# The Theory

The Disturbed Dreaming Model (DDM) implements Nielsen & Levin's Affect Network Dysfunction model of nightmare production. The key publications are:

* Levin, Ross, and Tore Nielsen. “Nightmares, Bad Dreams, and Emotion Dysregulation: A Review and New Neurocognitive Model of Dreaming.” *Current Directions in Psychological Science* 18, no. 2 (2009): 84–88.
* Levin, Ross, and Tore A. Nielsen. “Disturbed Dreaming, Posttraumatic Stress Disorder, and Affect Distress: A Review and Neurocognitive Model.” *Psychological Bulletin* 133, no. 3 (May 2007): 482–528. <https://doi.org/10.1037/0033-2909.133.3.482>.
* Nielsen, Tore, and Ross Levin. “Nightmares: A New Neurocognitive Model.” *Sleep Medicine Reviews* 11, no. 4 (August 1, 2007): 295–310. <https://doi.org/10.1016/j.smrv.2007.03.004>.

Nielsen & Levin's neurocognitive model hypothesizes that nightmares are caused by the malfunctioning of an adaptive fear extinction process that occurs during normal dreaming. When working properly, the fear extinction process activates elements of fear memories decontextualized from their real-world contexts and recombines them with elements of other non-fearful memories thereby gradually extinguishing fear and helping the dreamer to effectively regulate their emotions. Neurologically, this fear extinction function is performed by a network of limbic, paralimbic, and pre-frontal regions: the hippocampus (Hip) controls memory context and is crucial to the decontextualization and recombination process; the amygdala (Am) controls fear memory acquisition and regulates emotional activation via stimulation of the brainstem and hypothalamus (Hyp); the medial prefrontal cortex (mPFC) stores fear extinction memories and regulates Am’s outputs to brainstem and hypothalamus, thereby maintaining tolerable levels of fear; and the anterior cingulate cortex (ACC) controls affect distress and works with the mPFC to downregulate Am’s outputs to brainstem and Hyp. During a nightmare, the mPFC and ACC fail to sufficiently dampen Am’s outputs to brainstem and Hyp, resulting in increasing heart rate, respiration, and motor activation and, eventually, to the dreamer awakening terrified. According to this model, the activation of the fear extinction process is determined by “affect load,” a hypothetical factor that reflects the cumulative effect of stressful and emotionally negative events, from major crises such as the death of a parent or the loss of a job to daily hassles such as commuting to work and paying taxes. Whether nightmares constitute a clinical problem is largely determined by “affect distress,” which is a dispositional factor that reflects a person’s tendency become highly distressed and emotionally disregulated in response to emotional stimuli.

# DDM model Diagram

A picture containing diagram

Description automatically generated

# Parameters

DDM is a discrete-event model describing the movement of images between various states. Model time is one hour per tick, and so 24 ticks per day. Each image is drawn from a specific event memory [EventMemoryImagesInSleep] and the image and corresponding event memory have identical values for three characteristics:

* ImageValence: This refers to the direction of the feeling or emotion evoked by the images. Ultimately this ascertains if the feeling evoked by the image is positive or negative, without mentioning how evocative it is.
* ImageArousal: This refers to the intensity of the emotion experienced in response to the image. It captures information about whether the material is calming or exciting, without reference to the positive or negative content of the image.
* ImageDominance: This refers to how the image is experienced in terms of feelings of being in control or being under control, without reference to the positive or negative valence of the image or the emotional intensity of the image.

In addition to image parameters, the mind processing images has personal characteristics. Some of these are fixed for a run of DDM and thus are represented as parameters:

* AffectDistressTendency: The tendency of which one’s affect load leads to distress.
* TraumaHistory: The history of trauma related to the dream imagery.
* InitialAffectLoad: The affect or stress level that is being experienced at the start of the simulation.
* FearExtinctionAttemptThreshold: The affect load threshold at which the brain will initiate fear extinction for a negative valence image, if fear is less than DandRFailureThreshold.
* FearExtinctionFailureThreshold: The fear threshold at which the brain will fail a fear extinction process that has already been initiated, described as an idiopathic nightmare.
* DandRFailureThreshold: If an image and affect load requires fear extinction, such fear extinction will be pre-empted by failure if the fear of the image is above the DandRFailureThreshold. This is described as a traumatic nightmare.
* MaxREMCyclesPerNight: The maximum number of REM cycles it is possible for the simulated individuals to experience in a night.
* MaxHoursSleepPerNight: The maximum number of ours the simulated individual will sleep attempt to sleep.
* IdealHoursSleepPerNigh: The “ideal” amount of sleep for the simulated individual.
* NormalSleepHour: The hour of the day that the simulated individual initiates sleep.
* IdiopathicNMAffectLoadIncrement: The amount that the affect load will be increased when the simulated individual experiences an idiopathic nightmare.
* TNMAffectLoadIncrement: The amount that the affect load will be increased when the simulated individual experiences an idiopathic nightmare.
* FEAffectLoadDecrement: The amount that the affect load will be decreased when the simulated individual experiences a successful fear extinction cycle.

Other personal characteristics change during a DDM run and thus are represented as variables:

* Fear: The level of fear stimulated by the dream image. The level of fear depends on personal factors, image factors, treatment factors, and nightmare history.
* Control: The level of control felt during a nightmare.
* AffectLoad: The affect load will increase or decrease over the simulation as fear extinction, idiopathic nightmares, traumatic nightmares, and/or treatment occurs.
* NightmareDistress: The distress caused by the nightmares during the nightmare.
* NightmareEffects: The negative psychophysiological effects caused by nightmares, including indirect impact such as REM deficit, sleep deficit, etc.
* DASSAnxiety: Depression and Anxiety levels caused by nightmares.
* ControlCapacity: The “muscle” to exert control during a nightmare.

# DDM Pathways

These images move between states during the day and night according to a sleep schedule. The top image pathway in the stock-and-flow diagram moves from images in the memory of an event to event memory images in sleep [EventMemoryImagesInSleep] and then through normal dreaming [Depotentiation] to depotentiated images in long-term memory [DepotentiatedImages]. Once images reach [DepotentiatedImages], the DDM run ends.

This dreaming-abetted memory-consolidation process can be altered when affect load [AffectLoad] is high due to high levels of stress and emotional agitation caused by difficult everyday events. If [AffectLoad] exceeds [FearExtinctionAttemptThreshold], DDM will attempt to move images through the fear-extinction process. When Fear is below DandRFailureThreshold, the fear extinction process begins with recontextualization [RecontextualizedImages]. This pathway attempts to decontextualize images, extracting them from their event-memory contexts, and then recontextualizing those images with other images drawn randomly from memory. During the decontextualization and recontextualization process (D&R), a dream occurs. If the fear this nightmare causes is below the [FearExtinctionFailureThreshold], fear-extinction succeeds; affect load is decremented and the image returns to [EventMemoryImagesInSleep] via path [FearExtinctionPartial]. At this point, the cycle will continue until the image is fully depotentiated, or until the night is over and the individual must wake up [WakeupAfterFEPartial\_NoNightmare]. Now in [AwakeImageAwareness] the individual will sleep at the next evening and continue fear extinction until depotentiation is complete. If during D&R the dream had caused a fear level above FearExtinctionFailureThreshold, fear extinction would fail [FearExtinctionFails], and the individual wakes from an idiopathic nightmare; affect load is incremented. The dreamer wakes up terrified, and the images are in a new state [AwakeImageAwareness]. Depending on the time of night, the level of [Fear], and the dreamer’s [AffectDistressTendency]—i.e. the dreamer’s trait-like tendency to be emotionally disturbed and dysregulated by upsetting memories and images—either the dreamer falls back asleep and dreaming restarts (the blue flow [RestartDreamingFromAwake]) or sleep ends and with it the possibility of further dreaming [EndSleep].

The attempt to start the D&R part of the fear extinction process may succeed (bringing the image from [EventMemoryImagesInSleep] to [RecontextualizedImages]) but it may also fail, in which case images move down [DandRFails]. D&R fails when the traumatic quality of the event memory images [EventMemoryImagesInSleep] is extreme and defeats the capability of the fear extinction process to decontextualize images. The dreamer wakes up terrified and the images are in the [AwakeImageAwareness] state. As in the case when [DandRSucceeds] but [FearExtinctionFails]), the dreamer may fall back asleep, in which case images flow along the blue path [RestartDreamingFromAwake], or sleep may end allowing nor further chances for dreaming along the cyan path [EndSleep].

During the day, after sleep ends [EndSleep], images are available in working memory [WorkingMemoryImages]. Note that these are fear-inducing images because the fear extinction process was triggered but did not work, so treatment may occur during the day. The individual may resist sleep in future night [SleepAvoidance] possibly for several nights, but will always eventually succumb to [SleepPressure] and sleep again.

# Treatments

**Treatments are not implemented in the current DDM model.** Below is a summary of treatments and how they may be implemented in DDM.

The sleep-science consensus from a major 2018 meeting is that Image Rehearsal Therapy and Klonopin are the standard treatments for nightmare disorder. We are considering those treatments alongside Rescript (using VR for image control), and we are adding Lucid Dreaming because it also targets control, like Rescript.

## Drug Treatments

Klonopin and other, similar drugs aim to suppress the adrenal fear response. DDM includes three dosages in the AdrenalineAntagonists (AA) variable, which ranges between 0 and 1.

* AdrenalineAntagonists = 0.0 means no drugs; the treatment is not in use.
* AdrenalineAntagonists = 0.5 means the drugs dampen (halve) the effect of AffectDistressTendency, which in turn reduces AffectLoad, allowing REM circuitry to function but hopefully without the amygdala and brainstem response that makes people wake up from nightmares, terrified. Note that IRT and AA can combine if AA=0.5.
* AdrenalineAntagonists = 1.0 means shut down REM circuits completely, eliminating dreaming and therefore nightmares. Note that IRT is superfluous unless there is dreaming, which can’t happen when REM cycles are suppressed.

## Image Rehearsal Therapy (IRT)

IRT involves a patient sitting down with a therapist, identifying a nightmare image that makes the patient avoid sleep. They work together to restructure the image by making it less terrifying, perhaps journaling about it, etc. This can also be done by the patient without a therapist. IRT aims to reduce NightmareDistress and nightmare frequency by reducing NightmareSalience. But IRT won't work for people with low ImageStabilizationCapacity, such as kids, TBI patients, elderly people.

IRT is more effective the more often sessions are held – the same holds for exposure treatments in general. In DDM, the maximum treatment frequency is one treatment per day, while the minimum is one treatment every seven days. A normal treatment run is 60 days.

## Image Rehearsal Therapy - Modified (IRT Modified)

Because IRT can increase TreatmentRetraum, retraumatizing patients by focusing on traumatic memories, it can make sense to use less threatening nightmare images or an image related to the nightmare.

## Lucid Dreaming (LD)

LD is very difficult for some people and easy for others. People who find it easy have high hypnotizability, thin boundaries, etc., which is called Lucidity in the model. The LD target is ControlCapacity through head-on confrontation. LD also reduces NightmareSalience because it is literally the terrifying dream images that are confronted in LD.

## Rescript

Rescript uses virtual-reality (VR) presentation and modification of images, aiming to increase the cognitive skill of image control within the dreamer. The images are not associated strongly with nightmare content and so do not reduce NightmareSalience and also do not increase TreatmentRetraum.

## Rescript-Modified

This treatment is identical except that it does use images strongly associated with nightmare content and so may reduce NightmareSalience and also risks increasing TreatmentRetraum.

# Memory Consolidation Generally

The focus on REM is only part of the memory-consolidation story; another part is slow-wave sleep (producing delta waves), especially at the beginning of the night. This appears to be important for information transfer, including memory consolidation, within the brain, and is the focus of intensive study at present. But DDM is only a model of dreaming, and memory consolidation associated with dreaming and its disruption by nightmares.

# DDM Test cases

We include several test cases in the AnyLogic DDM model. The test cases are contained in the following AnyLogic experiments:

* Tests\_SingleNight: This contains cases over a single night.
* Tests\_TwoNights: This contains cases over two nights.
* Tests\_ManyNights: This contains cases over many nights.

Graphical user interface

Description automatically generatedTo run the test cases, right-click one of the test simulations and click Run:

Graphical user interface, text, application, chat or text message

Description automatically generated

Once the simulation is open, you must select a test case by clicking one of the buttons:

A picture containing text

Description automatically generated

The buttons and/or their description will describe the expected behavior of the test case.

**If you wish to observe the simulation occurring step by step,** you must click the “x1” button in the lower left of the simulation window. (You may also wish to slow the simulation down by pressing the slow down button on the bottom left).

Finally, the simulation will start when you press the “Run” button, which shows a triangle.

# Code Updates

The **Initialization [Init[** procedure initializes the individual as if they had perfect sleep for the past week – since some parts of the model depend on a week sleep history.

The **HourlyEvent** procedure updates tracking variables and makes them available for use in flow rate calculations and reporting. The variables are as follows:

* ControlCapacity: Tracks impact of treatments for disturbed dreaming. [ControlCapacityHistory accumulates this daily at noon]
* AffectLoad: Tracks the variable used to determine whether dreaming needs to employ the fear extinction process (Affect Load > FearExtinctionAttemptThreshold) and whether fear extinction is complete (Affect Load < FearExtinctionCompletionThreshold). AffectLoad is decreased once each REM Cycle if image processing doesn’t waken the dreamer in fear (staying asleep is the gold path in DDM). The amount of decrease is in the parameter FEAffectLoadDecrement; the decrease is the same fixed amount regardless of when during the night the REM cycle occurs. AffectLoad is also increased by traumatic nightmares (TNMAffectLoadIncrement) and Idiopathic nightmares (IDIOPATHICNMAffectLoadIncrement), which are increases in the form of the percentage of space remaining between AffectLoad and 1. [AffectLoadHistory accumulates AffectLoad daily at noon]
* HoursSleepTonight: Tracks the number of hours slept on a given night. An hour doesn’t count if dreaming leads to waking up from high fear. [HoursSleepHistory accumulates this daily at noon]
* REMPeriodsTonight: Tracks the number of REM periods completed on a given night. A REM period doesn’t count if dreaming leads to waking up from high fear. [REMPeriodsHistory accumulates this daily at noon]
* SleepDeficitLastWeek: Tracks sleep deficit for the last seven nights by comparing HoursSleepTonight to MaxHoursSleepPerNight each day at noon. [SleepDeficitHistory stores the nightly sleep deficit in an array at noon each day]
* REMDeficitLastWeek: Tracks the REM deficit for the last seven nights by comparing REMPeriodsNow to MaxREMCyclesPerNight each day at noon. [REMDeficitHistory stores the nightly REM deficit in an array at noon each day]
* IdiopathicNMTonight: Tracks count of traumatic nightmares (purple path) during the current night. (IdiopathicNMHistory accumulates this daily at noon)
* TraumNMTonight: Tracks count of non-traumatic nightmares (red path) during the current night. (TraumNMHistory accumulates this daily at noon)
* NMIntensityLastWeek: Tracks a measure of the frequency and intensity of nightmares each night = average of nightly nightmare count (traumatic nightmares count twice as heavily as Idiopathic nightmares) divided by MaxREMCyclesPerNight. (NMIntensityHistory accumulates this daily at noon)
* HourOfDay: Tracks the hour of the day. This is used to decide when to sleep (or try to sleep or need to sleep) and when to update history arrays.
* HourOfRun: Tracks the number of hours since the simulation run began (simulation runs begin at noon on day 0).

# Formulas

*(Note for coders: be sure when copying these formulas that they are using the proper dash for subtraction. In some places, an em-dash may be being used instead of an en-dash.)*

## Link Conditions

FearExtinctionStarts: (ImageValence < 0) && (AffectLoad > FearExtinctionAttemptThreshold) && (Fear < DandRFailureThreshold)

DandRFails: (ImageValence < 0) && (AffectLoad > FearExtinctionAttemptThreshold) && (Fear >= DandRFailureThreshold)

Depotentiation: Both FearExtintionStarts and DandRFails NOT triggered

FearExtinctionFails: Fear > FearExtinctionFailureThreshold

WakeupAfterFEPartial\_NoNightmare: (HourOfRun - RunHourMostRecentlyAttemptedSleep + 1 >= MaxHoursSleepPerNight) && (Fear <= FearExtinctionFailureThreshold)

FearExtinctionPartial: Both FearExtinctionFails and WakeupAfterFEPartial\_NoNightmare NOT triggered

EndSleep: (HourOfRun - RunHourMostRecentlyAttemptedSleep >= MaxHoursSleepPerNight)

|| (Fear >= PostNightmareSleepThreshold)

RestartDreamingFromAwake: EndSleep NOT triggered

StartSleep: (HourOfDay == NormalSleepHour) && (SleepAvoidance < SleepPressure)

## Dynamic Variable Definitions

Perseveration = ((ImageDominance \* ImageArousal) + TraumaHistory)/2 \* AffectDistressTendency

SleepAvoidance = ((TraumaHistory + AffectDistressTendency) / 2) \* (NMIntensityLastWeek + Perseveration) / 2

SleepPressure = ((SleepDeficitLastWeek / 7) + (REMDeficitLastWeek / 7)) / 2

Fear = (ImageValence<0.0)

? (

(

(

AffectDistressTendency+TraumaHistory +

(1.0-Control) +

ImageDominance+ImageArousal + IdiopathicNMTonight +

2.0\*TraumNMTonight+NMIntensityLastWeek

)

/9.0

)

\* (1.0-AdrenalineAntagonists)

)

: 0.0

Control = (ImageValence < 0.0) ? ((1.0 - TraumaHistory) + (1.0 - ImageDominance) / 2.0) \* ControlCapacity : 1.0

## Output Variable Definitions

NightmareDistress = (ImageValence < 0)

? ((ImageArousal \* ImageDominance) + TraumaHistory + NightmareSalience) / 3

\* AffectDistressTendency \* NMIntensityLastWeek

: 0

NightmareEffects = (ImageValence < 0)

? (

(REMDeficitLastWeek + SleepDeficitLastWeek + calculatePerseveration() + NightmareDistress + NightmareSalience)

/ 5

)

\* (1 - AdrenalineAntagonists)

: 0

DASSAnxiety = (ImageValence < 0) ? (ImageDominance + ImageArousal) / 2 \* (AffectDistressTendency + NMIntensityLastWeek + NightmareSalience) / 2 : 0

## Transition events

Upon every transition from state to state, the hour of the run is incremented and the hour of the day is moved forward. If transitioning out of a state where the individual was sleeping, the number of hours slept that night are incremented.

Some important events happen during some transitions:

* Traumatic nightmare occurs at [DandRFails]: TraumNMTonight increments, AffectLoad increments by TNMAffectLoadIncrement
* Idiopathic nightmare occurs at [FearExtinctionFails]: IdiopathicNMTonight increments, AffectLoad increments by IdiopathicNMAffectLoadIncrement.
* Fear extinction completes one cycle at [FearExtinctionPartial]: REM cycle count is increments, AffectLoad decrements by FEAffectLoadDecrement
* End sleep at [EndSleep] and [WakeupAfterFEPartial\_NoNightmare]: histories are updated to include the events of the most recent sleep cycle. Tracking variables for the current night are reset.