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A Stochastic Recoupment Model for the Increase of Oxytocin Due To Human Stress

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Abstract

The theoretical study for the effect of stress induced by the psychosomatic drug cocaine on the Oxytocin levels is investigated. Using a stochastic recoupment model, the expected number of failures and failure intensity function of Oxytocin has been obtained in the high responders (HR) and low responders (LR) to novelty. The results show that high responders displayed a higher increasing level of Oxytocin than low responders.

Keywords: Stochastic Recoupment Model, Failure intensity, Oxytocin, High responders, Low responders.

2010 Mathematics Subject Classification: 97Mxx, 93A30, 60-XX

1. Introduction

Consider a system which is at any time either in operation (up) or under recoup (down) after a failure. The effectiveness of the system can be measured by the total amount of time the system has been down during a given time interval. Maintenance of a deteriorating system is often imperfect, with the condition of the system after maintenance being at a level somewhere between new, and its prior condition. Therefore, a stochastic recoupment model is more realistic to describe the practical maintenance effort.

The neuroendocrine and physiological systems related to pain and stress has long been subjected to study. More recently, the corresponding systems, promoting anti-stress and restoration have also come into focus. It is not only important to investigate the mechanisms underlying disease, but also to examine the physiological and psychological mechanisms which protect and heal the body and soul. The Oxytocin is known to stimulate labor and milk ejection and induce anti stress like effects such as blood pressure and cortisol levels. It increases pain thresholds, exerts an anxiolytic like effect and stimulates various types of positive social interaction. In addition, it promotes growth and healing[5], [6], [8].

Here Oxytocin secretion is taken as an after effect of human stress. If the Oxytocin secretion level exceeds the threshold level, which is assumed to be a continuous random variable, the system reaches the stress related behaviors. Here we assume that, during every stress induced by the administration of psychosomatic drug cocaine, which releases Oxytocin is considered as the recoup. For a repairable system, repair actions can bring the system to one of the states, perfect repair or general repair or minimal repair. Many stochastic models for repairable systems have been developed by assuming different repair effects. The majority of these models considers only perfect repair and minimal repair [1], [9]. Recently general repairs have received much attention [2], [3].

2. Notations

N(t)	-	Cumulative number of failures up to time t.
m(t)	-	E [N (t)]

$\lambda(t)$	-	Failure intensity function
$\lambda_0(t)$	-	Baseline failure intensity function
a, b, γ	-	Parameters of the model

3. Assumptions of the stochastic model

1. The dosages of the drug levels are non – renewable.
2. Stress effect is the source of increase in Oxytocin levels.
3. Oxytocin secretions are caused due to successive stresses whose inter arrival times are i. i. d. random variables.
4. Here the threshold level is the accumulated level in Oxytocin secretion due to successive stresses.
5. The states of stress are mutually independent when the influence of the environment is unaccounted for.

4. A Stochastic Recoupment Model

Assume that the cumulative number of recoups or failures is a useful metric that captures the age, use behavior, operating conditions of the system. Consider a general recoupment model based on the expected cumulative number of recoups (failures) as

$$\lambda(t) = \lambda_0(t)\ \exp\ [\gamma\, m(t)] \qquad \text{---------------}\rightarrow (1)$$

Where $\lambda_0(t)$ is the baseline failure intensity function, and the recoup effect is reflected by the second term $\exp[\gamma m(t)]$ with parameter γ. By considering the effective recoups, i.e. the system reliability is recovered or at least not worsened after each recoup we have $\gamma \leq 0$.

The closed form solution of m(t) can be obtained by solving the differential equation

$$\lambda(t) = \frac{dm(t)}{dt} = \lambda_0(t)\exp[\ \gamma\, m(t)]$$

$$\Rightarrow m(t) = -\frac{1}{\gamma}\ln\left[-\gamma\int \lambda_0(t)dt + C\right] \qquad \text{---------------}\rightarrow (2)$$

where C is a constant .

If the log-linear baseline intensity function is $\lambda_0(t) = e^{a+bt}$ then the model (1) becomes,

$$\lambda(t) \ = \ e^{a+bt}\, e^{\gamma\, m(t)} = e^{a+bt+\gamma\, m(t)} \qquad \text{---------------}\rightarrow (3)$$

Now the equation (2) becomes,

$$m(t) = \ -\frac{1}{\gamma}\ln\left[-\gamma\int e^{a+bt}dt + C\right]$$

$$= \ -\frac{1}{\gamma}\ln\left[-\gamma\left(\frac{1}{b}e^{a+bt} + C\right)\right] \qquad \text{---------------}\rightarrow (4)$$

Using the boundary condition m(0) = 0 in (4), we have

$$0 = -\frac{1}{\gamma}\ln\left[-\gamma\left(\frac{1}{b}e^{a}+C\right)\right]$$

$$\Rightarrow \quad \ln(-\gamma)+\ln\left(\frac{1}{b}e^{a}+C\right)=0$$

$$\Rightarrow \quad C = -\frac{1}{\gamma}-\frac{1}{b}e^{a} \ , \text{When } b \neq 0 \qquad \text{---------------}\rightarrow (5)$$

Sub.(5) in (4), we get

$$m(t) = -\frac{1}{\gamma}\ln\left[\frac{-\gamma}{b}e^{a+bt}+1+\frac{\gamma}{b}e^{a}\right], b \neq 0 \qquad \text{---------------}\rightarrow (6)$$

From equation (3), we have

$$\lambda(t) \ = \ e^{a+bt}.e^{\gamma\left\{\frac{-1}{\gamma}\ln\left[\frac{-\gamma e^{a+bt}+b+\gamma e^{a}}{b}\right]\right\}}$$

$$= e^{a+bt}.e^{\ln\left[\frac{b}{-\gamma e^{a+bt}+b+\gamma e^{a}}\right]}$$

$$= \frac{be^{a+bt}}{b-\gamma e^{a+bt}+\gamma e^{a}}, b \neq 0 \qquad \text{---------------}\rightarrow (7)$$

5. Application

Individual differences in the susceptibility to psycho stimulant have extensively reported, both in humans and in animals [4]. The subjects are selected on the basis of their locomotors response to a novel open field and, accordingly, labeled high responders (HR) and low responders (LR) to novelty [7], [10]. Both LR and HR were injected 15 mg / kg of cocaine. After the exposure to novelty, the accumbal extracellular concentration of Oxytocin was recorded for a period of 95 minutes. It is seen that after the administration of Cocaine, the Oxytocin levels more strongly in HR than in LR.

The parameters of the stochastic recoupment model for the HR group were measured as $a = 301.5$, $b = 2.22$ and $\gamma = -0.003$. The parameters of the stochastic recoupment model for the LR group were measured as $a = 167.4$, $b = 2.84$ and $\gamma = -0.006$. The failure intensity $\lambda(t)$ and the expected number of failures $m(t)$ of Oxytocin levels in HR and LR were calculated using the Stochastic recoupment model and is given in Fig. 2 and Fig. 3.

6. Conclusion

A stochastic model for the release of Oxytocin due to stress induced by the administration of the psychosomatic drug cocaine is developed by using a stochastic recoupment model. Form the Fig 5.2 and Fig 5.3, we found that the mean number of failures and failure intensity of HR and LR. It is seen that HR displayed a higher expected number of failures and failure intensity than LR. The results are consistent and the stochastic recoupment model concludes that HR displayed a higher increasing level of Oxytocin than LR.

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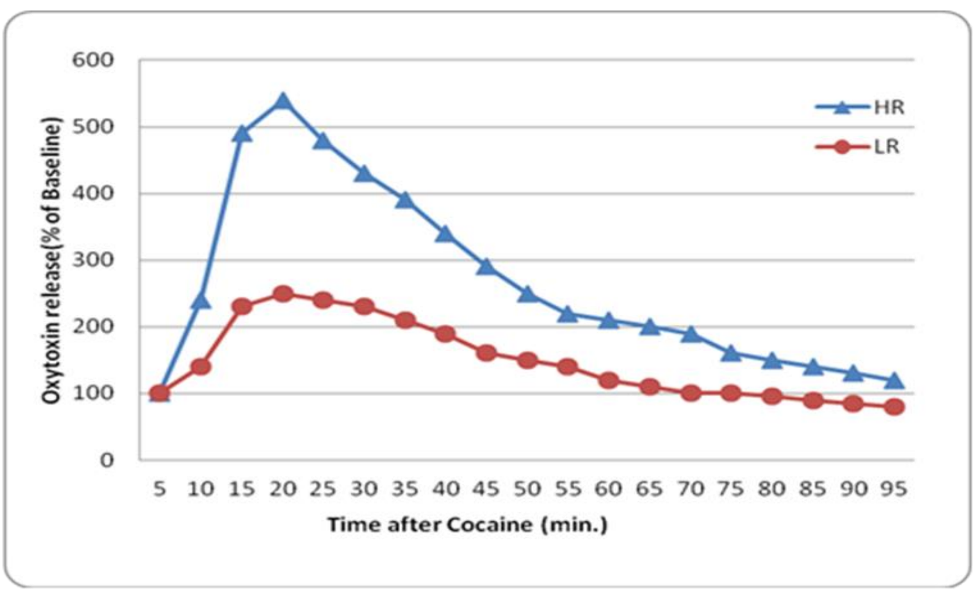


Fig. 1: Effects of 15 mg / kg Cocaine on the Oxytocin levels (% of baseline) for HR and LR.

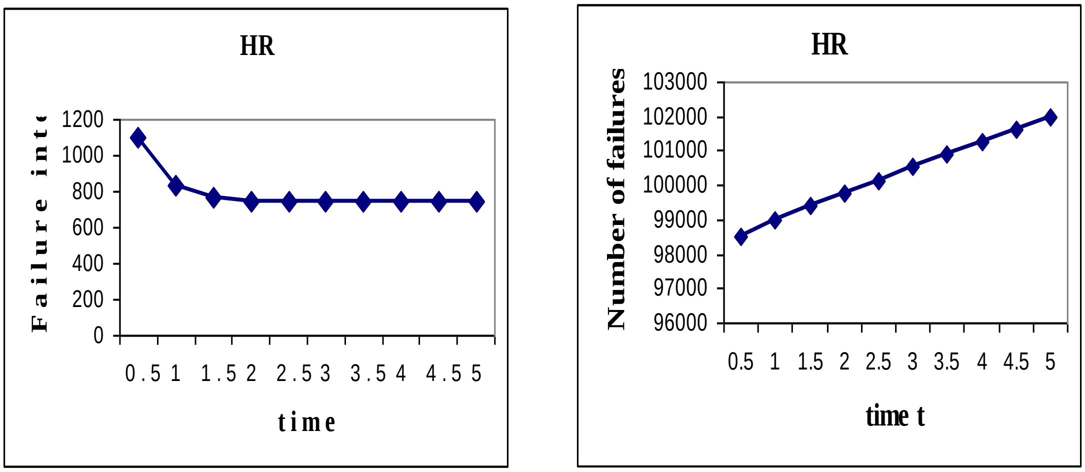
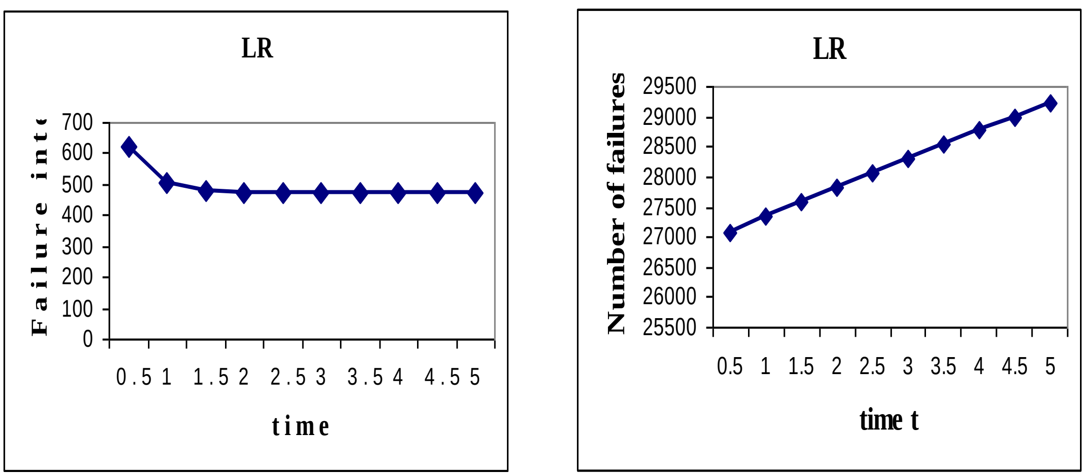


Fig. 2: Estimates of (a) the failure intensity λ(t) and (b) the expected number of failures m(t) of Oxytocin levels in HR



(a) (b)

Fig. 3: Estimates of (a) the failure intensity λ(t) and (b) the expected number of failures m(t) of Oxytocin levels in LR