BIOLOGY AND PERSONALITY: A MATHEMATICAL APPROACH TO THE BODY-MIND PROBLEM

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Abstract
The *body-mind problem* is an ancient inquiry in the history of knowledge that has not had a satisfactory answer yet. The present study attempts to deal with it from a mathematical *invariance principle* that relates personality dynamics in two levels of description: the psychological level, measured by the *General Factor of Personality* (*GFP*), representative of mind, and the biological level, measured by the glutamate concentration in blood, representative of body. On a hand, the *response model*, an integro-differential equation, is capable to reproduce the personality dynamics as a consequence of a determined stimulus. The invariance principle asserts that the response model can reproduce the personality dynamics at the two levels of description. As a consequence, the *bridge model*, a second order partial differential equation, can be deduced. It provides the co-evolution of the *GFP* (mind) and the glutamate (body). An application case is presented by setting up an experimental design with a subject: the *GFP* and the *glutamate* dynamics are evaluated as a consequence of a 20 mg methylphenidate dose. With the outcomes of the application case the response and the bridge models are validated.

Keywords*: body-mind problem; general factor of personality; glutamate; response model; integro-differential equation; bridge model; second order partial differential equation; methylphenidate*.

1. Introduction

The first rational approach to the *body-mind problem* is given to Plato as a dualism between sensitive (body) and intelligible (mind) worlds. Aristotle substitutes Plato's dualism for a matter-shape dualism, considering in his approach psychology, in early ages of philosophy, as a part of physiology. In the Middle Ages the Christian dualism between body and soul (mind) is the dominant thought. Descartes defends a substantial dualism of body and mind but connected through the pineal glandule, although Spinoza and Leibnitz reduce the dualism to two aspects of an all, rather than two total separated aspects. In the twentieth century the positivism proposes the associationism as a way to study the relationship between body and mind through the scientific method. Basically, ending the twentieth century and starting the twenty-first century, two philosophers of science have studied deeply the body-mind problem: Karl R. Popper (Popper, 1994) and Mario Bunge (Bunge, 2002).

No researcher denies in the present that body and mind work intimately integrated. A way to observe their relationship is to study the psychological and biological responses to drug consumption. Kraepelin is considered the first researcher that used widely drugs to study the biological bases of personality, creating the first psyco-pharmacology laboratory (Carlson, 1990, López.-Múñoz & Alamo 1998). In addition, the discovering of neurotransmitters and their functions were fundamental to deepen in these biological bases (Torres & Escarabajal, 2005).

In the application case presented to study the body-mind problem, methylphenidate is the drug used. It is a powerful psycho-stimulant. This psycho-stimulation can be measured by the *General Factor of Personality* (*GFP*), as a universal observable of personality (mind). In fact, to measure the *GFP*, the five adjectives scale has been used in the application case (Amigó, Micó & Caselles, 2009a). This scale is based on the *General Factor of Personality Questionnaire* (Amigó, Caselles & Micó, 2010), which has been constructed specifically to assess *GFP* in the context of the *Unique Trait Personality Theory* (*UTPT*) (Amigó, 2005; Amigó et al., 2010). The *UTPT* claims for a unique trait, as synonymous of single trait, substituted later by the equivalent concept of *GFP*, to describe the overall human personality. The *GFP* is the psychological expression of the activation level of the organism stress system. In fact, in the context of the *UTPT*, *GFP* is called as well as *extraversion* in a wider sense than the used in behavioral science, i.e., in the sense of activation level of the organism stress system.

Glutamate (body) is connected with the *GFP* (mind) because it plays a system roll in the overall biological processes related to the activation of the organism stress system, and thus to *GFP*. See the work Amigó (2005) for this question. The raison to use methylphenidate as the stimulus in the application case is because, in addition to the psycho-stimulant effect, its acute administration actives the production of glutamate (Boldyrev, Carpenter & Johnson, 2005). Thus, it is a universal observable of the biological bases of personality (body), and it can be measured by its molar concentration in blood (Amigó, Caselles, Micó & García, 2009b). Therefore, the double response produced by methylphenidate, psychological (mind) and biological (body), emphasizes its importance in the application case presented.

The *response model* is an integro-differential equation that has been widely assessed in the context of different experimental designs. It can reproduce the acute effect of a stimulant drug at the both levels of description considered in this work (Amigó, Caselles & Micó 2008; Caselles, Micó & Amigó, 2011; Micó, Amigó & Caselles, 2012; Micó, Caselles, Amigó, Cotolí & Sanz, 2013; Micó, Amigó & Caselles, 2014). The model reproduces the dynamical pattern forecasted by Solomon & Corbit (1974) and Grossberg (2000), by using the hedonic scale, and Amigó (2005) for the *GFP*, i.e., a typical inverted-U.

The assumption of the mathematical *invariance principle*, which claims that the psychological (mind) and biological (body) responses hold the response model, provides *the bridge model*, a second order partial differential equation. It has been assessed, in a more primitive mathematical structure (a first order partial differential equation), where the drug provided is caffeine (Micó et al., 2014), to study the co-evolution of the *GFP* and the Big Five traits. Although published before, it has been assessed subsequently in a more evolved mathematical structure: a coupled system of two first order partial differential equations (Micó et al., 2013). There, the co-evolution of the *GFP*, the regulator gen c-fos and glutamate are studied as a consequence of methylphenidate consumption. However, it is still more primitive than the bridge model here presented.

In this paper the response model is presented, and by using the invariance principle, the bridge model is deduced. By using the outcomes of the application case both models are validated. The response model is validated by calibration for both responses: the *GFP*, measured by the five adjectives list, and the glutamate, measured by the molar concentration in blood. Subsequently the bridge model is validated by using the calibrated values of the response model parameters.

2. The response model

The kinetic part of the response model provides the evolution of the drug stimulus amount, $s(t)$, in organism, after being consumed by the individual. It is given by the time function:

$$s(t) = \begin{cases} \frac{\alpha \cdot M}{\beta - \alpha} (\exp(-\alpha \cdot t) - \exp(-\beta \cdot t)) : \ \alpha \neq \beta \\ \alpha \cdot M \cdot t \cdot \exp(-\alpha \cdot t) : \ \alpha = \beta \end{cases} \quad (1)$$

Equation (1) is the solution of two coupled differential equations (Micó et al., 2014), which assumes that no drug is present in the organism before consumption. In (1) M is the initial amount of a drug single dose, α is the drug assimilation rate and β is the drug distribution rate. The dynamics of the *GFP* is given by the following integro-differential equation (Micó et al., 2014):

$$\left.\begin{array}{c}\frac{dy(t)}{dt} = a(b - y(t)) + \frac{p}{b}s(t) - b \cdot q \cdot \int_0^t e^{\frac{x-t}{\tau}} \cdot s(x) \cdot y(x)\, dx \\ y(0) = y_0\end{array}\right\} \quad (2)$$

In (2), $s(t)$ represents the stimulus given by (3); $y(t)$ represents the *GFP* dynamics; and b and y_0 are respectively its tonic level and its initial value. Its dynamics is a balance of three terms, which provide the time derivative of the *GFP*: the *homeostatic control* ($a(b - y(t))$), i.e., the cause of the fast recovering of the tonic level *b*, the *excitation effect* ($p \cdot s(t)/b$), which tends to increase the *GFP*, and the *inhibitor effect* ($\int_0^t e^{\frac{x-t}{\tau}} \cdot s(x) \cdot y(x)\, dx$), which tends to decrease the *GFP* and is the cause of a continuously delayed recovering, with the weight $e^{\frac{x-t}{\tau}}$. Parameters *a*, *p*, *q* and τ are named respectively the *homeostatic control power*, the *excitation effect power*, the *inhibitor effect power* and *the inhibitor effect delay*. All the parameters of the model depend on the individual personality or individual biology and on the type of stimulus.

3. The bridge model

To deduce the bridge model, the starting point is assuming the invariance principle, i.e., the dynamical response of the glutamate can be also described by the response model (2), but with different parameter values. If $g(t)$ is the glutamate variable, g_0 its initial value, and A, B, P, Q and T are the corresponding parameters, the response model corresponding to the glutamate response can be written as:

$$\left.\begin{array}{c}\frac{dg(t)}{dt} = A(B - g(t)) + \frac{P}{B}s(t) - B \cdot Q \cdot \int_0^t e^{\frac{x-t}{T}} \cdot s(x) \cdot g(x)\, dx \\ g(0) = g_0\end{array}\right\} \quad (3)$$

Note in (3) that *s*(*t*) is the stimulus function (1). Thus, the invariance principle assumes that the influence of the stimulus on the *GFP* and on glutamate is the same. To find the mathematical relationship between glutamate and the *GFP* and the time *t*, the hypothesis stated is:

$$g = g(t, y) \quad (4)$$

Taking the time derivative in (4):

$$\frac{dg(t,y)}{dt} = \frac{\partial g(t,y)}{\partial t} + \frac{\partial g(t,y)}{\partial y}\frac{dy}{dt} \quad (5)$$

Substituting (2) and (3) in (5), and considering now that the time function $g(t)$ is, from (4), a two-variables function:

$$A(B - g(t,y)) + \frac{P}{B}s(t) - B \cdot Q \cdot f(t,y) = \frac{\partial g(t,y)}{\partial t} + \frac{\partial g(t,y)}{\partial y}\left(a(b - y) + \frac{p}{b}s(t) - b \cdot q \cdot z(t)\right) \quad (6)$$

Take into account in (6) that, in order to simplify, and for subsequent computations:

$$z(t) = \int_0^t e^{\frac{x-t}{\tau}} \cdot s(x) \cdot y(x)dx = e^{-\frac{t}{\tau}}\int_0^t e^{\frac{x}{\tau}} \cdot s(x) \cdot y(x)dx \quad (7)$$

$$f(t,y) = \int_0^t e^{\frac{x-t}{T}} \cdot s(x) \cdot g(x,y)dx = e^{-\frac{t}{T}}\int_0^t e^{\frac{x}{T}} \cdot s(x) \cdot g(x,y)dx \quad (8)$$

The way to avoid the delayed term $f(t,y)$ in (6), specified by (8), is to convert it in a second order partial differential equation. To do this, the time partial derivative is taken in both sides of (6):

$$-A\frac{\partial g(t,y)}{\partial t} + \frac{P}{B}s'(t) - B \cdot Q\frac{\partial f(t,y)}{\partial t} = \frac{\partial^2 g(t,y)}{\partial t^2} + \frac{\partial^2 g(t,y)}{\partial t\, \partial y}\left(a(b - y) + \frac{p}{b}s(t) - b \cdot q \cdot z(t)\right) + \frac{\partial g(t,y)}{\partial y}\left(\frac{p}{b}s'(t) - b \cdot q \cdot z'(t)\right) \quad (9)$$

Note from (7) and (8) that:

$$z'(t) = -\frac{1}{\tau}z(t) + s(t) \cdot y \quad (10)$$

$$\frac{\partial f(t,y)}{\partial t} = -\frac{1}{T}e^{-\frac{t}{T}}\int_0^t e^{\frac{x}{T}} \cdot s(x) \cdot g(x,y)dx + e^{-\frac{t}{T}} \cdot e^{\frac{t}{T}} \cdot s(t) \cdot g(t,y) = -\frac{1}{T}f(t,y) + s(t) \cdot g(t,y) \quad (11)$$

The substitution of (10) and (11) in (9) provides:

$$-A\frac{\partial g(t,y)}{\partial t} + \frac{P}{B}s'(t) + \frac{B \cdot Q}{T}f(t,y) - B \cdot Q \cdot s(t) \cdot g(t,y) = \frac{\partial^2 g(t,y)}{\partial t^2} + \frac{\partial^2 g(t,y)}{\partial t\, \partial y}\left(a(b - y) + \frac{p}{b}s(t) - b \cdot q \cdot z(t)\right) + \frac{\partial g(t,y)}{\partial y}\left(\frac{p}{b}s'(t) + \frac{b \cdot q}{\tau} \cdot z(t) - b \cdot q \cdot s(t) \cdot y\right) \quad (12)$$

The next step is the elimination of the integral term $\frac{B \cdot Q}{T}f(t,y)$ in (12). First, the term $B \cdot Q \cdot f(t,y)$ is isolated from (6):

$$B \cdot Q \cdot f(t,y) = A(B - g(t,y)) + \frac{P}{B}s(t) - \frac{\partial g(t,y)}{\partial t} - \frac{\partial g(t,y)}{\partial y}\left(a(b - y) + + \frac{p}{b}s(t) - b \cdot q \cdot z(t)\right) \quad (13)$$

Subsequently (13) is substituted in (12), and after reorganization:

$$\frac{\partial^2 g(t,y)}{\partial t^2} + \left(a(b-y) + \frac{p}{b}s(t) - b\cdot q\cdot z(t)\right)\frac{\partial^2 g(t,y)}{\partial t\,\partial y} + \left(\frac{p}{b}s'(t) + \frac{b\cdot q}{\tau}\cdot z(t) - b\cdot q\cdot s(t)\cdot y + \frac{1}{T}\left(a(b-y) + \frac{p}{b}s(t) - b\cdot q\cdot z(t)\right)\right)\frac{\partial g(t,y)}{\partial y} + \left(A + \frac{1}{T}\right)\frac{\partial g(t,y)}{\partial t} = \frac{A}{T}(B - g(t,y)) - B\cdot Q\cdot s(t)\cdot g(t,y) + \frac{P}{T\cdot B}s(t) + \frac{P}{B}s'(t) \quad (14)$$

Equation (14) must be completed with the boundary conditions:

$$g(0,y) = g_0 \quad (15)$$

$$\frac{\partial g}{\partial t}(0,y) = A(B - g_0) \quad (16)$$

Equations (14), (15) and (16) provide the bridge model sought. Note that $z(t)$ is considered a time function obtained from the numerical solution of equations (2) and (10).

4. The response and bridge model validations

The application case consists in one subject that consumed 20 mg of methylphenidate. The five adjectives scale (adventurous, daring, enthusiastic, merry and bored) was filled out before consumption and after consumption every 15 minutes for 4 hours, and the interval of the *GFP* measures is $y \in [0{,}25]$. In addition, a sample of blood was extracted to the subject, before consumption and after consumption every 1 hour. A mass spectrometer is used to obtain the glutamate level in blood. The analysis of the sample provides concentrations of glutamate measured by the direct molar concentration (mc) in blood, and it is used with a scale multiplied by 10^{18} mc. With this scale, the glutamate concentration varies in the interval $g \in [0{,}60]$.

The calibration of the response model for the *GFP* dynamics is provided in Figure 1 and for the glutamate dynamics in Figure 2.

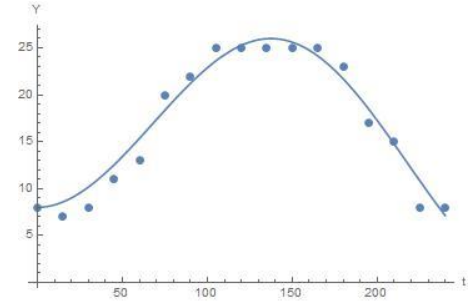

Figure 1: *GFP* (Y) versus time (t). The dots are the experimental values and the line the response model calibrated. R^2=0.97.

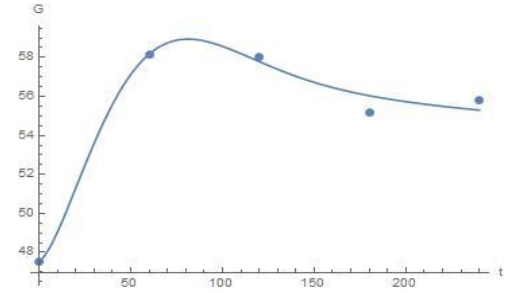

Figure 2: Glutamate (G) versus time (t). The dots are the experimental values and the line the response model calibrated. R^2=0.85.

The theoretical values of the bridge model, $g(t,y)$, are given by the numerical solutions of (14), (15) and (16), by considering the optimal parameter values arisen in the calibration of the response model. These numerical solutions have been obtained with the NDSolve function of the MATHEMATICA 10.4 program. The validation is provided in Figure 3.

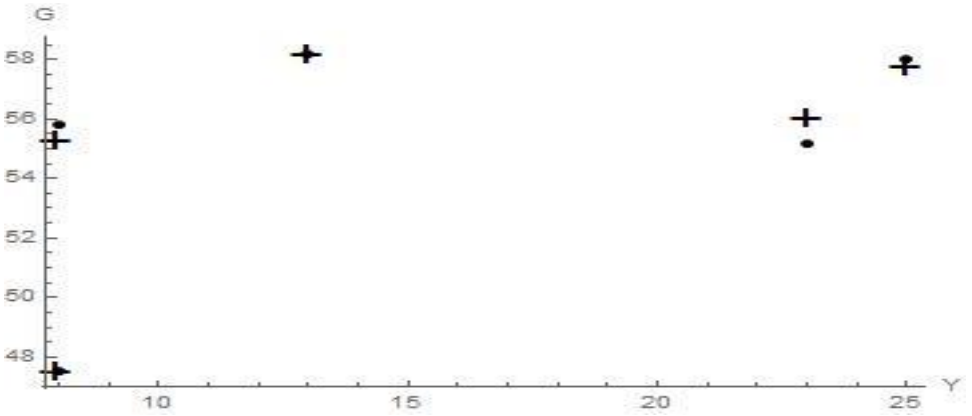

Figure 3: Experimental values (dots) and theoretical bridge model values (crosses) of glutamate (G) versus experimental values of *GFP* (Y). R^2=0.85.

5. Conclusions

Figures 1 and 2 provide the calibration of the response model, respectively for the *GFP* response (mind) and for the glutamate response (body), as a consequence of 20 mg of methylphenidate. The visual inspection of these figures as well as the high determination coefficients (R^2) supports the response model validation. In addition, the visual inspection of Figure 3 and the corresponding high determination coefficient (R^2) provide also the bridge model validation.

Particularly, the response model can be considered validated in the context of the application case presented, supporting its universality, due to it has been already validated in the context of different application cases provided in the literature of Section 1.

However, the bridge model has been validated for first time in the present mathematical structure. The two past application cases cited in Section 1 where it has been validated presented a lesser complexity. The growth in complexity is necessary to overcome two difficulties. In (Micó et al., 2014) the invariance principle is applied to a differential equation with a

non-delayed inhibitor effect. As a consequence, by assuming the invariance principle, the bridge model becomes a first order partial differential equation. In fact, the simplified response model fits the caffeine response. But generally, other stimuli, such as methylphenidate, need to have a delayed inhibitor effect to fit the response. The way to find a more general bridge model is to convert first the delayed integro-differential equation in a system of two coupled differential equations. Subsequently, by assuming the invariance principle, the bridge model is deduced with a third artificial independent variable in two coupled first order partial differential equations. However, this bridge model provides often unstable numerical solutions, due to the arbitrariness of the boundary conditions (Micó et al., 2013). Therefore, the present bridge model is an attempt to overcome these difficulties. Then, it needs to be validated in the context of more future application cases.

Let us stress the importance of the bridge model: it represents the co-evolution of the *GFP* (mind) and glutamate (body) as a consequence of methylphenidate consumption. On a hand, the importance of the *GFP* as representative of mind must not be neglected. The *GFP* represents the apex of a hierarchical model of personality that involves the Big Five traits (Amigó, 2005; Amigó et al., 2010). In addition glutamate as representative of body has neither to be neglected. It takes part of an overall set of biochemical processes related with the stress system in the organism (Amigó, 2005).

Therefore, the co-evolution that provides the bridge model is a fruitful mathematical approach to study the integrated relationship of body and mind. In fact, its structure shows that this relationship has a dynamical nature, which can be considered a scientific discovering about the subject in question. It is, finally, a step to better understand the ancient body-mind problem from a mathematical and successful approach.

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