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Biological and Dynamic Nature of Personality: a Dynamic System Approach

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Abstract

A system dynamic response model of personality to a stimulus is presented, although its validation is performed for a unique dose of a stimulant drug (caffeine). From the Unique Trait Personality Theory, proposed by Amigó [1] and Amigó, Caselles and Micó [2], the dynamic response is represented by the brain excitation level. In addition, it is representative of personality, which arises in the psychological level of description as the extraversion trait, and it can be measured through the sensation seeking scale of the MAACL by Zuckerman and Lubin [3]. Thus, our hypothesis is that personality has two different, but compatible, natures: biological and dynamic. On a hand, biological nature lies in the stress system, whose activity in brain can be observed by the brain excitation level. Different brain excitation levels represent different extraversion personalities. On the other hand, dynamic nature is given by the response of brain to a stimulus. The dynamics incorporates the classical psychological approach to personality, which asserts that extraversion is also a trait, as a steady state given by the genetic activation level. In other words, as the stimulus vanishes, the activation level returns to its genetic value. The model provided here bestows the novelty that the dynamics of the activation level variable, for a unique dose, can be described by a differential equation without delay. This allows presenting further trends in the definition of personality, based on the activation level variable and its time derivative, which, respectively, illustrate the state and the expectation of new experiences of individuals.

Key words: Personality, Brain Activation Level, Extraversion, Dynamics, Differential Equation.

1. Introduction

The present article is devoted to the brain dynamic response to a dose of a stimulant drug. The response of brain is measured by its activation level, through the hedonic scale, given by 12 adjectives of the sensation seeking scale, selected from MAACL [3]. Our start point is the model presented by us [2] to describe the dynamic response of the brain activation level as a consequence of a unique dose consumption of a stimulant drug.

Following the Unique Personality Trait Theory (UPTT from now onwards) of Amigó [1], the brain activation level represents the biological base of the unique trait here considered for the psychological description: extraversion. The highest extravert individuals correspond to the lowest brain activation levels (the minimum in the MAACL scale), and they are the most extreme sensation seekers, and vice versa, the lowest extraverted individuals (introvert individuals) correspond to the highest activation levels, and they are the most insignificant sensation seekers (the maximum in the MAACL scale). All the intermediate states are considered in a continuous way in the MAACL scale. An individual situated in half of this scale is called ambivert individual.

The model is constituted by three coupled differential equations, being the state variables: the *non-assimilated drug* variable, the *drug in blood* variable (which represents

the stimulus), and the *brain activation level* variable (*activation level*, for short). The derivative respect to the time of the activation level is the sum of three flows. Two of them arise as a consequence of the stimulus while the third flow appears with a finite and positive delay. The first flow, called *homeostatic control*, is a mechanism of fast recovering of the genetic activation level. The second flow, called *excitation effect*, increases the activation level as a consequence of the stimulus. The third flow is a slow control mechanism, called *inhibitor effect* which, after the time delay (called *inhibitor effect delay*), decreases the activation level. Thus, the equation corresponding to the activation level is a delay differential equation with finite delay and, therefore, it represents an "all or nothing" phenomenon. This equation predicts de the time patterns described by Solomon and Corbit [4], Grossberg [5] and Amigó [1].

On the other hand, the "all or nothing" phenomenon belongs to a microscopic level of description, but at a macroscopic level of description (which corresponds to the here presented work), a continuous approach can be provided. Thus, a discrete delay can be substituted by a continuous one, arising as a consequence an alternative model, the so-called *continuous delay model*, which reproduces the same time patterns than the discrete delay model [6].

Further simulations with the model show that the model for a unique dose of a stimulant drug can be also described without (discrete or continuous) delay, although an addiction model needs that delay must be considered, as Solomon and Corbit points out [4]. The model without delay can reproduce the same time patterns mentioned above. Following the science principle of choosing the simplest model, we are going to work, in the context of this paper, with the model without delay, leaving for future investigations if an addiction model will need of the mathematical consideration of a delay. The qualitative study and experimental validation of the model without delay, moreover of a dynamic quantitative definition of personality, are the other goals of this paper.

From the consideration of this model, two different natures of personality arise. On a hand, the biological nature, given by the consideration a unique trait, extraversion. Extraversion is the psychological representation of the biological brain activation level. This nature is compatible with the dynamic nature, which provides the dynamic quantitative definition of personality.

In Section 2 the discrete delay model is revised. In Section 3 we deal with the qualitative study of the model without delay. In Section 4 the same model without delay is validated experimentally for an individual that consumed coffee, thus, caffeine is the stimulant drug considered. Section 5 is devoted to the dynamic quantitative definition of personality. In Section 6 the article conclusions are developed.

2. The discrete delay model

Let $y(t)$, b and y_0 be respectively the activation level variable (representative of the extraversion unique trait), its tonic (genetic) level and its initial value. In [2] we demonstrate that the delay differential equation for this variable is:

$$\frac{dy}{dt} = \begin{cases} a\ b - y(t) + \frac{p}{b} s(t) : \ 0 \le t \le \tau \\ a\ b - y(t) + \frac{p}{b} s(t) - b \cdot q \cdot s(t-\tau) \cdot y(t-\tau) : t > \tau \end{cases} \qquad (1)$$
$$y(0) = y_0$$

Equation (1) has an analytical solution [2], with a recurrent structure that includes definite integrals of the stimulus. The stimulus, $s(t)$, is given by the amount of non

consumed drug by cells in blood. If *c(t)* is the non assimilated drug by blood, *s(t)* and *c(t)* are computed by two coupled differential equations:

$$\left.\begin{aligned} \frac{dc(t)}{dt} &= -\alpha \cdot c(t) \\ c(0) &= M \end{aligned}\right\} \tag{2}$$

$$\left.\begin{aligned} \frac{ds(t)}{dt} &= \alpha \cdot c(t) - \beta \cdot s(t) \\ c(0) &= s_0 \end{aligned}\right\} \tag{3}$$

In (2) M is the initial amount of drug consumed in an only dose, and α is the drug assimilation rate. In (3), s_0 is the amount of drug present in blood before consumption, and β is the drug consumption rate.

Following (1), the term $a\ b - y(t)$, called *homeostatic control*, is the cause of the fast recovering of the tonic (genetic) level *b*. The term $p \cdot s(t)/b$ is the so called *excitation effect*, which tends to increase the brain activation level, being *p* a parameter called *excitation effect power*. The term $b \cdot q \cdot s(t-\tau) \cdot y(t-\tau)$ is the so called *inhibitor effect*, which tends to decrease the brain activation level, and it is the cause of the slow recovering of the brain activation level, being *q* a parameter called *inhibitor effect power*.

Observe in (1) that the homeostatic control and the excitation effect takes place before the time τ, called *inhibitor effect delay*. After this delay the inhibitor effect takes place, which means that an "all or nothing" effect holds, similar to the electrochemical transmission by the neuron axon [7].

The model given by (1), (2) and (3) reproduces the dynamic patterns forecasted by Solomon and Corbit [4], Grossberg [5] and Amigó [1], and it can be considered theoretically validated though the scientific literature about the subject [2].

Equation (1) without delay states as the following differential equation:

$$\left.\begin{aligned} \frac{dy}{dt} &= a\ b - y(t) + \frac{p}{b} s(t) - b \cdot q \cdot s(t) \cdot y(t) \\ y(0) &= y_0 \end{aligned}\right\} \tag{4}$$

The model that here is studied qualitatively and validated is the provided by Equations (2), (3) and (4).

3. Qualitative study of the model

In order to obtain the singular points of the model without delay, we equal zero Equations (2), (3) and (4). The only singular point is *(c,s,y)=(0,0,b)*. The approximation by the first order Taylor's terms about this singular point provides the following linear system:

$$\frac{d}{dt}\begin{bmatrix} c \\ s \\ y \end{bmatrix} = \begin{bmatrix} -\alpha & 0 & 0 \\ \alpha & -\beta & 0 \\ 0 & p/b - qb^2 & -a \end{bmatrix} \begin{bmatrix} c \\ s \\ y - b \end{bmatrix} \tag{5}$$

The eigenvalues λ of the square matrix involved in (5) are λ=-α, -β, -*a*. Being positive all the parameter values, the eigenvalues are negative, thus, the singular point

(c,s,y)=(0,0,b) of the model is a steady state, moreover, it is asymptotically stable, therefore, all the trajectories of the activation level, *y(t)*, tend asymptotically to its tonic value *b*. This corresponds with the biology of human individual, i.e., after the consumption of a stimulant drug, and in absence of other stimuli, his/her organism recovers his/her genetic state (the classical extraversion trait).

4. The model validation

The model validation has been performed on an individual that has consumed two cups of coffee, equivalent to M=330 mg of caffeine. The brain activation level has been assessed by the subjective scale (hedonic scale) given by the 12 adjectives of the *sensation seeking scale* score, selected from MAACL [3]. The measure unit has been called activation unit (au).

First of all, the individual fills the 12 adjectives of the score, just before the coffee consumption, on fast conditions. This result is taken as initial condition. In the following, the individual consumes the stated dose of coffee and, each four and half minutes, fills the score. This is made during a period of 90 minutes, i.e., the individual has filled the score 20 times moreover the initial condition.

The model is programmed in MATHEMATICA 6.0. On a hand, the validation is made visually, by fitting the theoretical curve provided by the model with the experimental data, through a trial-error method. Once a good fit is observed, the determination coefficient (R^2) between experimental and theoretical data is computed, in order to assess quantitatively the fit of both sets of data. A following trial-error method is developed in order to improve the coefficient determination and to obtain a normal and random distribution of the residuals.

The outcome of the graphic validation can be seen in Figure 1. The determination coefficient obtained is R^2=0.94. This result, together the visual inspection of Figure 1, confirms the acceptance of the model. The parameter values obtained are: α=0.058 min^{-1}; β=0.048 min^{-1}; a=1.265 min^{-1}; b=12.0 au; p=6.8 $au^2 \cdot mg^{-1} \cdot min^{-1}$; q=0.00017 $au^{-1} \cdot mg^{-1}$. These values belong to each individual and they describe a biological feature of him/her. For instance, the value α=0.058 min^{-1} asserts that 5.8 mg per thousand are assimilated by the organism per minute. A significant value is the corresponding to the tonic level b=12.0 au. Observe that it is quite similar to the initial condition value, y_0=11.0 au. These similar outcomes between both parameters are expectable, due to the initial condition value must be similar on fast conditions in the morning to the activation genetic value (b), when individual has an almost absence of stimuli.

5. A dynamic quantitative definition of personality

From the UPTT of Amigó [1], personality can be described by a unique trait, extraversion. In addition, we assert that personality, i.e., extraversion, has a biological nature: the brain activation level. As it has been said above, there exists a correspondence between extraversion values and activation levels. These extraversion values can be measured by the *sensation seeking scale* score, selected from MAACL.

In addition, we assert that personality has a dynamic nature. Extraversion or activation level can be described dynamically through three coupled differential equations that include the stimulus dynamics. Observe in Figure 1 the time pattern obtained for this dynamics. It has an inverted-U shape, characteristic of the elevation of the activation level, due to the stimulus influence, and its return to the tonic or genetic level. Note that this dynamic definition of personality includes the classical psychological definition of personality, which claims that personality is a stable trait: the stable trait is represented by the tonic or genetic level, which is a steady state of the dynamics. This dynamics can change eventually due to arbitrary stimuli, but, in stimulus absence, the

activation level variable will return to its tonic level value. Thus, a main conclusion of our model is that it contains both approaches of personality. Through the time pattern given by *y(t)*, the static nature is represented by its steady state or tonic level, and the dynamic nature is given by the dynamic response as a consequence of a stimulus.

Nevertheless, this dynamic quantitative definition of personality is not complete. Why? Observe in Figure 1 that, due to the inverted-U shape, the curve has the same values in the last period of the time pattern, when the individual returns to his/her genetic value, than the values at the first period, when the individual has just consumed the drug. Nevertheless, it is psychologically demonstrated that individuals have not the same predisposition to be a sensation seeker [1] in both periods (significantly more in the first period). Our hypothesis is that this predisposition must be assessed by the curve slope in each curve point, i.e., by the derivative *y'(t)*.

Observe Figure 1, in the period of the first minutes, being increasing the curve, the predisposition of individual will be psychological positive to new experiences, but in the period of the last minutes, being decreasing the curve, the predisposition of individual will be psychological negative to new experiences. The psychological positive and negative predisposition has a correspondence with the values of the derivative *y'(t)*. In Figure 2 the derivative of the theoretical curve has been represented. Observe that the predisposition to have new experiences increases from the initial condition until reaching a maximum. This is *the sensitizing phase*; in this phase, for each instant, the individual is a greater sensation seeker than the before instant. After the maximum, the habituation phase arises; in this phase, for each instant, the individual is a lesser sensation seeker than the last instant, until the minimum is reached. After the minimum, the *return phase* emerges, which individual reaches the initial value of the activation level for, but with a lesser predisposition to have experiences. Finally, have the negative values of the curve derivative any sense? Our hypothesis is that they represent the phase called as craving, which individual has the worst sensations.

As conclusion of these ideas, a dynamic quantitative definition of personality must incorporate the time derivative of the activation level variable. Thus, personality is given by the pair (*y(t)*, *y'(t)*), where *y(t)* is supplied by the model (2), (3) and (4). The brain activation variable of the model evaluates the dynamic evolution of extraversion as a consequence of a stimulus, and *y'(t)* evaluates the evolution of the predisposition to have new experiences.

6. Conclusions

The present paper postulates a system of three coupled differential equations that describes the dynamics of the stimulus of a stimulant drug together the dynamics of the brain activation level. The model is a simplified adaptation of the one presented in [2]. The simplification consists of the non consideration of the delay, and it becomes also validated. The UPTT of Amigó [1] claims that brain activation level is the biological base of the psychological extraversion factor, which is the unique trait, considered here, in order to forecast human personality. The results of the model, for a stimulus given by the consumption of a unique dose of a stimulant drug, confirm the theories cited in [1], which are integrated in the UPTT.

The qualitative study of the model provides that the model has a steady state, given by the tonic activation level. This parameter is the genetic individual extraversion. As the stimulus vanishes, the activation level returns to it. In addition, the lower its value is, the higher the phasic response or time pattern is, and vice versa. Given the inverse correspondence between the brain level activations and the extraversion variable values, an individual with lower activation level will be more extraverted, and an individual with higher activation level will be more introverted.

The model validation has been performed with an individual that has consumed 330 mg of caffeine. The extraversion variable has been assessed by the subjective

scale (hedonic scale) given by the 12 adjectives of the sensation seeking scale score, selected from MAACL [3]. The measure unit has been called activation unit (au). The experiment provides a determination coefficient of R^2=0.94 between the experimental data and theoretical data given by the model. This result confirms the relationship between the model and the reality. Thus, our next investigations will have to consider this more simplified model without delay, in order to focus mathematically the problem of addiction.

Therefore, does this model bestow fluctuant solutions, as observed in the model with delay, which are observed as well experimentally in the dynamics of some individual? Could we use this model without delay in order to construct an addiction model, despite the importance that the theories [1] [4] offer to the delay? These questions must be answered in future investigations. Other questions to be investigated are the importance of the existence or not of chaos for the model presented. If we compare our model with a logistic model, it has also a nonlinearity of second order. Taking into account that the logistic model has chaotic trajectories, a plausible hypothesis is that our model should have them as well. However, what psychological sense would a chaotic trajectory have? Would the sensitivity to the initial conditions that chaos represents be a prediction of sudden changes of personalities under determined stimulus scenarios? Could we study the pathological personalities from this paradigm?

To end, a dynamic quantitative definition of personality has been proposed, as the pair given by the time patterns of the extraversion variable and its derivative. Despite the reductionism in a science as Psychology that this definition represents, it predicts the different phases which an individual runs through when he/her consumes a dose of a stimulant drug. In conclusion, the model presented, and the quantitative definition of personality afforded, attempt to set up the bases of a psychological dynamic mathematics, in the context of the General Systems Theory.

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Figure 1

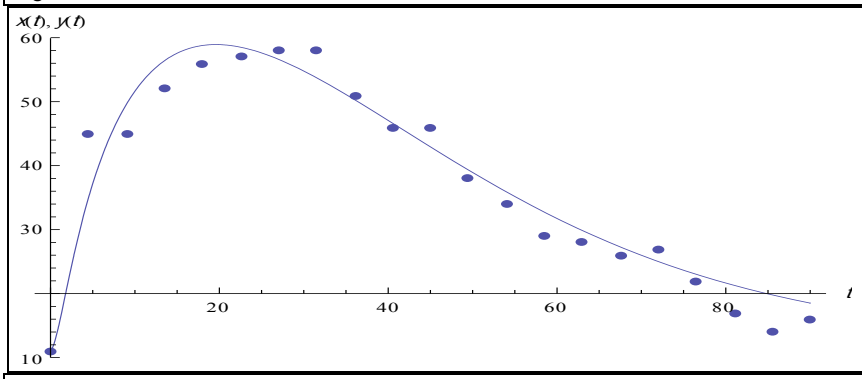

Figure 1: Experimental values of the activation level in a hedonic scale (points) *x(t)*, together the theoretical values (line) *y(t)*, versus time in minutes. R^2=0.94.

Figure 2

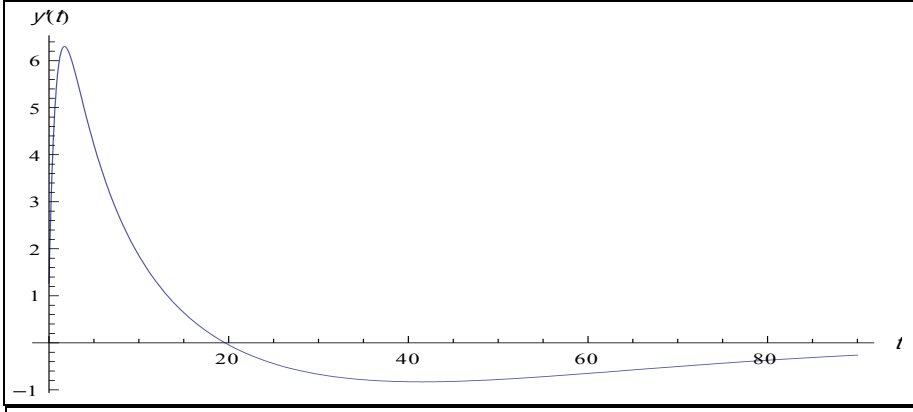

Figure 2: Derivative of the activation level in a hedonic scale *y'(t)*.