translation* of a narrative theory includes the identification of a theory in text or diagrams, converting it into causal links and loops, formulating and simulating it, and eventually testing its predictive claims (Wheat 2007). The present work is an example of a partial SD translation which identifies the PD theories from various text books and academic papers and converts the narrative descriptions of these theories into causal loop diagrams (CLDs). The CLDs explicate the implicit feedback loops within these theories and, hence, make it easy to understand the physiology and psychology of PD.

SD translations have been successfully applied to many theories from different fields, for example, Luna and Davidsen (2007) have translated Velásquez's (1997) work regarding innovation performance in the capital good sector in Colombia (Luna and Davidson 2007), Campbell (2007) has translated Okin's (1989) theory regarding justice, gender and family and Wheat (2007) has translated Sach's (2005) poverty trap theory from the field of economics. Richardson's (1991) book *Feedback Thought in Social Science and System Theory* also contains many "partial" SD translations i.e., feedback loop diagramming without stock-and-flow simulation modeling. His work focuses on providing a careful and an incisive analysis of the feedback mechanism in social science and systems framework (Bailey 1992).

From Psychology, Richmond et al (1997, 35-47) have taken Freud's theory of personality (presented in Wortman and Loftus 1985) and provided a full SD translation of one of the theory's main constructs, "the id". Their translation work is divided into four sections. In the first section, words from the textbook are used to develop a simple snapshot (or a *map*) of the structural relationships which lie beneath Freud's conception of the id. The second section transforms that map into a

5 These theories explain how a panic attack is triggered, how the panic symptoms manifest and how panic attacks lead to PD.

simulation model. The third section reveals the dynamics, implied by the theory, through simulation and highlights a weakness in Freud's conception of pleasure – providing an impetus to extend the model and, hence, the theory itself. The fourth section summarizes the illustration and provides suggestion of how to further improve the model. (Richmond et al. 1997, 36) To highlight the need of SD translations, they write in the introduction of their translation work:

> *"Textbooks rely on verbal descriptions as the primary vehicle for exposition of concepts. Such descriptions are far more ambiguous, and open to multiple interpretation... In addition, verbal descriptions do not lend themselves to rigorous testing... Stock/flow framework provides a disciplined language that can help students (and faculty!) to 'pin down', and make sense of, important qualitative ideas in the textbooks. As the words on a page are translated into a map of the concept or theory, the associated abstractions become more concrete and operational. Ambiguities are squeezed out, and any internal inconsistencies are brought into sharp focus. The questions that arise during model construction, testing and extension will provide ample fodder for informed classroom discussion, and can provide the impetus for further directed research into the subject matter."* (Richmond et al. 1997, 35)

The goals of all the translation works[6] mentioned above may be summarized as follows:

- To make explicit dynamic processes implicit in the narrative presentations.
- To test whether the proposed structures generate the expected behaviour.
- To analyze the pros and cons of each theory.
- To provide a common, simple and clear language (SD model) to further discuss each theory and open up new research horizons.

The goal of the present effort is to make explicit the biological and psychological aspects of PD through an easy-to-understand illustrative language – the CLDs.

3. A Short Literature Review

There are many theories about the origin of panic disorder (PD) which may be categorized under the two main headings: biological and psychological (Salkovskis 1998). However, most of the practising psychotherapists view PD as an outcome of both the human anatomy and psychology (Psyber Square 1999). The present study tends to provide a partial system dynamics (SD) translation of the contemporary biological and psychological conceptualizations of PD.

Stress response is a hard-wired automatic biological response of the nervous system to a stressor or danger. The panic attacks of a PD patient are the outcome of an "unnecessary" stress response reaction, i.e., without any real danger (Wehrenberg and Prinz 2007, 59-61). The amygdala plays a vital role in initiating such a stress response before the cortex could analyse the situation in detail and inform the amygdala that stressing is not the appropriate response (LeDoux 1998, 164; Wehrenberg and Prinz 2007, 194-95). The amygdala quickly forms association between pain, danger and specific situations (Wehrenberg and Prinz 2007, 28). This information is stored in an unconscious memory system which may, later on, serve to repeatedly activate the stress response reaction (LeDoux 1998, 200-01). Fig. 2 highlights some of the important brain areas involved in the stress response reaction.

6 Except for Richardson's (1991) partial translations aiming at analyzing the feedback mechanism.

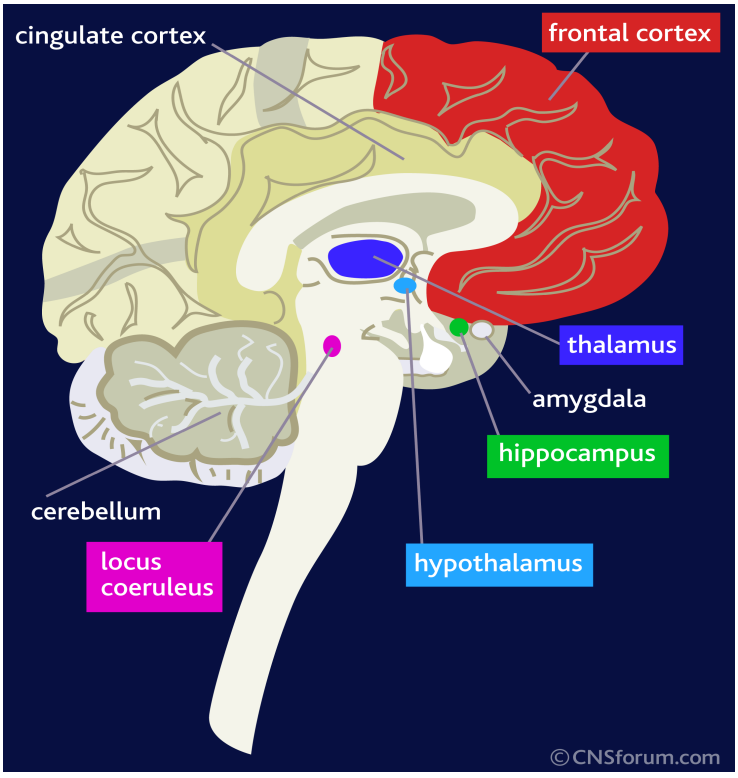

Fig. 2: Some Important Brain Areas Involved in the Stress Response Reaction (Source: www.cnsforum.com)

The more often a brain goes into a panic attack, the more easily a panic attack can be set off the next time. This process is called kindling. In respond to the physical symptoms of panic attacks, the cognitive symptoms develop which expand panic attacks into PD. These cognitive symptoms include erroneous thoughts, that a person is dying, losing control or going crazy etc., which are referred to as "cognitive error". (Wehrenberg and Prinz 2007, 55)

There may be problems with certain brain structures and functions of some individuals which contribute to the development of PD (Wehrenberg and Prinz 2007, 57-8). Some individuals have naturally over-reactive stress response system which generates a lot of stress in relation to the intensity of the trigger (Wehrenberg and Prinz 2007, 62-3). Similarly, some individuals have sporadic firings of neurons in the basal ganglia which causes out of the blue panic attacks (Wehrenberg and Prinz 2007, 69).

Various neurotransmitters are important to the etiology of PD. Low levels of serotonin (SE) in the nervous system may largely contribute to the sensation of panic (Wehrenberg and Prinz 2007, 100). Some people have an excess release of norepinephrine (NE) which results in a cascade of symptoms that are anxiety producing and lead to panic symptoms (Wehrenberg and Prinz 2007, 96-7). Gamma Aminobutyric Acid (GABA) is another neurotransmitter which when not working well in the brain may manifest significant anxiety and panic-like symptoms in an individual (Wehrenberg and Prinz 2007, 100).

4. Sub-system Diagram

Various aspects of PD are summarized with the help of a sub-system diagram (presented in Fig. 3 below) to provide an overview of the forthcoming CLDs. The figure shows that the *fear inducing information* or the very *first stimulus* enters into the brain and starts a self-reinforcing vicious panic

cycle. It first arouses the amygdala which initiates the *fear emotion*[7] that brings on the panic symptoms (the first panic attack). These *panic symptoms* give rise to a state of *cognitive error and kindling* and also contribute in forming *new stimuli* for future panic attacks. The *panicky sensations* shown within the c*ognitive error and kindling* circle also take part in the creation of new stimuli. *Cognitive error and kindling* intensifies the *fear emotion* and through it the *panic symptoms* which reinforce back *cognitive error and kindling*. The *newly created stimuli* frequently arouse the amygdala and with it the whole panic cycle – leading to various panic attacks over time or, in technical terminology, PD. *GABA* is a calming neurotransmitter and it helps calming down the amygdala whenever it is aroused.

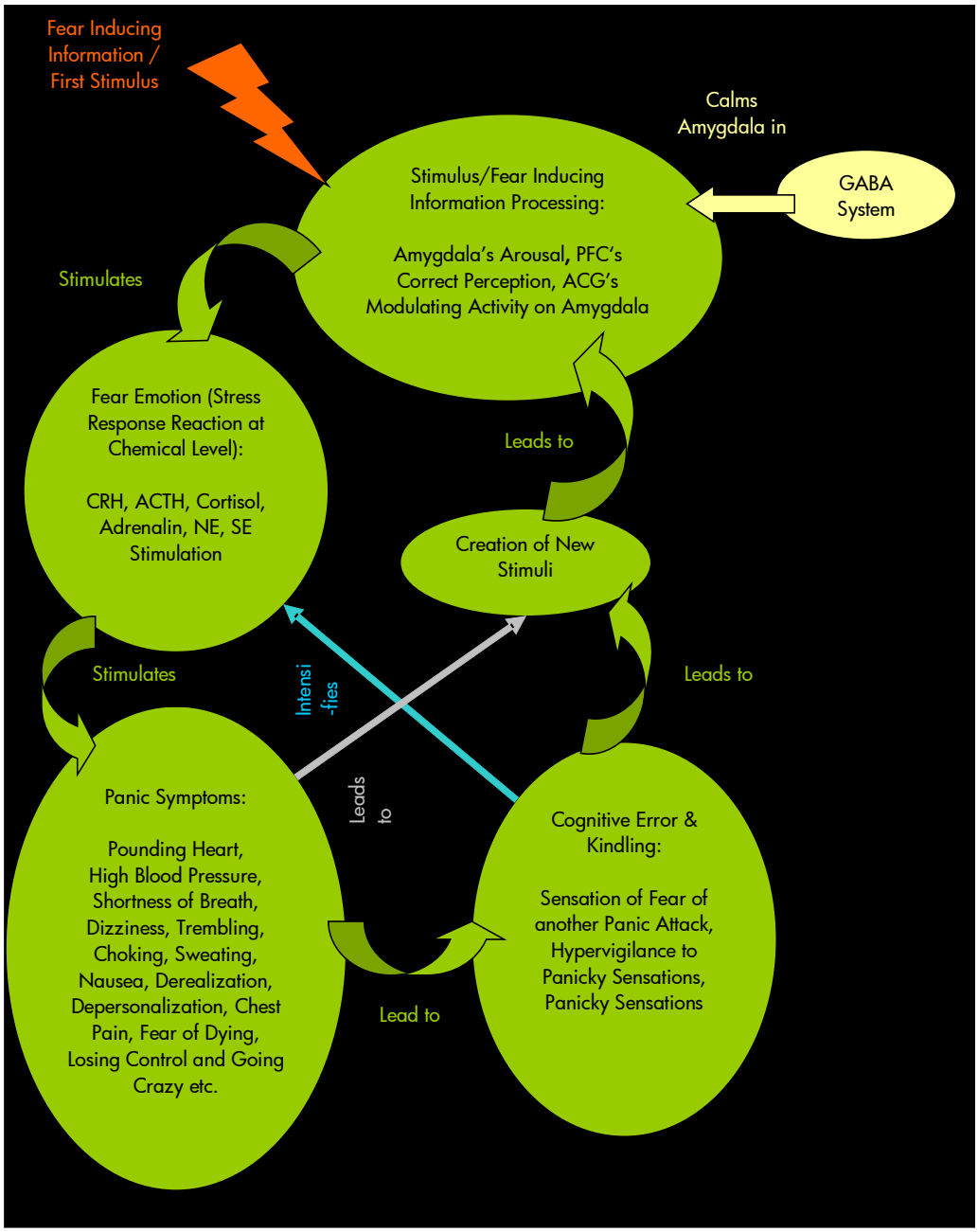

Fig. 3: A Sub-system Diagram Summarizing Various Aspects of PD

7 In the present study, the difference between emotion of fear and the conscious feeling/sensation of fear is taken into consideration. Where the "fear emotion" is referred to, it means the unconscious hard-wired biological (stress response) functioning of the nervous system whereas the "feeling of fear" means the conscious perception of this functioning. In other words, the latter is a product of the conscious mind – the label given to the unconscious stress response function or emotion (LeDoux 1996).

5. Translating the PD Theories into Links and Loops (CLDs)

This section, one by one, translates the key aspects of the panic disorder (PD) conceptualizations into the causal loop diagrams (CLDs).

5.1 Translation of the Amygdala and Prefrontal Cortex (PFC) Circuitry:

The *fear inducing information* is first *received in the thalamus* (See Fig. 4). From there, it is relayed on to the *amygdala* as well as *prefrontol cortex (PFC)*. The *amygdala's crude stress perception* instantly boosts up upon receiving this information. It is being referred to as "crude" because there is no thinking or analysis of the *fear-inducing information* involved in this instant boost up. However, on the other hand, the *cortex* analyses the same *fear information* in detail taking help from some other brain regions (these regions are not shown in Fig. 4) to see whether it is worth stressing for but this does not happen without a cost which is time (See Loop 'B1'). First, the *fear inducing information* is received in the *cortex* far too late as compared to its reception in the *amygdala*. Secondly, involving other brain regions and analysis of the very *information* causes a further delay in this process. This allows the *amygdala's crude or blind stress perception* to stay high for some time until the *PFC* regulates it back through the *anterior cingulate gyrus (ACG)* (See Loop 'B2'). In the case of a PD patient, as the *fear inducing information* is typically fake, the *cortex* has to tone down the *amygdala's stress perception* rather than reinforcing it which would be the case if the *fear inducing information* were real, for example, an encounter with a snake or a known serial killer. (Holt 1998, 2; Wehrenberg and Prinz 2007, 194-95; LeDoux 1998, 164)

One contributing factor to the panic attacks of a PD patient may be that the circuitry between the *amygdala* and *cortex* (shown in Fig. 4) may not be working properly (LeDoux 1998, 164). The *PFC* may not have enough energy to perform its work or the *ACG* may not calm down the *amygdala's stress perception* properly due to some reason (Wehrenberg and Prinz 2007, 175-6). This allows the *amygdala's stress perception* to stay high for a prolonged period of time which literally means that the amygdala would keep stimulating the stress response hormone, and through it, the fear emotion - eventually leading to the panic symptoms (See sec. 5.3). (Wehrenberg and Prinz 2007, 28, 59-60)

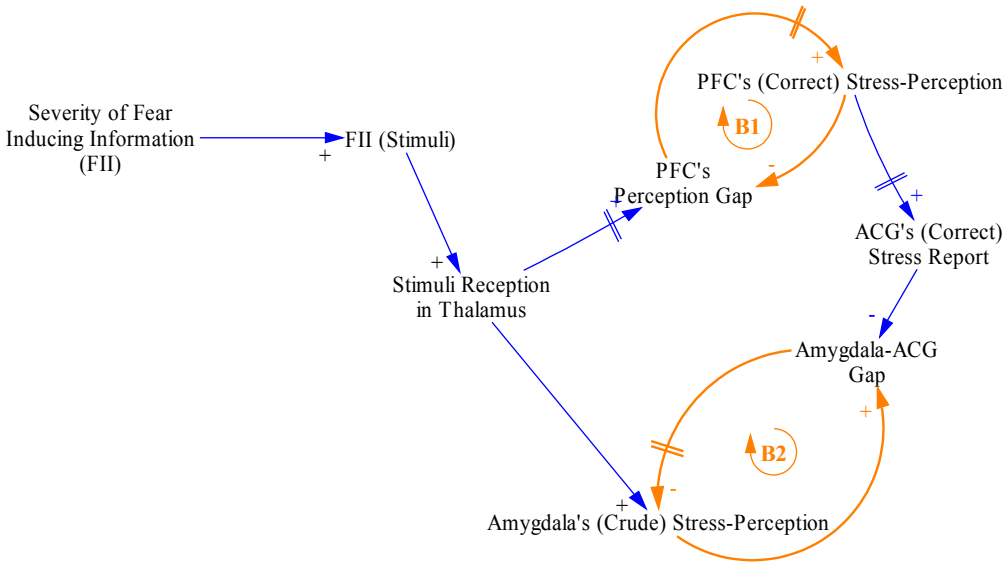

Fig. 4: A CLD Showing the Fear Inducing Information (FII), Amygdala and PFC Connections

5.2 Translation of Norepinephrine (NE) and Serotonin (SE) Feedback System:

When *serotonin (SE)* is low in the brain, it stimulates the *norepinephrine (NE)* production which, in return, stimulates the production of *SE*. When *SE* is sufficiently produced, it stops stimulating the *NE* production. (Wehrenberg and Prinz 2007, 100) This *SE* and *NE* feedback system is highlighted in Fig. 5. In this figure, *SE* and *NE* both adjust to the same goal, i.e., the *NE-SE desired ratio*. The low *SE* levels increase the *NE* (divided) *by SE* value and with it *NE by SE ratio gap* which results in increasing the *SE activation rate* and, hence, the *SE* levels (See Loop 'B', Fig. 5). Note that as the *SE* levels rise, the *NE by SE* value decreases causing the *NE by SE ratio gap* to diminish which slows down the *SE activation rate* as a result of which the *SE* levels do not keep rising infinitely but balance towards a certain level. This process seeks to "balance" the fallen *SE* levels back to normal, therefore, it is highlighted as a balancing loop. Now take *NE*. When the low *SE* levels increase the *NE by SE* value and with it the *NE-SE ratio gap*, it results in increasing the *NE activation rate* and with it the *NE* levels. When the *NE* levels rise, the *NE by SE ratio gap* increases which increases the *SE activation rate* and with it the *SE* levels. With the rising *SE* levels, the *NE-SE ratio gap* diminishes which slows down the *NE activation rate* and, hence, *NE* does not keep rising infinitely but balances towards a certain level. Without the involvement of *SE*, *NE* would only reinforce itself through the *NE-SE ratio gap* that is why this feedback process is highlighted as a reinforcing one.

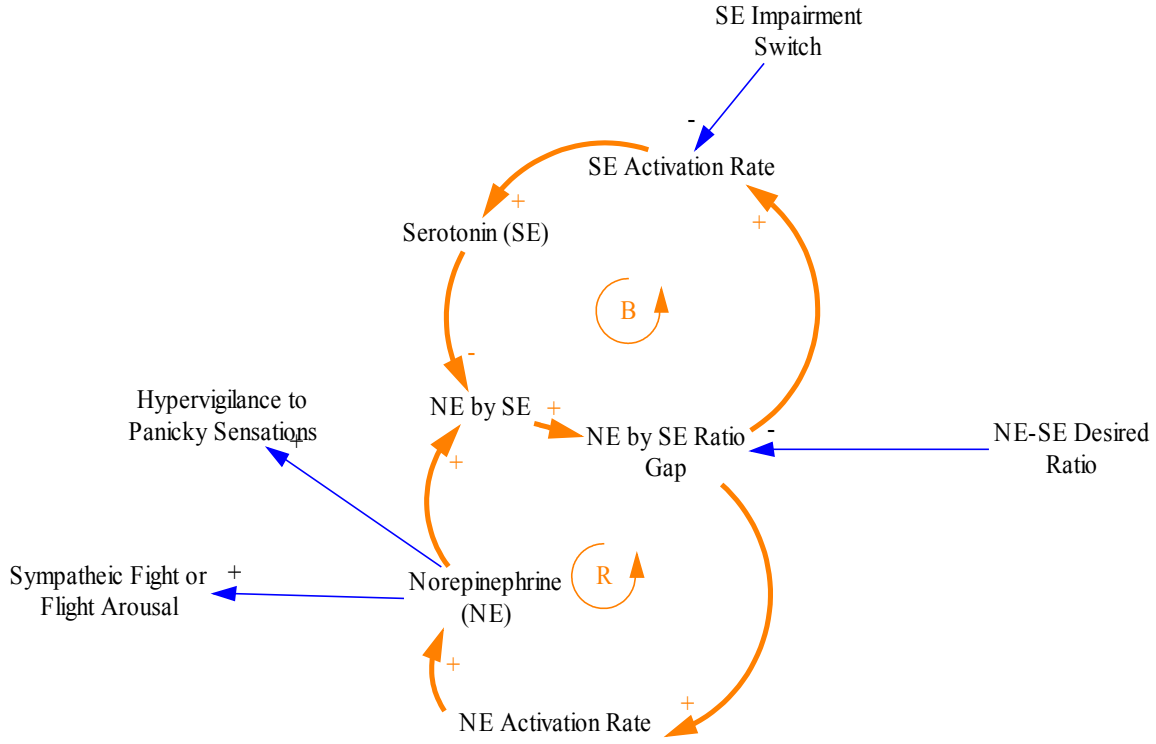

Fig. 5: The NE/SE Feedback System

In a brain in which the *SE* production is impaired for some reason, the loop which balances the *SE* levels becomes inactive (Wehrenberg and Prinz 2007, 100). To be precise, when the *SE* levels fall, they increase the *NE-SE ratio gap* (through increasing *NE by SE*) which, contrary to its normal response, cannot increase the *SE activation rate* and, hence, the *SE* levels (See Fig. 6 - the dotted line highlights the broken link of the balancing loop). On the other hand, this *gap* increases the *NE activation rate* and through it, the *NE* levels. The rising *NE* levels further increase this *gap* which again, in this *SE impairment* scenario, only keeps reinforcing the *NE* levels and remains unable to do any good to the fallen *SE* levels. Eventually, this leads to high levels of *NE* in the brain which

not only result in the panicky symptoms by activating the *sympathetic nervous system (SNS)* but also create *hypervigilance to the panic-like sensations*. This raises a fundamental question here: How will NE levels come back to normal (or adjust towards some level) after being constantly reinforced in an SE impairment case? The answer to this question could not be found in the literature. The impact of *sympathetic arousal* on panic attacks will be discussed later in Sec. 5.5 and the role of *hypervigilance* in converting panic attacks into panic disorder (PD) will be explicated in Sec. 5.7. The low levels of *SE* also contribute to PD independent of SE/NE feedback mechanism; this issue will be undertaken in Sec. 5.3.

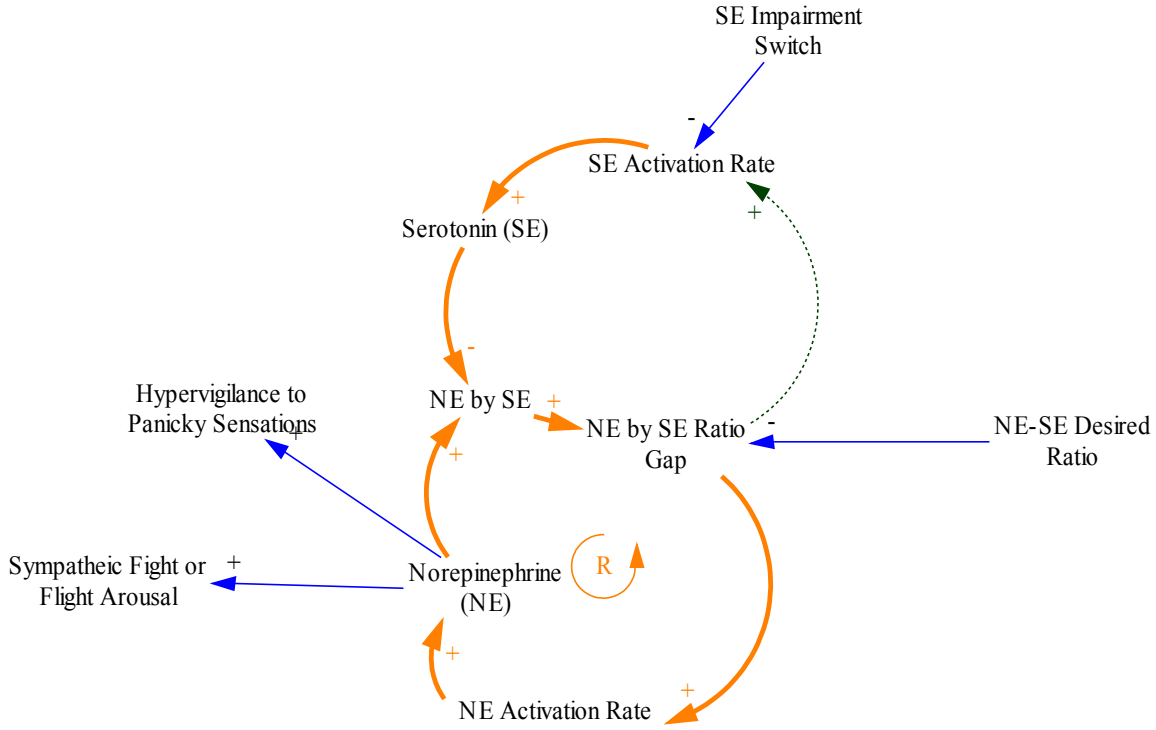

Fig. 6: The NE/SE Feedback System when SE is Impaired

5.3 Translation of the Activation of the Stress Cycle (Fear Emotion) through the Amygdala:

When stress is perceived in the *amygdala*, it initiates the stress response reaction by stimulating the *stress response hormone* (Wehrenberg and Prinz 2007, 28, 59-60). *CRH* activates the whole chain of chemicals by simulating *adrenocorticotropin hormone (ACTH)* which stimulates *adrenalin (AD)* which further stimulates *norepinephrine (NE)* (Wehrenberg and Prinz 2007, 60). *NE* when stimulated in this way activates *serotonin (SE)* (Wehrenberg and Prinz 2007, 100). *SE* provides energy for the *prefrontal cortex (PFC)* to work; the more the *SE*, the greater the *PFC's* energy to carry out its *correct perception of stress* (Wehrenberg and Prinz 2007, 175-6). The *PFC*, upon realising that the *fear-inducing stimulus* is fake (which is a typical case in PD), tones the *amygdala* down through the *anterior cingulate gyrus (ACG) (*Wehrenberg and Prinz 2007, 194-95). This whole circuitry is highlighted in Fig. 7 with the help of the balancing loop 'B1'. It is a balancing loop as it weakens the *amygdala's stress perception* which initiates the stress response reaction. Note that the *amygdala's stress perception* initiates the *panting respiration*, *AD* the *shakiness* and *NE* the *sympathetic arousal* during a stress response reaction (Wehrenberg and Prinz 2007, 28, 60).

SE levels effect the *ACG's correct stress reporting activity* in the way that the more the *SE* levels, the more effective the *ACG's correct stress reporting to the amygdala* (Wehrenberg and Prinz 2007,

69, 175-6). This cause-and-effect relationship is highlighted in Loop 'B2' of Fig. 7. Rest of this loop consists of the same variables as that of Loop 'B1'. 'B2' is a balancing loop as, like 'B1', it helps lower the *amygdala's stress perception* which, when rises, initiates the stress response reaction (the emotion of fear).

SE levels, in addition to indirectly effecting the *amygdala's stress perception* through the functioning of *PFC* and *ACG*, directly effect it as well. Sufficient *SE* levels in the brain help the *amygdala* tone down its *stress perception*. (Wehrenberg and Prinz 2007, 175) This relationship is highlighted in Loop 'B3' (Fig. 7). It is a balancing loop as its overall function helps calming down the *amygdala's stress perception*.

SE works in a feedback loop with *NE* which is already discussed in Sec. 5.2. In Fig. 7, it is highlighted with the help of the balancing Loop 'B4'. Loops 'B1', 'B2', 'B3' and 'B4 all include *SE* as an important variable. When *SE* is low, the *PFC* and *ACG* cannot work efficiently to help tone down the unnecessary activation of the *amygdala* (*amygdala's stress perception*) in a PD patient (See Loops 'B1' and 'B2', Fig. 7). More so, the *amygdala* itself cannot tone down its *stress perception* in the absence of sufficient *SE* levels (See Loop 'B3', Fig. 7). (Wehrenberg and Prinz 2007, 69) Consequently, the *amygdala's stress perception* stays high in a PD patient activating the stress response reaction for no apparent reason. Low *SE* levels stimulate the production of *NE* so that *NE* may help rising the depleting *SE* levels. *NE*, however, cannot serve this purpose as the *SE* is impaired due to some reason in such a way that, no matter how high *NE* levels may get, the *SE* levels cannot rise. Hence, the *SE* levels rapidly diminish and, courtesy the SE/NE feedback mechanism, the *NE* levels keep rising. (See Loop 'B4', Fig. 7) The excessive production of *NE* triggers the *fight or flight sympathetic arousal* for no good reason. This unnecessary or false activation of the *fight or flight activity* is actually referred to as a panic attack that a PD patient frequently suffers from. (Wehrenberg and Prinz 2007, 100)

The stress response reaction turns itself off with *cortisol*. *ACTH* where stimulates the production of *AD*, stimulates *cortisol* as well. *Cortisol* helps diminish the production of *CRH* which is the chemical with which the stress response reaction initiates (Wehrenberg and Prinz 2007, 60). This feedback process is highlighted through Loop 'B5' in Fig. 7. It is a balancing loop as it has a braking effect on the production of *CRH*.

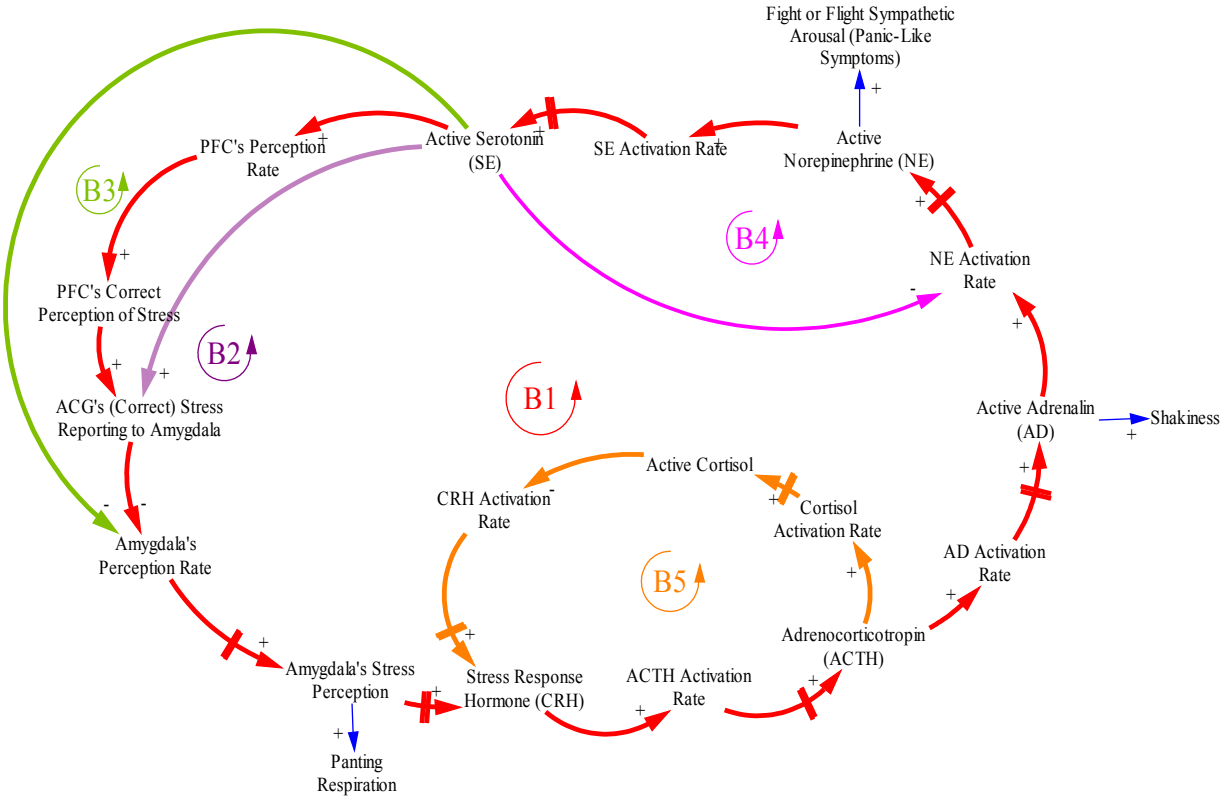

Fig. 7: A CLD Highlighting the Activation of the Stress Cycle through the Amygdala

5.4 Translation of the Inborn Over-reactive Stress Response System:

As discussed above, the corticotrophin release hormone (CRH) is crucial in generating fight or flight activity. It is the release of this hormone by the hypothalamus which initiates the stress response reaction. When an individual has more CRH-producing neurons than normal, even an ordinary stimulus which would not trigger the stress response in other individuals, would trigger it in such an individual. It means that the more the CRH levels, the more intense is the stress response. (Wehrenberg and Prinz 2007, 44-5, 62-3) This aspect has already been translated in Fig. 7 (See Loop 'B5').

5.5 Translation of the Excess Release of Norepinephrine (NE), Fight or Flight Activity and Hypervigilance:

Excess release of *NE* is hypothesised to be a cause of panic disorder (PD) (Wehrenberg and Prinz 2007, 96-7). This excess release, in addition to low SE levels (discussed in Sec. 4.2), has another important contributing factor which is the *efficiency of alpha-2 receptor site*[8]. The more efficient it is, the less the *NE* production. The *efficiency of alpha-2 receptor site* may be low due to the presence of *alpha-2 antagonist agents*, which serve to block the receptor site, and/or the *hyposensitivity* of a PD patient at the very receptor site (See Fig. 8). (Wehrenberg and Prinz 2007, 98)

Excess *NE* leads to a state in which one *hypervigilantly* monitor one's panic-like sensations

8 *"An alpha-2 auto-receptor is a presynaptic NE receptor located on the NE neuron that is releasing the NE. If activated (i.e., if it receives an NE molecule), the alpha-2 auto-receptor will slow down the release of NE. It has a breaking effect on NE release. When the braking action stops, more NE is released. This is how a healthy brain functions to regulate the release of NE."* (Wehrenberg and Prinz 2007, 97)

(Wehrenberg and Prinz 2007, 47-8, 55-6). This *hypervigilance* contributes to trigger more panic attacks. This issue will be taken up in the forthcoming discussion of the cognitive error and kindling in Sec. 5.7. In addition, excess *NE* production activates the sympathetic nervous system which leads to the panic symptoms of *tremor, racing heart, flushing, muscular tension, sweating* and *high blood pressure* (See Fig. 8). For clarity and simplicity, certain feedback loops, that *NE* takes part into, are removed from Fig. 8. For a high-level view of how *NE* contributes to the whole panic system, see Figs. 7 and 12.

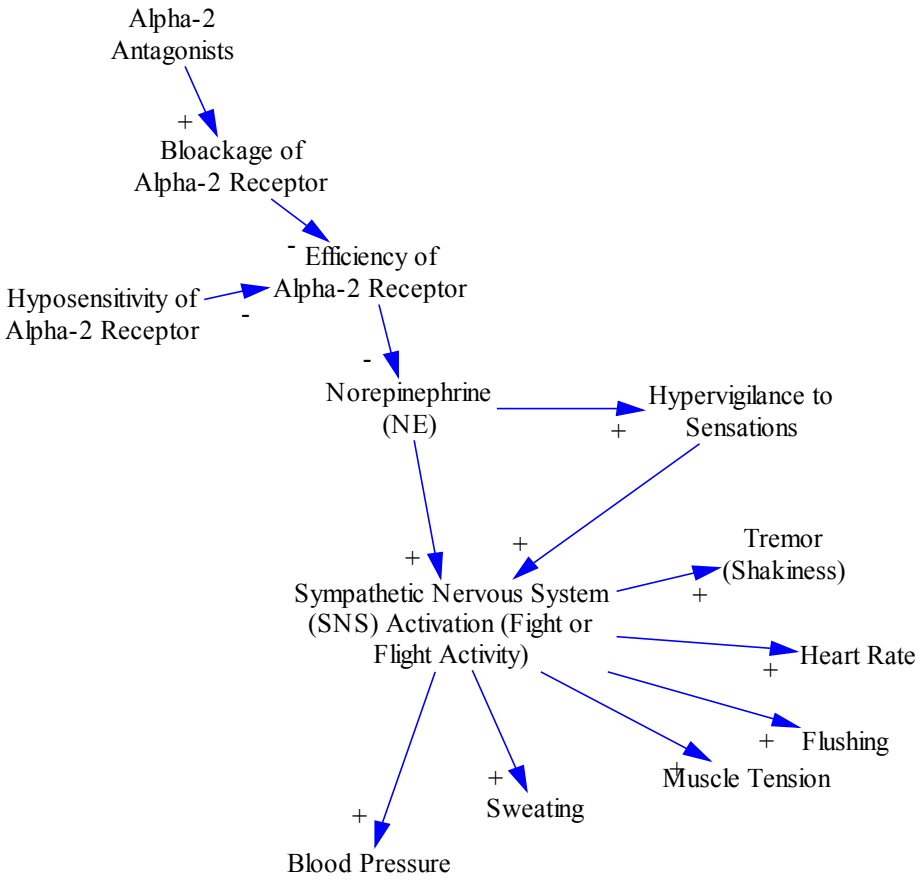

Fig. 8: NE, Fight or Flight Activity and Hypervigilance

5.5 Translation of the Role of GABA in Panic:

Low *efficiency of GABA* neurotransmitter is hypothesised to be an important factor in the etiology of PD. *Benzodiazepines* are the brain chemicals which affect the *GABA's functional efficiency* to relax the nervous system. The *benzodiazepine receptor site* is located on the *GABA* neurons. The more *efficiently* this site works, the more effectively *benzodiazepine* regulates *GABA* (See Fig. 9). The *efficiency of the bezodiazepine receptor site* decreases if it is *dysregulated*, having any difficulty to receive *bezodiazepines* and/or not sufficiently *sensitive to benzodiazepine*. In addition, the presence of any *anxiogenic inverse agonist* also serves to decrease the very *efficiency*. The more the *effectiveness of benzodiazepines to regulate GABA*, the more the *efficiency of GABA* to:

- Help the *anterior cingylate gyrus (ACG) modulate the amygdala*.
- Calm down the erratic firing of neurons in the *basal ganglia*.
- Help the *amygdala* calm down its *crude stress perception*. (Wehrenberg and Prinz 2007,

100-01, 177)

It should be noted here that the *efficiency of GABA* also depends on the *GABA* levels in the brain in a way that the more the *GABA* levels, the more the *efficiency of GABA*. Similarly, the *effectiveness of benzodiazepines to regulate GABA* depends on the *benzodiazepine* levels in the brain; the more the latter the more the former (See Fig. 9).

Out of the blue panic attacks, which seem unrelated to the life events, may be a result of sporadic firings of neurons in the basal ganglia (BG) (Wehrenberg and Prinz 2007, 26, 69). GABA when sufficient and working properly diminishes such firings and, hence, keeps one from such panic attacks (Wehrenberg and Prinz 2007, 127-8). The more the efficiency of GABA, the less the erratic firings of neurons in the BG.

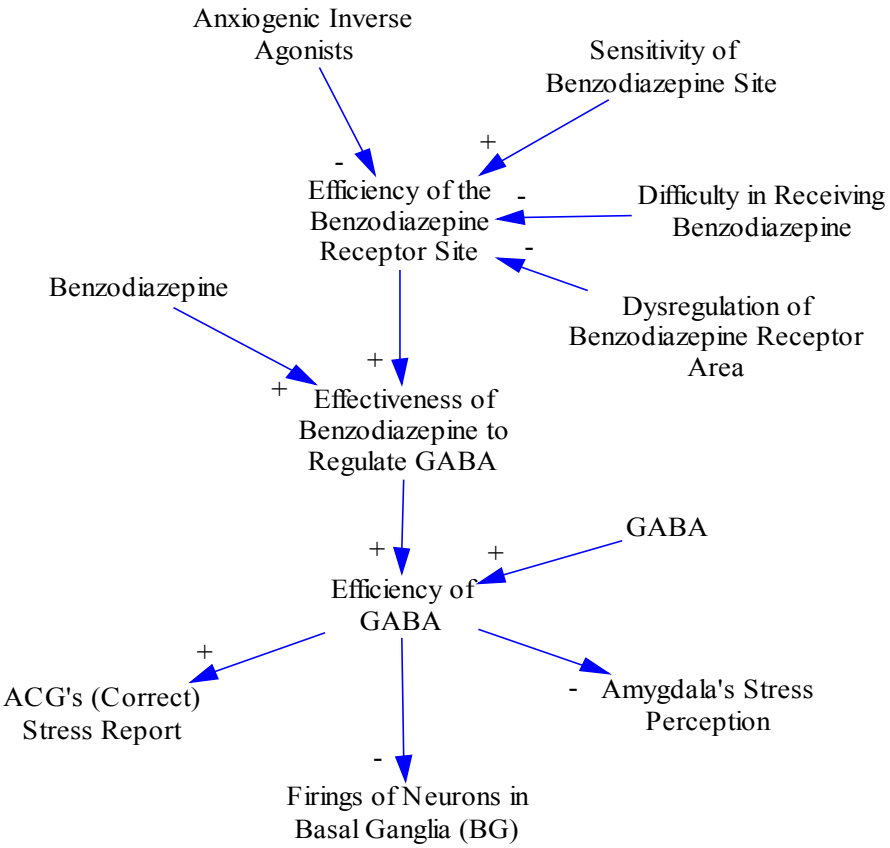

Fig. 9: A CLD Showing the Role of GABA in Panic

The detailed picture of how *GABA* takes part in the stress response reaction is highlighted in Fig. 10. For simplicity, the details of the factors on which the *efficiency of GABA* depends are omitted from this figure. The *firing of neurons in the BG* is directly connected to the *amygdala's perception rate* as, unlike the fear inducing information, this information does not come from the way of thalamus. The more the *firings of neurons in the BG*, the more the *amygdala's stress perception* and, consequently, the stronger the stress response reaction.

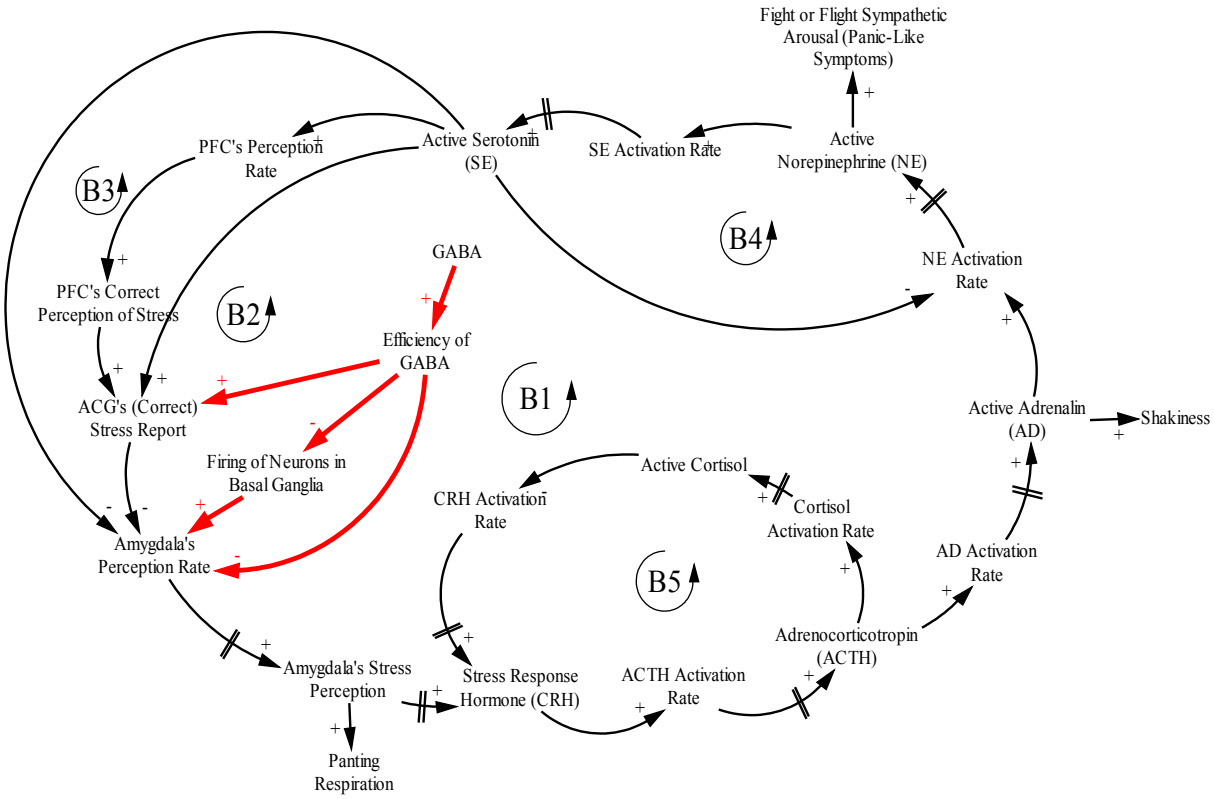

Fig. 10: A CLD Showing the Role of GABA in the Stress Response Reaction

5.6 Translation of the Stress and the Creation of Stimuli Mechanism:

Once a stressful (traumatic or frightening) event takes place, the amygdala remembers that experience by storing some of its information into its emotional memory. It actually associates that event with the things which happen or are present at the time it occurs because it perceives those things as the factors responsible for the stress (irrespective of the fact if they are actually responsible or not). Thus, these things are stored into the amygdala's emotional memory as "dangerous" and whenever they are encountered, the amygdala's stress perception boosts up and it starts energizing the body either to fight or flee from the plausible danger. For example, if a person somehow undergoes a panic attack while having a cup of coffee, the amygdala may easily associate the panic with the coffee – referring to the coffee as a dangerous enemy responsible for the panic attack. Next time, as it would see the cup, taste or smell of coffee as an enemy (the stress stimulus), which causes the stress, its stress perception would immediately boost and it would straightaway start to prepare the body for a fight or flight response. (Wehrenberg and Prinz 2007, 28-30, 64-66; LeDoux 1998, 200-1, 259-60) Such false activation of the fight or flight reaction, without the presence of a real threat or danger, causes PD in some individuals (Wehrenberg and Prinz 2007, 60).

Fig. 11 illustrates that the more the *stressful (traumatic) events* in an individual's life, the more the *magnitude of the amygdala's emotional memory* as the amygdala learns what is dangerous by associating specific situations with pain, danger or negative outcome (Wehrenberg and Prinz 2007, 28). The more things the amygdala would associate with pain, danger or negative outcome in its *emotional memory*, the more *stimuli* would be created which would repeatedly serve to generate the *fear emotion* eventually leading to the frequent *panic attacks*. As a *panic attack* itself is a *stressful event*, its occurrence adds to the number of *stressful events* in an individual's life paving way to the vicious cycle illustrated in Fig. 11. This cycle reinforces each of its variables with time and, thus, forms a reinforcing loop.

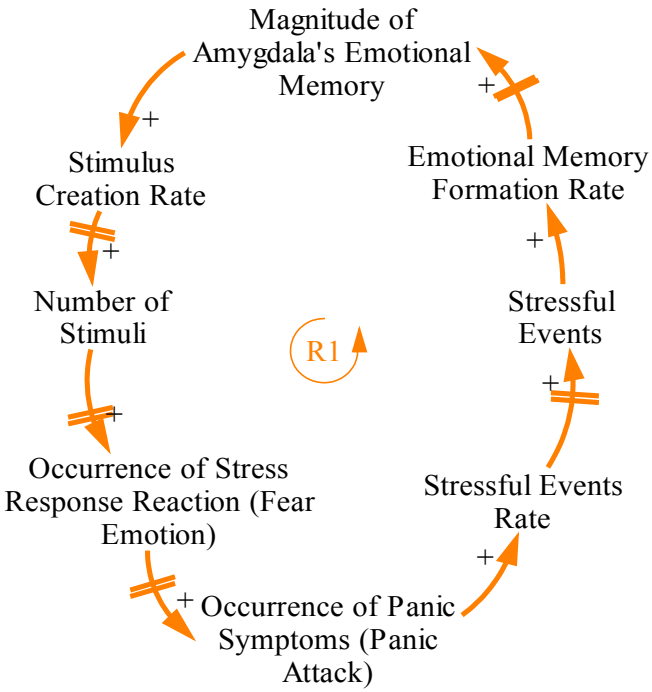

Fig. 11: A CLD of the Stress and Stimuli Feedback Relationship

5.7 Translation of the Circular Nature of a Panic Attack (Cognitive Error and Kindling):

The *panicky sensations*, developed as a result of the *panic symptoms*, lead an individual to a state of *cognitive error* in which the individual forms erroneous thoughts of dying, losing control or going crazy. These thoughts maintain the *conscious feelings of fear of another panic attack* which leads to a state of *hypervigilance*. In such a state the individual maintains a high awareness of his heart and breathing rate, sweating, stomach distress, choking, chest pain etc. in the anticipation of another panic attack. The *hypervigilance* magnifies the sensations of the beating of the heart, shortness of breath, stomach distress or chest pain etc. even though, in reality, the change in the heart or breathing rate, stomach distress or chest pain etc. may be negligible (See Loop 'R3', Fig. 12). This unnecessary increase in the *panicky sensations* would activate the amygdala and, through it, the stress response reaction (emotion of fear). The very reaction would lead to the *panic symptoms* which would give rise to the *panicky sensations*, and again, contribute to develop a state of *cognitive error.*

See Loop 'R1'; there is a circular interaction between the *panic symptoms* and *panicky sensations*. The *panic symptoms* may be weak to begin with but they reinforce themselves through the *panicky sensations* which initiate the stress response reaction. This reinforcement eventually gives rise to a full blown panic attack with strong *panic symptoms.*

Note that the *panicky sensations*, once developed, reinforce themselves by means of the *fear of another panic attack* and *hypervigilance* (See Loop 'R2', Fig. 12). When these *sensations* become strong enough, through this circular reinforcement, only then they trigger the stress response reaction effectively enough to generate the *panic symptoms* on some scale (See Loop 'R1'). (Wehrenberg and Prinz 2007, 55-6)

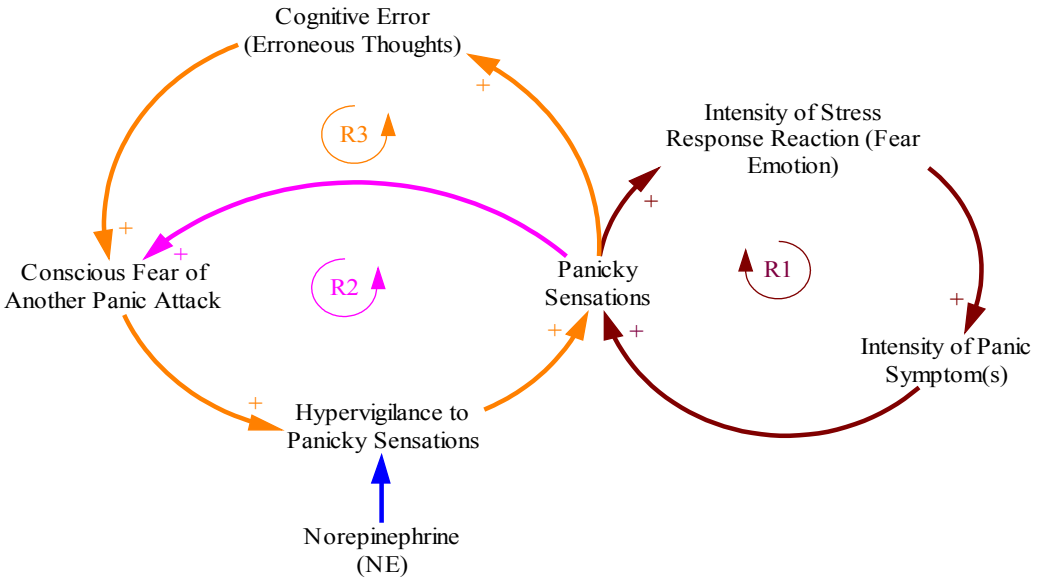

Fig. 12: The Cognitive Error and Kindling Feedback Structure

Note that the *panicky sensations* effect the stress response reaction in another way which may be better understood in context of Fig. 11. The occurrence of *panicky sensations* itself is a stressful event for the sufferer and, hence, it would tend to increase the *number of stimuli* which would result in increasing the frequency of the occurrences of the stress response reaction. Every time a *stress response reaction* would take place, it would obviously give rise to the *panicky sensations* and, hence, a circular interaction would take place between these variables which is highlighted in Fig. 13 with the help of Loop 'R2'.

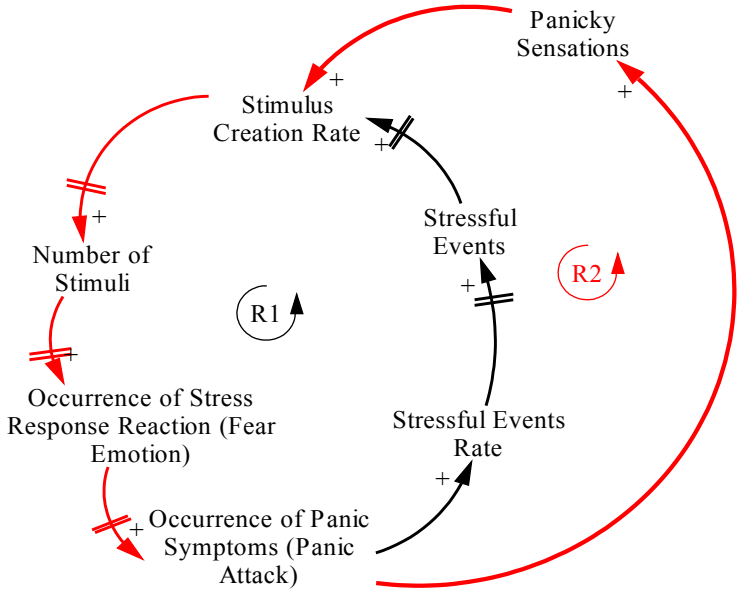

Fig. 13: A CLD Highlighting the Role of Panicky Sensations in the Stress and Stimuli Feedback Relationship

Fig. 14 elaborates the Loops 'R1' and 'R2' of Fig. 12 in more detail. In this figure, the variable *intensity of panic symptoms* (of Fig. 12) is replaced by the individual panic symptoms. Also, the variable *amygdala's stress perception* is included in this figure to highlight the importance of the amygdala in generating panic. The variable *(intensity of) stress response reaction* in Figs. 12 and 14

refers to the stress response reaction at the chemical level (also known as the 'fear emotion') which is shown in Fig. 7 in detail. Here the whole fear emotion is condensed in one variable so that the reader's focus remain on the concepts of cognitive error and kindling.

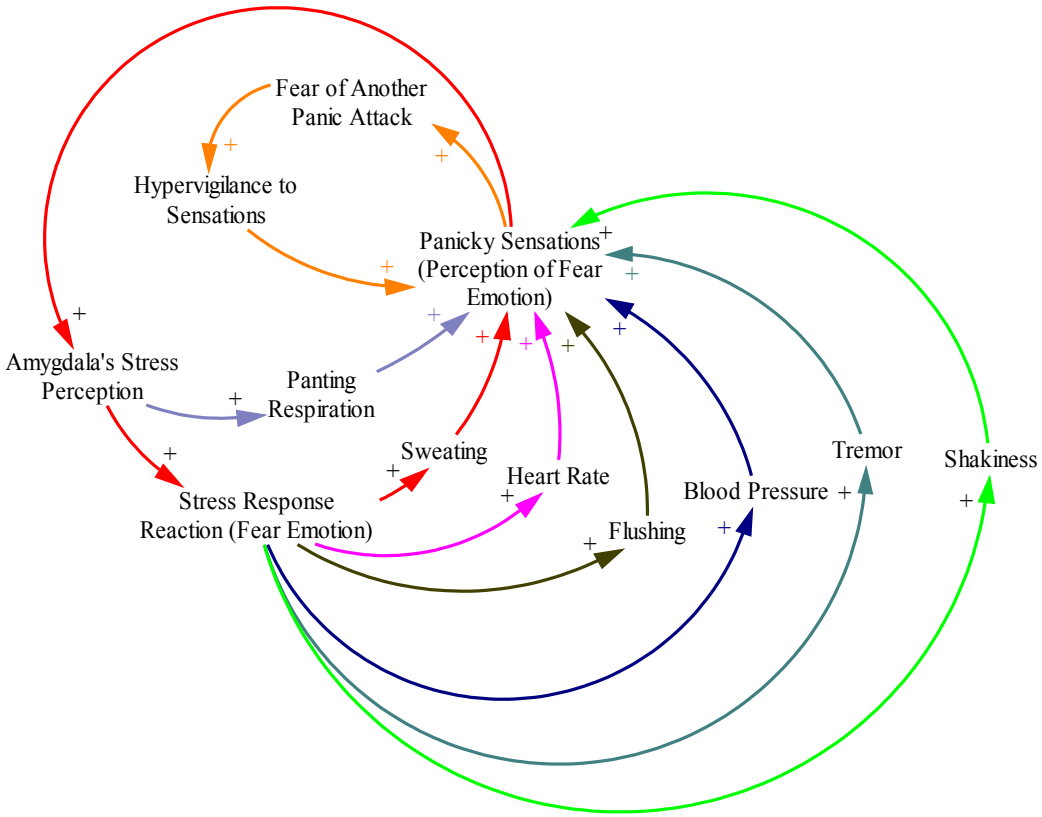

Fig. 14: The Cognitive Error and Kindling Feedback Structure (Elaborating Loops "R1" and "R2" of Fig. 12)

6. Conclusion

In this section, the usefulness of the present study is highlighted and its future directions are outlined.

6.1 Usefulness of the Present Study:

The present study is expected to be useful in the following ways:

- It makes explicit the dynamics processes implicit in the narrative presentations of the PD theories, through the causal loop diagrams (CLDs), which makes it easy to visualize and understand them.
- The CLDs provide a common language for the researchers of different fields to further understand and critically examine the biological, psychological and cognitive aspects of PD.
- The sub-system diagram and CLDs may also prove effective for educational purposes in abnormal psychology and related fields.
- Psychoeducation about how panic is generated and why the physical methods work to stop panic attacks is an important part of PD treatment (Wehrenberg and Prinz 2007, 73).

Therapists may use the CLDs, sub-system diagram and stock and flow model developed in this study to help their patients understand that PD is a biopsychosocial problem.

- Brain based models are uncommon in system dynamics (SD) although the structure of the brain is full of interesting feedback systems busy interacting with each other and causing a wide range of dynamics throughout the life span of an individual. The present effort helps highlighting this aspect of the brain and invites other researchers to apply SD on the brain based dynamics, e.g., to comprehensively study the serotonin dynamics which is hypothesised to be a root cause of many psychiatric problems like obsessive compulsive disorder (OCD), depression, fibromyalgia, PD etc.

6.2 Future Directions:

The future directions for this study may be summarized as follows:

- A number of different stock and flow models, from simple to detailed ones, may be developed on the basis of CLDs presented in this study. Using the very CLDs, Hassan (2008) developed a model which aimed at analysing whether the proposed structure in PD theories is capable of producing the problematic behaviour (shown in Fig. 1). The model replicates the reference mode and is capable of producing the panic episodes with an increasing frequency which is an important observation in PD. However, it highlights some important shortcomings of these theories and indicates a need for further research.

- The translation work may be extended to include the impact of different treatment methods in resolving PD. These methods include medication, psychotherapy, cognitive-behavioural therapy (CBT), energy therapies, eye movement desensitization and reprocessing (EMDR) etc. They help restoring the depleted Gamma Aminobutyric Acid (GABA) and serotonin (SE) levels in the brain and help the patient get rid of the cognitive error and fear of another panic attack.

- The translation work may also be extended to include the “agoraphobia” (See Sec. 1.4) aspect of PD.

References

American Psychiatric Association. 2000. *Diagnostic and Statistical Manual of Mental Disorders* (4th ed. Text Revision). Washington, DC: Author.

American Psychological Association Help Center. "Articles and Information, Facts and Statistics: Panic Disorders." http://www.apahelpcenter.org/articles/topic.php?id=6 (accessed Fabruary 18, 2008).

Bailey, Kenneth D. 1992. Review: Feedback Thought in Social Science and System Theory, by George P. Richardson. *Contemporary Sociology,* Vol. 21, No. 4: 546-7.

Barlow, D. H. And V. Mark Durand. 2002. *Abnormal Psychology: An Integrative Approach* (3rd ed.). California: Wadsworth, Thomson Learning.

Barlow, D. H. 1988. Anxiety and its Disorders. New York: Guilford Press.

Barlow, D. H. 1991. Disorders of Emotion. *Psychological Inquiry* 2 (1): 58-71

Beck, A. T. 1988. Cognitive Approaches to Panic Disorder: Theory and Therapy. In S. J. Rachman and J. Maser (Eds.), *Panic: Psychological Perspectives.* Hillsdale, NJ: Erlbaum.

Berman, Carol W. 2005. *100 Questions & Answers About Panic Disorder.* Sudbury: Jones and Bartlett Publishers

Campbell, D. 2007. Dynamics that Maintain the Leadership Gap: An Interpretation of Justice, Gender, and the Family by Susan Moller Okin. Master's Thesis, University of Bergen.

Clark, D. M. 1986a. A Cognitive Approach to Panic. *Behaviour Research and Therapy* 24: 461-70.

Clark, D. M. 1986b. Cognitive Therapy for Anxiety. *Behavioural Psychotherapy* 14: 283-94.

Clark, D. M. 1988. A Cognitive Model of Panic. In S. J. Rachman and J. Maser (Eds.), *Panic: Psychological Perspectives.* Hillsdale, NJ: Erlbaum.

Charney, D. S. and Heninger, G. R. 1986. Abnormal Regulation of Noradrenergic Function in Panic Disorders. *Archives of General Psychiatry* 43: 1042-54

Clarke, Valerie and Susan Gillet. 1997. *Psychology for VCE* (2nd ed.). Melbourne: Nelson ITP.

Federal Citizen Information Center, Pueblo, Colorado. "Panic Disorder". http://www.pueblo.gsa.gov/cic_text/health/panic/panfly.htm#pan5 (accessed: November 9, 2008).

Ford, Andrew. 1999. Modeling the Environment: An Introduction to System Dynamics Modeling of Environmental Systems. Washington DC: Island Press.

Gorman, J. M., Liebowitz, M. R., Fyer, A. J. And Stein J. 1989. A Neuroanatomical Hypothesis for Panic Disorder. *American Journal of Psychiatry* 146: 148-61

Hassan, J. 2008. Capturing the dynamics of panic disorder: a system dynamics translation of the contemporary biological and psychological conceptualization of panic disorder, M. Phil. thesis, University of Bergen.

Holt, Doug. 1998. The Role of the Amygdala in Fear and Panic. *Biology 202*: Web_Report #2

Klein, D. F. 1980. Anxiety Reconceptualised. *Comprehensive Psychiatry* 21: 411-27

Klein, D. F. 1981. Anxiety Reconceptualised. In D.F. Klein and J. Rabkin (Eds.), *Anxiety: New Research and Changing Concepts*. New York: Raven Press.

Klein, D. F. And Klein, H. M. 1988. The Status of Panic Disorder. *Current Opinion in Psychiatry* 1: 177-83.

Klein, D. F. And Klein, H. M. 1989a. The Nosology, Genetics and Theory of Spontaneous Panic and Phobia. In P. Tyrer (Ed.), *Psychopharmacology of Anxiety*. Oxford UK: Oxford University Press.

Klein, D. F. and Klein, H. M. 1989b. The Definition and Psychopharmacology of Spontaneous Panic and Phobia. In P. Tyrer (Ed.), *Psychopharmacology of Anxiety*. Oxford UK: Oxford University Press.

Ley, R. 1985a. Agoraphobia, the Panic Attack and the Hyperventilation Syndrome. *Behaviour Research and Therapy* 23: 79-82

Ley, R. 1985b. Blood, Breath and Fears: A Hyperventilation Theory of Panic Attacks and Agoraphobia. *Clinical Psychology Review* 5: 271-85

Ledoux, Joseph. 1996. Using Rats to Trace Routes of Fear by Sandra Blakeslee. http://www.cns.nyu.edu/ledoux/the_emotional_brain/book_time_reviw.htm (accessed: March 11, 2008).

LeDoux, Joseph. 1999. *The Emotional Brain*. London: Phoenix, a division of Orion Books Ltd.

Luna A. M. M. and Davidsen, P.I. 2007. An Investigation of the Innovation Performance in the Capital Goods Sector in Colombia Using the System Dynamics Approach. *International System Dynamics Conference*, Boston, MA.

National Institute of Mental Health. "Health and Outreach, Publications, Anxiety Disorders: Panic Disorder." http://www.nimh.nih.gov/health/publications/anxiety-disorders/panic-disorder.shtml (accessed April 22, 2008).

Okin, S.M. 1989. *Justice, Gender, and the Family*. New York, NY: Basic Books.

Rachman, Stanley and Padmal De Silva. 2004. *Panic Disorder: The Facts* (2nd ed.). New York: Oxford University Press Inc.

Richardson, George P. 1991. *Feedback Thought in Social Science and Systems Theory*. Philadelphia: University of Pennsylvania Press.

Richmond, Peterson, and Chris Soderquist. 1997. *Stella: An Introduction to Systems Thinking*. Hanover, New Hampshire: High Performance Systems.

Robledo Velásquez, J. 1997. The Role of Higher Education Institutions and the Government in the Industrial Innovation Process: The Case of the Colombian Capital Goods Industry. Ph.D. diss., University of Sussex.

Rosenzweig, Mark R., S. Marc Breedlove and, Neil V. Watson. 2005. Biological Psychology: An Introduction to Behavioral and Cognitive Neuroscience (4th ed.). Massachusetts: Sinauer Associates, Inc.

Roy-Byrne, Peter P., Michelle G. Craske and Murray B. Stein. 2006. Panic Disorder. The_Lancet: v.368 i.9540 p.1023(10).

Sachs, J. D. 2005. *The End of Poverty: Economic Possibilities of Our Time.* New York: The Penguin Group.

Salkovskis, Paul M. 1988a. Phenomenology, Assessment and the Cognitive Model of Panic. In S. J. Rachman and J. Maser (Eds.), *Panic: Psychological Perspectives.* Hillsdale, NJ: Erlbaum.

Salkovskis, Paul M. 1998. Panic Disorder and Agoraphobia. *Comprehensive Clinical Psychology* Vol. 6: 399-437

Sichel, Mark. 1999. The Biochemistry of Panic. http://www.psybersquare.com/anxiety/panic_biochem.html (accessed January 04 , 2008).

Sterman, John D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World.* New York: McGraw-Hill Companies, Inc.

Vensim from Ventana Systems, Inc. "Documentation." http://www.vensim.com/documentation/html/22610.htm (accessed Oct. 15, 2008).

Wehrenberg, Margaret and Steven M. Prinz. 2007. *The Anxious Brain: The Neurobiological Basis of Anxiety Disorders and How to Effectively Treat Them.* New York: W. W. Norton & Company, Inc.

Whalen, James L. and Robin E. McKinney. 2007. Panic Disorder: Characteristics, Etiology, Psychosocial Factors, and Treatment Considerations. Annals of the American Psychotherapy Association: v.10 i.1 p.12(8).

Wheat, David. 2007. Sachs' Poverty Trap Theory: A System Dynamics Translation. Congreso Latinoamericano de Dinámica de Sistemas, Buenos Aires, Argentina.

Wortman, Camille, and Elizabeth F. Loftus. 1985. *Psychology* (2nd ed.). New York: Alfred A. Knopf, Inc.