

Emotional theory of rationality

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ABSTRACT:

In recent decades, it has been definitely established the existence of a close relationship between the emotional phenomena and rational processes, but we still do not have a unified definition, or effective models to describe any of them well. To advance our understanding of the mechanisms governing the behavior of living beings we must integrate multiple theories, experiments and models from both fields. In this paper we propose a new theoretical framework that allows integrating and understanding, from a functional point of view, the emotion-cognition duality. Our reasoning, based on evolutionary principles, add to the definition and understanding of emotion, justifying its origin, explaining its mission and dynamics, and linking it to higher cognitive processes, mainly with attention, cognition, decision-making and consciousness. According to our theory, emotions are the mechanism for brain function optimization, besides being the contingency and stimuli prioritization system. As a result of this approach, we have developed a dynamic systems-level model capable of providing plausible explanations for some psychological and behavioral phenomena, and establish a new framework for scientific definition of some fundamental psychological terms.

KEYWORDS

Emotions, cognition, evolution, behavior, consciousness, reality distortion, decision making.

Introduction

The human brain is, by far, the most advanced and complex biological system we know. With one hundred billion neurons (10^{11}), and hundreds of billions of synapses (10^{14}) it is the physical substrate of our mind, and is in charge of making sense of everything that happens to us, either internally or externally.

It is this structural and functional complexity which, today, still makes it extremely difficult for us to understand its design and dynamics. Our current technical limitations in the field of brain scan, do not yet allow us to observe all the processes that occur inside our alive mind with the necessary detail to achieve a full understanding (Logothetis, 2008). Moreover, the inherent characteristics that define the growth and development of the brain (Bell & Hardingham, 2011; Inokuchi, 2011; Goda & Sabatini, 2011), based on synaptic plasticity induced by the individual's own life experiences as a modeler (Hebb, 1949), make each object of study unique, inevitably forcing us to focus on a more general model search that allows us to glimpse and understand human behavior from a statistical standpoint (Denk, Briggman, & Helmstaedter, 2012).

Numerous pieces of scientific research have addressed the different areas and capabilities that the nervous system exhibits, thus providing us with theories, experiments and observations that shed light on many facets of its operations, and generate a huge amount of information. Those all data sets still suffer from enormous knowledge gaps that must be completed in the coming years but, above all and most importantly, all these results are still unconnected and should be integrated into broader theoretical models, that would not only describe, but also explain and use them to make predictions (Gamez, 2012). These new theories should serve as a link between low-level observations (molecular, neuronal, etc ...) (DeFelipe, 2010) and their psychological and behavioral manifestations (Franks, 2005).

Sometimes, to find new routes that let us move forward, we need to go back and get another perspective hitherto unexplored. The large number of different structures, networks and functional levels involved within the study of the human brain require us to take that step back, and try to find more general

principles that facilitate the integration between all those elements, and deduce important implications that, other way, would pass unnoticed.

This article is divided into three complementary sections that describe the full reasoning leading to the proposed model, its functional structure and, finally, its dynamics.

In the first section we use an evolutionary reasoning to find general principles that allow us to justify the features of the nervous system and the key variables that determine the quality of its operation. We then analyze the interdependence between all these variables, justifying the automaticity process and the existence of three different hierarchical levels of response. Then, we reason the existence of intrinsic resource constraints in the system and how these constraints give rise to the attentional mechanism. From this perspective, we define the concept and role of emotions and how they control and optimize the activation and operation of advanced cognitive mechanisms. Later on, we analyze the different types of cognitive responses and how they can operate over different functional elements of the model, thus leading to different behaviors and psychological phenomena.

In the second section we introduce the functional structure of the model, which is deduced from the reasoning followed in the first section.

In the third section we analyze the dynamic of the model and the interactions that occur between its different functional elements, as well as the implications that those dynamics have to explain the different psychological and behavioral phenomena we intend to address.

Section 1: Evolution

1.1. Physics and evolution

Why does a living being relate to its environment? If we want to understand the functioning of the nervous system that lets living beings to adapt and respond to changes, we must begin by asking this question. Thus, the fundamental physical laws are the starting point for our evolutionary analysis; the second law of thermodynamics requires living beings to exchange energy and matter, at an appropriate rate, with their environment to maintain the structural order inherent to life, as we define it today (Prigogine, 1997; Kleidon, Lorenz, & Lorenz, 2005; Martyushev & Seleznev, 2006; Michaelian, 2009).

Thus, the exchange and degrade of energy in the form of nutrients and heat, stands as a fundamental principle for life existence (Kooijman, 2010). From a practical standpoint for the maintenance of life, the goal of a living being should be trying to solve their needs at the lowest cost possible (MacArthur & Pianka, 1966; Charnov, 1976). On this basis, the higher level evolutionary models (Eldredge & Gould, 1972; Sterelny, 2001; Gould, 2002; R. Dawkins, 2006) explore the need for every living organism to interact with its environment in order to carry out the life cycle, whether for feeding, breeding or protection (O'Neill, Johnson, & King, 1989).

The evolutionary process has been selecting the different species (Darwin, 1859), each with specific adaptive systems, allowing them to detect environmental conditions under which they lived, as a first step to adapt (Barton, Briggs, Eisen, Goldstein, & Patel, 2007). But, it would be useless being able to detect environmental conditions if the living being couldn't act on them, whether to change, remove or seize, adapting to them.

Until recently, the "*Modern Evolutionary Synthesis*", primarily based on genetics and statistical mechanisms of mutation, transference and selection of genes, was the foundation on which the evolution studies were based (Richard Dawkins, 2009; Hurst, 2009) but it is a fact that, at present, there are many approaches that question the uniqueness of this central "dogma" of molecular biology (Shapiro, 2002a; John S. Mattick, 2009; Danchin et al., 2011). In this sense, one of the most recent and impacting epigenetic experiments has

been recently developed to study the relationship between odor experience and its influence in offspring's innate behaviors (Dias & Ressler, 2014). Today, mechanisms such as epigenetics (Shapiro, 2002b, 2005; Holliday, 2006; Jablonka & Raz, 2009; Zhang & Meaney, 2010; Maher, 2012; Fischer, 2014; Burggren & Crews, 2014; González-Pardo & others, 2013; Mendizabal, Keller, Zeng, & Yi, 2014) and evolutionary ecology (Fussmann, Loreau, & Abrams, 2007; Schoener, 2011) are allowing us to explain how changes motivated by the interaction of living beings with their environment, influence the selective and dynamic activation of genes (J. N. Thompson, 1998; Hairston Jr, Ellner, Geber, Yoshida, & Fox, 2005; S. P. Carroll, Hendry, Reznick, & Fox, 2007; Free & Barton, 2007), which in turn give place to different behaviors. These new approaches also provide us with new tools for understanding evolutionary situations hitherto unexplained as the "stasis" (J. Smith, 1983; Estes & Arnold, 2007), variations in the molecular clock (Kumar, 2005; Takahata, 2007), the "C-Value Enigma" (J.S. Mattick, 2009; Fedoroff, 2012) or the Cambrian Explosion (Marshall, 2006).

Far from being a complication, this change of paradigm on the mechanisms, networks and dynamical systems that underlie the processes of development and evolution of living beings opens the door for trying to address their knowledge in a more fundamental and inclusive way (Barabási & Oltvai, 2004; Eugene V Koonin & Wolf, 2006; E.V. Koonin & others, 2007). From these discoveries, we can approach the study of the development and conservation of different adaptive systems, structures and dynamics, in accordance with general principles that will serve as the basis for our reasoning.

1.2. Evolutionary principles

In order to find those principles on which we will found our modeling, we need to analyze what the different adaptive systems have in common among the different species that they currently own or have owned in the past (Butler & Hodos, 1996; Striedter, 2005; Abzhanov et al., 2008). To do that, we must consider the fact that, whenever a new species appears, all inherited systems and tactics have to face new conditions, environments, constraints and requirements for survival and reproduction that will probe the limits of its operating range (Badyaev, 2005). From a Darwinian point of view, we can say that each species

within their habitats are a new "experiment" that fronts all its functional elements to the filter of natural selection (Elith & Leathwick, 2009).

If we take into account that 99% of species that have existed since the origin of life became extinct, we can postulate that the greater the number of species and the longer they retain a certain adaptive system, the more necessary, evolved and versatile this system should be. This reasoning allows us to articulate three fundamental and hierarchical principles on which we will base our reasoning.

Necessity Principle

To be able to adapt to certain conditions, be they environmental, ecological, sexual or otherwise, a living organism needs a system or a set of systems capable to detect those conditions and evaluate them, identify or develop one or several appropriate responses to address them, choose the better available and, above all and most important, implement such a response, acting on the stimulus either to use, avoid or modify it. If the individual does not have such systems, or the ability to adapt the existing ones, also called exaptations (Gould & Vrba, 1982), and the stimulus does not spontaneously disappear, it won't be able to resolve the challenge. This fact is even more evident if we refer to a change affecting a system shared among a large number of very different species, as it will be exposed to very different selection conditions (Boffelli, Nobrega, & Rubin, 2004; Hurst, 2009). We call this principle the "**Necessity Principle**".

Efficacy Principle

We can assume that, over evolutionary time periods, the environmental conditions to which species are exposed within an ecological niche can change dramatically, thus testing the responsiveness of different adaptive systems. If effective, that is, if they successfully resolve the situation for which they were selected, the individual survives, reproduces and the system is conserved. If they are not or cease to be effective, individuals perish and disappear. We call this conditioning "**Efficacy Principle**". An example of the application of this principle may be the extinction of the large dinosaurs. Having existed for over 150 million years, all their adaptive systems failed (ceased to be effective), when a series of dramatic global changes

converged in a short period of time. Instead birds, the living descendants of dinosaurs, and mammals survived.

Efficiency Principle

We must consider that not only the effectiveness defines success in survival. As we have already seen, energy is the key component to maintain the structural order of a living being (E. D. Schneider & Sagan, 2005). All adaptive systems have an implicit energy cost and thus, the body has to permanently devote a variable amount of resources to maintain it (McEwen & Wingfield, 2003). Along the broad evolutionary periods, all the resources necessary to maintain different adaptive systems have not always been available, so that nature will have preserved only the most efficient ones, that is, those that while maintaining their resolving ability, are also able to do so with as few resources as possible (J. M. Smith, 1978; Parker & Smith, 1990; Sousa, Domingos, & Kooijman, 2008; Kooijman, 2010). We call to this fact the **“Efficiency Principle”** and we can also observe it at different scales. The importance of this principle can be seen in the fact that the human brain is able to do all the things we do just with the power of a light bulb of 25 W (Kandel, 1999)

The fact that these principles are hierarchically related makes sense of some biological “inefficiencies” that, if taken isolation, some species can show (Wedel, 2012). Hereinafter we will apply these three hierarchical evolutionary principles to different levels and scales of the nervous system, both in the study of its functional structure, and the dynamics of its operation, thus facilitating the identification of the critical variables that define its quality.

1.3. Nervous system: critical variables and optimization strategies

If we now focus on the nervous system, we can easily infer that responses are the last link in the processing chain to face a challenging stimulus. Thus, responses integrate and summarize all the processed information, from lower sensory levels to decision-making and behavior. The success or failure of the nervous system’s adaptive capacity depends, ultimately, on **the quality of the responses** it is capable to generate (Llinás & Roy, 2009), and **the quality of the execution** of those responses. Thus, we will try to identify which specific variables are to be adjusted and balanced to maximize the quality of both.

The first reflection we do is about the "*necessity*" of nervous system activation, understanding by "*need*" the generation of a response only in those cases where it is really necessary. If the responses were generated randomly or continuously, without mediating a need, maybe some would be effective, few, but what is certain is that it would be inefficient. In order to assess the concept of necessity, the nervous system must have an indicator to define when to execute a response. The variable that indicates whether or not to generate a response is called "**Activation Threshold**", and it is defined as the minimum difference between the stimulus received and an internal reference that produce neural circuitry activation (Platkiewicz & Brette, 2010). This variable is permanently and dynamically readjusted (Lu, Roach, Song, & Berger, 2012). A too low threshold is inefficient, generating unnecessary responses, at great cost in time, resources and energy. A too high threshold is not very effective, preventing the individual to appropriately react to important stimuli, thus putting him at risk (Nagasako, Oaklander, & Dworkin, 2003).

The second variable that we must consider is the "**Reaction Time**". This indicates the time that elapses between sensory circuit activation by the onset of a stimulus, and the moment when the corresponding response is available and starts running (Donders, 1969; S. Sternberg, 1969; Meyer, Irwin, Osman, & Kounois, 1988; Meyer, Osman, Irwin, & Yantis, 1988; Jensen, 2006; Kosinski, 2008). We can infer that, the shorter the nervous system takes to choose the most suitable response (Kahneman & Tversky, 1979; Doya, 2008; Cisek & Kalaska, 2010), even if inhibitory (Gordon D. Logan, Cowan, & Davis, 1984), the greater the chances of survival.

Third, it is clear that speed to find a response can save the life of an organism, but it is also true that the "**Accuracy**" is crucial in most cases. In this sense, we define "*accuracy*" as the difference between the response and the best possible option to respond to a stimulus, considering that both are characterized by a set of variables, such as intensity, specificity, location, timing, sequencing, etc... Each of these variables has an operating range within which we can say it is effective. Thus, we say that a response is effective when the accuracy of all variables is within the range that successfully solves the triggering stimulus. For example, a tennis player is *effective* if he hits the ball hard enough, in the right direction, within a limited time window, in a specific spatial zone, so that it passes through the network falling anywhere within the

attacking half. We say that he is **accurate** if, in addition and intentionally, gets to place the ball to a certain point where he knows his opponent will not reach it. He will be **precise** if he can place the ball away from his opponent consistently.

If we consider that the nervous system is a specialized system to process information to elaborate responses, and that the quality of their responses is given by the three critical variables already identified, it makes sense that evolution had selected some strategies to optimize these variables, allowing it to improve its overall performance. The very existence of the following biological mechanisms that implement these strategies could be considered a confirmation of the importance of these three variables.

Thus, mechanisms such as **"Memory"** (Atkinson & Shiffrin, 1968; Baddeley, 1992) able to encode, store and quickly retrieve previously processed information, making it suitable for being efficiently incorporated in new processes and operated again. **"Pattern Recognition"** which allows to share information, encoding it with fewer connections, saving resources (Attwell & Laughlin, 2001), more quickly and perhaps reusing already developed responses. **Predictive Systems** (Davidson & Wolpert, 2005; Bar, 2011; Kveraga, Ghuman, & Bar, 2007) which can recognize patterns that occur separated in time or sequences that, according to our reasoning, are closely related to memory capacity (Hassabis, Kumaran, Vann, & Maguire, 2007). **Feedforward**, which starting with a "prediction" coming from predictive systems, is able to activate in advance neural and physiological components of the responses, thus creating faster circuits to send activation information through shortest paths (Chklovskii, Mel, & Svoboda, 2004; Serre, Oliva, & Poggio, 2007). **Feedback**, that acts as a regulating element, allowing nervous system to dynamically adjust its operation by checking the effectiveness of its own responses and the effects they exert on the eliciting stimuli. For example, *efferent copy* which, combined with the *inverse models* (Wolpert, Miall, & Kawato, 1998), give place to the *corollary discharge* (Crapse & Sommer, 2008) allowing us to explain for example why we cannot tickle ourselves (Blakemore, Wolpert, & Frith, 2000; Wolpert & Flanagan, 2001). **Mirror System** (Rizzolatti & Craighero, 2004) makes it possible to anticipate the actions of other individuals, as well as imitation (Schaal, 1999; Molenberghs, Cunnington, & Mattingley, 2009; Monfardini et al., 2013), thus triggering advanced social interactions and behaviors (Iacoboni, 2009; Soressi et al., 2013). Or a high-level

strategy to optimize the critical variables like **Mental Imagery** (Kosslyn, Ganis, & Thompson, 2001). If the information developed through predictive systems is re-fed through sensory circuits (Decety, 1996; Héту et al., 2013), it can be managed as new self-generated stimuli, which in turn can elicit new responses, either neural or physiological (Milton, Small, & Solodkin, 2008; MacIntyre, Moran, Collet, & Guillot, 2013; Guillot, Di Rienzo, & Collet, 2012). In turn, this self-generated information could be in the basis of self and social interactions (Decety & Grèzes, 2006), which is a good example of an advanced system that emerges as a combination of simpler ones. Table 1 summarizes how these strategies improve the overall quality of the nervous system responses through an optimization of the three critical variables we have already identified.

Table-1. Optimization strategies and critical variables.

| Strategies | Variables | | |
|---------------------|----------------------|-----------------|-----------------|
| | Activation threshold | Reaction time | Accuracy |
| Memory | | <i>Improved</i> | <i>Improved</i> |
| Pattern recognition | | <i>Improved</i> | <i>Improved</i> |
| Predictive systems | <i>Improved</i> | <i>Improved</i> | <i>Improved</i> |
| Feedforward | <i>Improved</i> | <i>Improved</i> | |
| Feedback | <i>Improved</i> | | <i>Improved</i> |
| Mirror system | | <i>Improved</i> | <i>Improved</i> |
| Mental Imagery | | <i>Improved</i> | <i>Improved</i> |

1.4. Automaticity

There is, however, a very important factor we should take into account. The three variables we have identified as critical to assess the quality of nervous system responses (*activation threshold, reaction time and accuracy*) are **interdependent**. This means that when modifying one of them, the others will be affected by this change. If we want to improve the accuracy we need to spend more time to generate and explore more alternatives (Garrett, 1922; Hick, 1952; Wickelgren, 1977; Meyer, Irwin, et al., 1988), but if we take too long it may happen that, when we finally find the best response it is no longer needed, either because the predator has devoured us, or because our potential partner has found another partner (Chittka, Skorupski, & Raine, 2009). Also, if we reduce the reaction time, the quality of response suffers and

may no longer be accurate enough to successfully resolve the stimulus that elicited it, thus becoming ineffective. If we displayed unnecessary responses, even if accurate and fast, we may waste our energy and time solving problems that do not require it (Missenard & Fernandez, 2011; Lan, Sartori, Neumann, Sourjik, & Tu, 2012), thus diminishing the availability of resources to address other and more important tasks.

The interdependence between these three critical variables is the greatest challenge the nervous system has to front when facing a stimulus. It should be able to find, at any time and for each stimulus, the best possible balance between them (Paulus et al., 2009).

The best way to achieve this optimum balance would be having, since the beginning, a specific neural circuit, already "wired" to provide the most accurate response in the shortest time possible, and fine-tuned to run only when it is really necessary. As it is the optimal mechanism, evolution have developed and selected as a priority and, because of its importance, it has also incorporated it at genetic level. This kind of circuits are known as **Reflex Circuits** (Purves, 2004; Barrett & Ganong, 2010) which allows the living beings to deploy a first type of highly optimized responses called **Innate Responses**. According to this reasoning, the more responses are available in the form of reflexes, the better the balance between the critical variables that define its quality, and thus the better the overall system performance.

But this raises a new problem. Given the enormous variety and variability of possible stimuli that a living being can front (the also called *Combinatorial Explosion*), it is obvious that not all responses can be genetically "wired" into a reflex circuit. The nervous system cannot, and should not, incorporate innately coded all the possible responses (Bateson & Mamerli, 2007), but the mechanisms to dynamically generate them in the most flexible and rapid way. As responses are encoded by networks of neurons and synapses, are the developing and neural plasticity processes (neurogenesis, synaptogenesis, LTP, LTD, neuronal apoptosis, synaptic pruning, etc...), along with the already described feedback and feed-forward mechanisms, which have to dynamically create and select the fastest, more effective and efficient networks (Raichle et al., 1994; Petersen, Mier, Fiez, & Raichle, 1998; Citri & Malenka, 2007; Kaiser & Peters, 2009;

Tau & Peterson, 2009; Chechik, Meilijson, & Ruppin, 1998). This optimization process leads to different levels of search, development, selection and implementation of responses we will see in the next section.

So, we call **Automaticity** to the process by which, the neural pathway associated to a response, reaches its optimal balance of interconnection between its elements, thus providing the best possible relationship between the three critical variables that characterize its quality. See (See Moors & De Houwer, 2006 for a review) for a review.

This doesn't mean that an automated response is the best possible response to solve a particular stimulus (G. D Logan, 1985; Yarrow, Brown, & Krakauer, 2009) but, that once found the best response available within the limitations of the individual capacities in a given context, the neural network that encodes it is optimized to do three things: recognize the stimulative pattern, compute the response and run it as quickly and accurately as possible (W. Schneider & Shiffrin, 1977; Richard M. Shiffrin & Schneider, 1977; R.M. Shiffrin & Schneider, 1984). Thus, **the automaticity concept refers to the response execution quality**. Depending on the intrinsic characteristics of the stimulus, it will be more, less or even not susceptible to be automated. The different degrees of automaticity give place to skills (Hikosaka, Yamamoto, Yasuda, & Kim, 2013), habits which are defined as *"sequential, repetitive, motor, or cognitive behaviors elicited by external or internal triggers that, once released, can go to completion without constant conscious oversight"* (Graybiel, 2008, p. 361), or even addictions. The most significant characteristics of automated responses are that the sensory events almost always elicit the behavior, are resistant to dual-task interference, that is, the behavior can be executed successfully while the subject is simultaneously engaged in some other demanding secondary task (Michael I. Posner & Snyder, 1975; G.D. Logan, 1979), they are behaviorally inflexible, and unaffected by reward devaluation (Ashby & Crossley, 2012).

Based on this definition, we state the **Automaticity Principle**:

As a result of its own mechanisms of growth and development, and to fully optimize their effectiveness and efficiency, the nervous system will automate, as much as possible, the new

circuits and neural networks that encode a stimulus recognition, calculation and execution of the response associated to it.

As expected if it was a fundamental functional mechanism, automaticity has been systematically observed in several and different studies and with different sensory, cognitive and motor requirements, like motor skills (Poldrack et al., 2005), driving (Charlton & Starkey, 2011), reading (Gordon D. Logan, 1997), music reading and playing (Stewart, 2005), and typing (Shaffer, 1975), among others. It has also been observed in learning processes that affect very different memory systems, whether declarative or procedural (Ashby & Crossley, 2012), and also in very different species (Helton, 2007). Despite its ubiquity, the neural bases for this mechanism are not clear yet, though it seems probed that prefrontal cortex (PFC) and basal ganglia (BG), mainly the cortico-striatum-cortical loops, are intimately related with the automaticity process (Hélie, Ell, & Ashby, 2015). Thus, the two competing paradigms, the automaticity as a *“Transfer of Control from the Associative Striatum to the Sensorimotor Striatum”* (Ashby, Turner, & Horvitz, 2010) and the automaticity as a *“Transfer of Control from the Striatum to Cortex”* (Belin, Jonkman, Dickinson, Robbins, & Everitt, 2009; Yin & Knowlton, 2006), have received wide experimental support, and opened the need for future research.

As a summary of this topic, we consider that the automation process can be understood as the process going from a **“discrete”** set of multidimensional values obtained on a limited number of cases, to a **“continuous”** multidimensional function codified after a large number of events (Fig. 1)

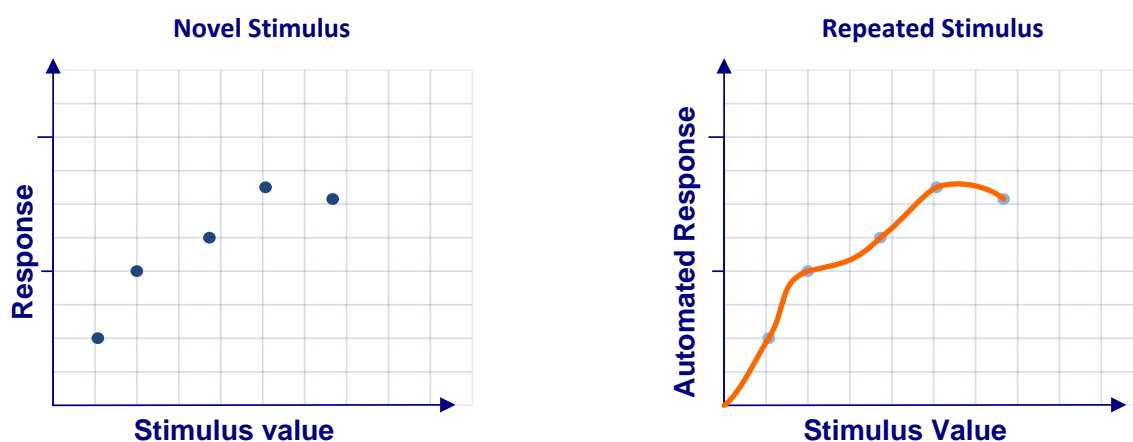


Figure 1. Automaticity conceptualization

1.5. Levels of response

We have already seen that the first kind of responses the nervous system has available to react to stimuli are **Innate Responses** (Mameli & Bateson, 2011). We say these responses are "wired" because it exists, since birth, a specific neural circuitry to resolve the stimulus. The same stimulus will produce the same response. The fact that the origin of this type of response is genetic, means that it has been preserved by species over generations, which in turn tells us that it has been useful in solving certain very specific, ancestral, frequent and repetitive stimuli. Among them we can mention crying, coughing, pupillary dilation to changes in light, sweat secretion or control heart rate and breathing, among others. Within innate responses we include reflexes (Purves, 2004), the Fixed Action Patterns or instincts, defined as "*patterns of behavior that are fully functional from the first time they are executed, even if the individual has had no previous experience with the stimuli that elicit the response*" (Alcock & Farley, 2001, p. 118).

But what happens if, because of the novelty or the variability of a stimulus, there isn't an innate response that allows solving it? The nervous system must develop new responses from the available elements. We call this new level of response **Cognitive Responses**. They form a broad set of strategies, more or less advanced, which enable the body to create new solutions to address the most diverse stimuli (Quartz & Sejnowski, 1997). These strategies are very flexible, but have the disadvantage of requiring more time and resources to find or develop, select and apply a response, thus reducing the biological fitness. This second level of responses is useful when either there is no other effective response, or the response time is not critical.

Once the brain, within its own capacity, finds the best possible response to a repetitive stimulus, it gets into action the *automaticity principle* that tries to create the most optimal pathway to process and execute the response, when necessary and do it as quickly and accurately as possible. This results in a third type of responses we call **Automated Responses** (Raichle et al., 1994; Petersen et al., 1998).

It is important to note the difference between **innate automatic responses** and **automated responses**. While all the innate responses are genetic (Manoli, Meissner, & Baker, 2006) and therefore automatic since

the beginning, the automated responses do not exist at first. They must be first generated through a cognitive process in the form of cognitive responses, which are later optimized, as expressed by the automaticity principle, though not all the responses are susceptible to be automated.


This way, and attending to their availability, we define a three level hierarchical structure for responses, starting with innate responses at the lowest level, going through cognitive responses and then finishing with automated responses. Now we will summarize the three different response levels we will use from now on:

Innate responses: Implemented by specific neural pathways, genetically encoded and selected to solve common situations, from the evolutionary point of view, which are highly critical for the survival of the organism. Provide automatic responses, very fast, accurate and highly efficient in their use of resources and very effective since the evolution has selected and preserved in the inherited baggage of the species over millions of years.

Cognitive responses: Developed by advanced information processing systems that enable the search for new responses to face novel stimuli, of very different complexity, repetitive or not, and less critical for survival. They have many strategies and multiple ways of combining them to find solutions, but it implies longer analysis times and broader resource utilization, resulting in higher energy expenditure. It is important to note that cognitive responses are developed for a specific range of operation, the experienced one, and that if this range is overpassed, the cognitive response may become ineffective again.

Automated responses: Developed by the brain optimization mechanisms that, once a new cognitive response has been found, enable the creation, selection and pruning of those neural circuits aimed at making automatic the new cognitive response. It is useful to optimize responses to repetitive stimuli, of diverse complexity, which are susceptible to be automated. The effectiveness and efficiency are reached with repeated exposure to stimuli, improving accuracy and speed as the

new created network consolidates. It needs more time to have these responses available and the process consumes more resources.

| Table - 2. Types of responses by its origin and grade of automaticity. | | | |
|---|--------------------------------|----------|--|
| | Genetic | | Developed |
| | | | <i>Cognitive Responses</i> |
| Non- automatic | | | <ul style="list-style-type: none"> • Problem resolution • Planning • Decision making ... |
| | | | <i>Automaticity process</i>  |
| Automatic | <i>Innate Responses</i> | | <i>Automated Responses</i> |
| | Reflex | | Skills |
| | Fixed Action Patterns | | Habits |
| | Instincts | Emotions | Addictions |

Returning briefly to the evolutionary level, we can see that there are species that exhibit one, two or all three levels of response. Since evolution does not develop or maintain systems if they are not necessary, we can reason that the different levels of response emerged as a result of adaptive pressure exerted on organisms by their environment. In other words, any organism whose environmental conditions would have allowed it to survive and reproduce without problems displaying only innate responses, there will not have invested resources to develop and maintain more advanced and costly brains. This explains why there are animals, like horseshoe crab, that have survived for hundreds of millions of years without the need to strengthen its nervous system beyond a certain level of response. Another example would be sharks, living on earth for about 420 million years, what means seventy times the period that separates us humans from chimpanzees (6-7 million years), and have not developed intelligence levels similar to ours.

1.6. Response structure

Regardless of the level to which a response may belong, it could include two types of complementary components that may or may not activate simultaneously:

- A **Physiological component** that includes autonomic and somatic systems with corresponding motor elements, endocrine, heart rate, blood pressure, etc., and is directed to allow the body to run the necessary physiological activation and physical actions to face the stimulus.
- A **Neural component** that will trigger the activation or regulation of other neural networks, thus initiating new complementary brain processes (e.g. imagining).

But all those components are dynamically activated and inhibited along time, thus giving place to different “**stages**”, each with its own set of active components (Dezfouli, Lingawi, & Balleine, 2014). Thus, a response, like a process it is, will be composed of a sequence of stages, each with its own set of physiological and/or neural components simultaneously activated (Bapi, Pammi, Miyapuram, & Ahmed, 2005) that are generated in different networks. This is a very important key for the reasoning we will do later. Therefore, finding a new *cognitive response* is the process to identify, select, order in time and link together the appropriate sequence of stages necessary to face a stimulus. Automaticity is the process by which that response is “wired” in a new specific neural network or pathway (Dezfouli et al., 2014).

1.7. Response assessment

Optimization has been the keystone for all our reasoning up to here; the nervous system must generate a response that effectively address the stimulus, only if necessary, and do it as quickly, accurately and with the least consumption of resources as possible. We have also seen how, to improve their performance, the nervous system has developed multiple strategies in their architecture and dynamics (memory, pattern recognition, predictive systems, feedback, feed-forward, mirror system, automaticity) and different levels of response (innate, cognitive and automated) that allow it to optimize both, the three critical variables (activation threshold, reaction time and accuracy), and the interdependence between them. Thus, different

strategies will be optimal depending on the context and the criticality, the novelty, the complexity and the variability of stimuli to solve.

But all these systems and strategies would be useless if the nervous system, once deployed a response, could not evaluate its success or failure. If an innate response was not effective solving a critical stimulus, the brain would fail in its function, with the consequent risk to the organism's survival. How does the brain evaluate the effectiveness of their responses?

In addition, and in order to achieve the goal of optimization, there should be some mechanism to enable and disable different levels of response on demand, as they are needed or not. Before activating cognitive systems, more advanced, but also expensive and slow, nervous system try to resolve the stimuli using innate and automated response levels, faster, more accurate and economic.

When possible, the brain uses predictive systems to generate an anticipated representation or **expectation**, both interoceptive and exteroceptive of the new characteristics of the stimulus once modified by its own response (Wolpert et al., 1998; Friston, 2010). Subsequently, the brain uses this expectation like a reference for comparison with the actual information received through the senses, once deployed the response (Blakemore et al., 2000). Importantly, this same process is also performed to neural information that, through feedback and feedforward loops, is processed without the intervention of afferent sensory and motor circuits, as in the case of thought or imagination (Phelps et al., 2001). Thus, we consider that **a response is effective if, by using some of the diverse strategies we will expose below, it is able to match the stimulus and the expectation information.**

Therefore, if a mismatch occurs, a specific response, if available, will be elicited. But what happens if there is no specific response available, because it is a novel stimulus? What if there is no expectation with which to compare it? And what if both match but, at a certain time, they stop matching? What if multiple and different expectations exist for the same stimulus?

1.8. Emotions

From an operational point of view, the best option to address these circumstances would be to have a system as fast as possible, innate and therefore automatic, which is enabled by default to minimize the possibility of failure, capable of generating a wide range of general purpose responses and to trigger the basic actions needed to address novel, variable or unexpected stimuli. This system is what we call **Emotional System** and its responses are **Emotions**.

Thus, a stimulus could be unexpected, or could be expected but not having an effective response to face it, or could be that there exist different expectations about the same stimulus, all of them with different response availability and also with different degrees of efficacy. For example, a predator could be, to some extent, “expected” by the prey, but not so the moment or the way it is going to attack (expectation mismatch); when the attack occurs, and depending on its experientially-acquired skills, the prey will or not have a specific response (response availability); even if the prey is able to deploy a specific response, it is not sure it will be completely effective (response efficacy); maybe the prey can recall what happened to others in the herd, some of which were devoured and others escaped (different expectations and maybe different responses for the same stimulus). All this different casuistic, which implies different functional elements along the information processing chain, will elicit an emotional response.

According with this reasoning, and though emotion definition is an active debate (Dixon, 2012) , we give now a first partial definition of emotions as **innate contingency action programs, which act as “indicators” about the incapacity of the already available responses, to effectively resolve a triggering stimulus in a given context.**

Thus, the first two actions to be carried out by the emotional system are complementary and simultaneous, and are of two types:

- **Contingency**, displaying innate stereotypical responses to allow the individual to start managing the stimulus (e.g. fight or flight), and saving time while finding or developing a new and more specific and effective cognitive response to resolve it. This component of emotional responses has

been systematically observed both in animals and humans (Peter J. Lang & Davis, 2006; LeDoux, 2012).

- **Regulation**, eliciting the selective potentiation or inhibition of higher cognitive mechanisms, more advanced but slower, expensive in energy consumption and fewer, to find or develop a new, more specific and more effective response (Kastner & Ungerleider, 2001; Pessoa, Kastner, & Ungerleider, 2002). We develop this point in more depth when we introduce the “attention” topic.

It is worth noting that, unlike the model based on the concept of “interruption” (Simon, 1967) that considers emotions as “deviations” from the normal flow of information processing to cope with an unexpected event, our theory considers the emotional system as **the main innate network for processing sensory information**, being actively inhibited only in the case that an effective response, whether innate, cognitive or automated already exist. That is, if a completely novel stimulus appears, a specific response won’t be available, so an emotion will be elicited. Anyway, to appropriately explain this approach we previously need to introduce some more concepts, so this point will be developed in more depth later on.

1.9. Attention

At this point, we have to face a new challenge. The brain, through the multiple afferent sensory and feedback loops it possesses, permanently receives a huge amount of information from numerous stimuli, both exogenous and endogenous (Chica, Bartolomeo, & Lupiáñez, 2013; Desimone & Duncan, 1995). In many cases these stimuli coincide or overlap in time (Fries, 2009), and must be discriminated, targeted and/or simultaneously attended, through a process of "binding" (Bosman et al., 2012; Ungerleider & Bell, 2011). But the characteristics of each stimulus are different, which may cause a great increase in computational requirements.

To solve this problem, the nervous system could develop as many advanced circuitry as necessary, but this would contradict one of the basic principles that we first stated in our analysis. The *efficiency principle* tells us that, as an evolutionary system it is, the nervous system must adjust its development and capabilities to

minimize, as far as possible, the consumption of resources and time used to fulfill its function, but without compromising its effectiveness.

This fact has some important effects for understanding brain dynamics:

- 1- The brain does not develop and even eliminates those neural pathways that are not needed or are inefficient (neuronal apoptosis and synaptic pruning) (Low & Cheng, 2006).
- 2- The brain adjusts the capabilities of those systems which remain necessary, and does so in accordance with the likely characteristics of number, frequency, complexity, variability and simultaneity of the stimuli to be solved (plasticity).
- 3- Once a stimulus has been fully resolved, and following the *efficiency principle*, the brain doesn't apply on it higher capacity mechanisms.

In addition, the *automaticity principle* tells us that once a response is found for a repetitive stimulus, and independently of whether it is completely or just partially effective, the brain will try, if possible, to automate its execution the most, as a way to optimize the balance between the critical variables that define its quality, thus giving place to skills and, sometimes also, to habits and even addictions.

From the application of these two principles (efficiency and automaticity) we can infer, on the one hand, the relationships between the number, the energy cost and the computational power of available resources and, in the other hand, the frequency, the variability and the complexity of the stimuli the brain must solve. Thus, we can reason that generally and throughout the evolutionary process, the number of simple and repetitive stimuli is greater than the complex and highly variable stimuli. We also know that many of the complex stimuli can be decomposed into simpler ones (Lerner, Hendler, Ben-Bashat, Harel, & Malach, 2001; Grill-Spector, 2003; Kersten, Mamassian, & Yuille, 2004; Ungerleider & Bell, 2011). Thus, simple and repetitive stimuli may be managed by simpler, more numerous innate or automated pathways, allowing parallel management while, more complex, novel and heterogeneous stimuli, require the joint intervention of more advanced, shortly automated and less numerous networks to be solved.

All these reasoning leads us to conclude that, the more novel, complex and variable the stimulus to resolve, the greater the necessary computing power and thus the lower the number of advanced networks available to carry out this function (Mani, Mullainathan, Shafir, & Zhao, 2013).

Because of this limitation of resources, conflicts often arise when accessing the cognitive resources (Grossberg & Levine, 1987; Marois & Ivanoff, 2005). This justifies the need for the brain to provide a mechanism that allows it to filter and select which stimuli, when, and for how long should have priority when using the advanced resources available. A classic example of interference, the color *Stroop Effect* (MacLeod, 1991; MacLeod & MacDonald, 2000), shows us what happens when two processes try to use the same system, in this case the verbalization system, to carry out its task, thus interfering each other. The more automated process due to daily lives, in this case the reading of written text (e.g. blue), prevails over the task of verbalizing the color in which the text is written (e.g. red), which is a much less common task.

But not only the **novelty**, **complexity** and **variability** of different stimuli are involved in the process. When assessing which stimuli must have priority, there is a fundamental variable that, from an evolutionary standpoint, can make a clear difference to the survival of a living being: the **Criticality** of the stimulus that requests the resources. If a critical process, independently of its complexity and variability, does not receive priority access to the most advanced tools, the result can be fatal for the organism.

To face these problems there is a specialized set of systems (Raz & Buhle, 2006) to effectively perform the task of alerting, orienting, filtering, prioritization and resource allocation: **Attention** (Norman & Shallice, 1986; M. I Posner & Petersen, 1990; Desimone & Duncan, 1995; Petersen & Posner, 2012). Their mission is to assess the various simultaneous requests to access different cognitive resources, prioritize and allow them to optimally access those resources depending on their characteristics. But, how can the attentional system evaluate the priority of different stimuli which are concurrently requiring access to cognitive systems?

According to our theory, **attention makes use of emotional information as a mean to prioritize and resolve conflicts when giving access to the cognitive resources**, thus assigning the available resources to

different stimuli according to their criticality. This structure assigns a new role to emotions, complementary to those already described of **contingency** and **regulation**: the **qualification** of stimuli priority according to their own critical characteristics, their simultaneity, the actual internal state and workload in the system.

Thus, we can now give a complete operational definition of what we understand as emotions, which are described as **“innate contingency action programs, which act as “indicators” about the incapacity of the already available responses to effectively resolve a triggering stimulus in a given context, thus qualifying the stimulus’ priority to compete for cognitive resources”**.

By applying criticality maps (Fecteau & Munoz, 2006) over emotional information, and together with workload information, attention computes priority for the different concurrent stimuli, thus creating and adjusting what we call **Attentional Windows**, namely selecting and filtering a greater or lesser number of simultaneous stimuli (Vuilleumier, 2005), and letting the most advanced resources to act on them. As a result of this process, attentional windows are continually readjusted in focus and size. Therefore, stimuli can be processed in parallel and integrated if they do not require access to the same cognitive network (Pessoa, 2010a), such as when we simultaneously process the image and the sound of a movie, or can be filtered, such as when we selectively listen a conversation among others in a party (Fritz, Elhilali, David, & Shamma, 2007). When an emotion-paired stimulus with high criticality is presented, the attentional window is reduced and focused on the stimulus associated with it. For example, the slowing effect of temporal perception (Eagleman, 2008), tunnel vision (Godnig, 2003) and auditory exclusion, phenomena very documented by combatants in situations of high stress (Artwohl, 2002; Drzewiecki, 2002). When there are no urgent requests, attention prioritizes less critical stimulus. At every moment we are exposed to lots of low criticality stimuli, both sensory and cognitive, so that attention has always some information to process.

It is important to note that we have not yet introduced the notion of “awareness” and so, attend to a stimulus doesn’t mean to be aware of it (Lamme, 2010). In that sense, and though we will expose in more depth below, it is worth clarifying that we clearly differentiate among attention (mechanism to prioritize

concurrent access to shared resources), orienting (e.g. the fact of fixing gaze in a stimulus) and “awareness” (be able to relate the occurrence of a stimulus). Thus, we can attend to different stimuli, with or without orienting and do it unconsciously (Armony & Vuilleumier, 2013, Chapter 14; Pessoa, 2013, Chapter 4). For example, in an unpublished experiment (Garcés, 2003) where subjects were rewarded when successfully detecting palindromic car plates while driving, we observed how the searching and assessment process, which initially needed to be effortful and consciously attended, gradually (in 3-4 months) became completely unattended, automatic and unconscious. Moreover, even when the task became unrewarded, and more than five years after the experiment finalization, most of the subjects reported about the persistence of that acquired capacity. It is interesting to note that all subjects also reported that, after reaching automaticity, palindromic plates, and only those, appear like suddenly capturing gaze and “jumping” into consciousness, with no subjective sensation to have been looking up for them, but eliciting a pleasant emotion when they became conscious. Interestingly, many subjects report that some of the “jumping” plates were numerically incorrect (not a palindromic number), but usually they were morphologically very similar to correct ones (e.g. 8838). This fact reinforces the possibility for the existence of an emotional network that works with coarse (low spatial frequency) information, before recruiting more advanced orienting and attentional resources (Vuilleumier, 2005).

Summarizing this paragraph, given the constraints the evolution process applies to living beings, not all the stimuli can be processed at the same time through specific networks. Therefore, stimuli must share a set of different “hub” resources, recruited into dynamic networks, to achieve the cognitive processes necessary to find or execute a response. The management of those resources is regulated and controlled by attentional systems that, according with our reasoning, use emotional information together with criticality maps to assess the priority of every different and simultaneous stimulus.

1.10. Innate and acquired attentional capacities

It is logical to think that, along the developmental process and early after birth, the individual only has available a few very specific (e.g. coughing) or very general (e.g. orienting reflex, startle) innate reflexive responses (Viding, Sebastian, & McCrory, 2013). As these innate responses alone are not yet able to

effectively resolve most of the novel stimuli the individual is front with, **emotions** — in the sense we have just defined — will be permanently elicited to regulate and prioritize attentional processes.

It is worth noting that, according with this reasoning, at birth, the most of stimuli will be emotion-laden (e.g. a baby gets startled even with his own hands' movements), and will be the dynamic processes (cognition, automation, habituation, extinction, etc...) which will gradually modify or not this status (see section 3). Thus, we consider that, at birth, all attentional processes begin as basic general purpose reflexes, such as orienting reflex (Evgeny N. Sokolov, Spinks, Näätänen, & Lyytinen, 2002), hardly influenced and regulated by what we have defined as emotions.

Experiments have shown that additional attentional capacities, such as voluntary orienting, sustained, focused or peripheral attention, arise as the individual develops along childhood and adolescence (Lellis et al., 2013). We consider these advanced attentional processes as necessary subtasks of what we have called cognitive responses and, as such, would follow a similar experience-related development (Raz & Buhle, 2006, p. 370 Box 1). As an example, we can refer the different attentional phenomena related with the “cocktail party effect” where voluntary (e.g. change the conversation we are listening to) or involuntary mechanisms (e.g. orienting when our name is pronounced in that noisy environment) show how attention can be differentially modulated (Fritz et al., 2007).

In that sense, we also consider motivation and goal-directed attention regulation mechanisms (Corbetta, Patel, & Shulman, 2008) as an extension of emotionally-regulated attentional processes where external cues in the former (e.g. monetary reward) or internal ones in the latter (e.g. a face to look for in a crowd) need to be previously associated to first or second order conditioned stimulus, thus inheriting their capacity to elicit an emotion that in turn regulates attention (CITA ver Armony y Vuilleumier 2013) . For example, a concept like “money” is culturally acquired and linked to positive (e.g. pleasure when buying goods) or negative (e.g. fear to go bankrupt) emotional processes. In turn, the concept “money” can be successively associated to new stimulus (e.g. lottery ticket) which in turn will inherit the capacity to elicit an emotional response to influence attentional processes.

In addition, as those advanced attentional subtasks have a wider scope than more specific cognitive subtasks, many different cognitive processes will repeatedly make use of them, thus inducing the advanced attentional capacities to be automated, becoming themselves high-level efficient sub-processes, operating over multimodal information to effectively achieve their alerting, orienting, filtering, searching and executive functions.

Importantly, as both, innate and acquired attentional sub-processes can't operate at the same time on the same resources, we postulate that innate systems are gradually and actively inhibited as more specific and effective responses are developed and automated (Whalen & Phelps, 2009, p. 54).

According with all this reasoning, emotion-attention interactions wouldn't be a linear function, thus depending on many different factors such as novelty of the stimulus, the existence or not of effective innate, cognitive or automated responses to face it, contextual information, simultaneity with other stimuli, saliency, expectations, or the existence of goal-oriented or motivated active processes. All these factors will determine the activation, or not, of different networks, within different levels and at different moments. Thus, our model offers a way to explain the gradual shift from basic innate attentional capacities, to the more advanced and acquired attentional capacities. As more cognitive responses are developed, also are their advanced attentional capacities, which gradually exerts increased inhibition over the innate ones, given that the new cognitive-attentional pathways not only become fast enough (Pessoa, 2013), but also much more specific, and thus more effective and efficient than the general-purpose innate capacities. For instance, this shift of attentional processes from innate toward acquired attentional networks could give account of the execution interference that appears when an already automated behavior is again executed under conscious control (Beilock, Carr, MacMahon, & Starkes, 2002). This neural shifting mechanism could also be implied in the capacity that goal-oriented tasks have to block emotional distractors (Vogt, De Houwer, & Crombez, 2011; Vogt, De Houwer, Crombez, & Van Damme, 2013; Pessoa, 2013).

This approach is consistent with the most recent advances in neuroanatomy and neurophysiology, thus letting us to go, from more classical attentional models based on "low" (innate, subcortical, coarse and

quick) and “high” (developed, cortical, fine, and slow) dual pathways (Vuilleumier, 2005, p. 589 Box 2), to more flexible models based on “dynamic networks” (Pessoa & Adolphs, 2010; Pessoa, 2013), which consider that emotion-attention interactions dynamically recruit multiple and heterogeneous resources, whether innate or acquired, to form flexible networks to resolve a stimulus (Pessoa, 2010a).

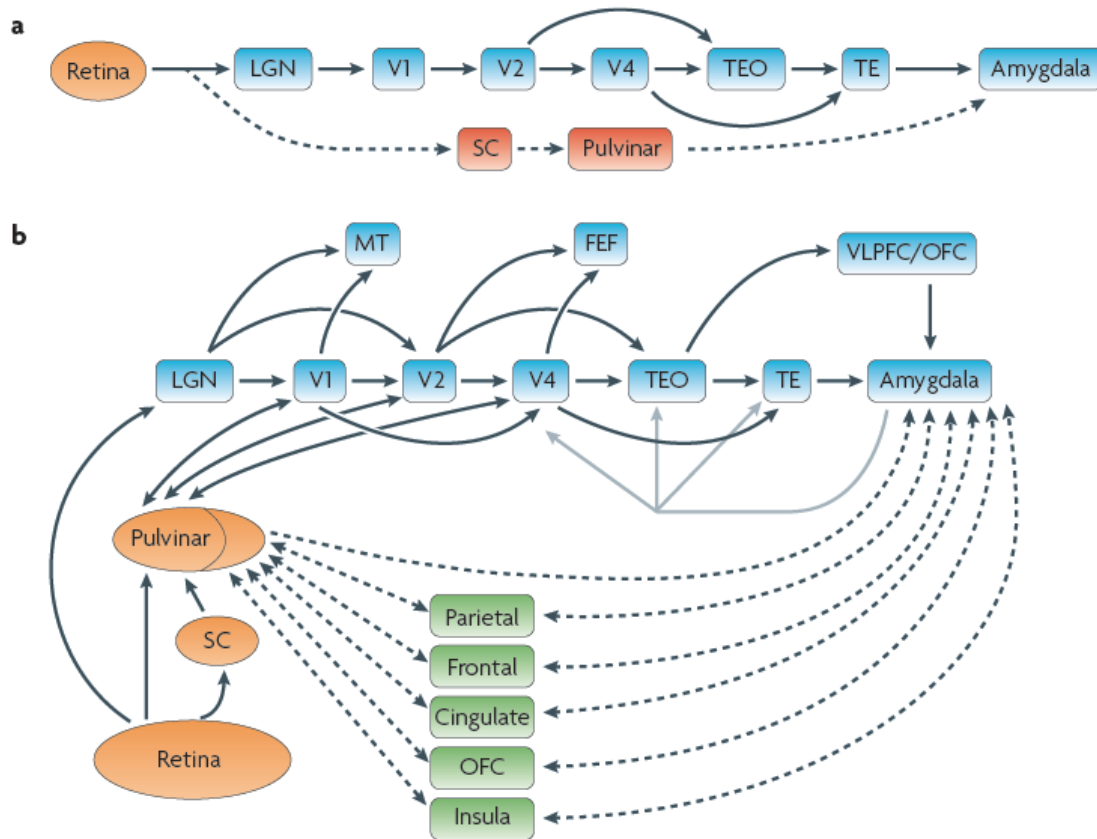


Figure 2. Visual pathways. a | A traditional flowchart of visual processing typically emphasizes the LGN – V1–V2–V4–TEO–tE pathway, although the scheme is not strictly hierarchical. The amygdala, in particular, is a recipient of visual signals from the anterior visual cortex. According to the ‘standard hypothesis’, a subcortical pathway involving the superior colliculus and the pulvinar nucleus of the thalamus provides fast and automatic access to the amygdala. **b** | An alternative view of the flow of visual signals includes multiple pathways, including both alternative routes (for example, LGN to MT) and shortcuts (for example, V2 to TEO). Only some of these are shown. The flow of visual information may be more appropriately viewed in terms of ‘multiple waves’ of activation that initiate and refine cell responses at a given processing ‘stage’. For simplicity, feedback pathways, which are known to be quite extensive, have been omitted. The existence of such feedback pathways dictates, however, that a complex ebb-and-flow of activation sculpts the neuronal profile of activation throughout the visual cortex, and likewise the amygdala responses. Some of the connections between the pulvinar and visual cortex, and between the pulvinar and ‘associational’ areas, are also indicated. The line in the pulvinar is intended to schematically separate the medial pulvinar (to the right of the line) from the rest of the structure. FEF, frontal eye field; LGN, lateral geniculate nucleus; MT, medial temporal area (also known as v5); OFC, orbitofrontal cortex; SC, superior colliculus; TE, inferior temporal area TE; TEO, inferior temporal area TEO; V, visual cortex; vLPFC, ventrolateral prefrontal cortex. Reproduced with permission from Pessoa & Adolphs 2010.

in that sense, and though further research is needed to elucidate the different networks implied in different attentional capacities, it seems clear that the anatomical components that functional experiments relate with emotional processing (amygdala, pulvinar, hypothalamus, basal forebrain, cingulate, ventro-medial, lateral, and orbitofrontal cortex) are among the most widely interconnected areas in the brain. This fact makes possible for the emotional processes to mobilize and engage multiple sensory, perceptual, motor and cognitive resources, together with bodily and homeostatic ones (Pessoa, 2013), as our model postulates.

Despite of multiple subcortical pathways that have been associated with emotional regulation of attention (Armony & Vuilleumier, 2013; Pessoa, 2013), it is worth to highlight the special relevance of the amygdala, that not only is one of the most interconnected regions of the brain, but also receives and sends highly processed information from multimodal cortices (Pessoa, 2010b) for both, negative and also positive valence stimuli. If we take into account the functions we have just assigned to emotions (contingency, regulation and prioritization), amygdala seems to play an important role “receiving relevant affective sensory information from cortex and thalamus, or memorized information from hippocampus and, in turn, activating other brain structures implied in orienting, vigilance, enhanced perceptual processing and efferent structures implied in defensive and appetitive reflex actions” (P. J. Lang, 2014, p. 93). Some studies have shown that amygdala can regulate and enhance the attention to critical emotional stimuli (e.g. fearful faces) by modulating the activity even in the primary visual cortex (Pessoa, 2010a; Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Santesso et al., 2008), while simultaneously suppressing attention to less critical stimuli (Kastner & Ungerleider, 2001). Thus, the amygdala has become a main functional element for emotional regulation of attentional processes (Pessoa, 2010a, p. 438), being itself also gradually regulated as cognitive responses, including acquired attentional subtasks, are developed. For example, fear conditioned experiments have demonstrated the active inhibition of amygdala central nucleus (CE) by infralimbic ventro-medial prefrontal cortex (vmPFC) (Ciocchi et al., 2010; Hartley & Phelps, 2009). On the other side, amygdala seems to be necessary for fear learning and recognition in early childhood, but not later, as some experiments with bilateral damage at different ages have shown (Adolphs, Tranel, Damasio,

& Damasio, 1994; Hamann, Stefanacci, Squire, Adolphs, & al, 1996). Thus, our reasoning about “functional shifting” could give some clues to understand the intact capacity, observed in adults with bilateral amygdala damage, to quickly and unconsciously detect fearful faces (Tsuchiya, Moradi, Felsen, Yamazaki, & Adolphs, 2009).

Summarizing this paragraph, as new cognitive responses are gradually developed, also are their advanced attentional subtasks, which in turn become highly effective and efficient sub-processes. These new attentional subtasks will dynamically make use of either innate or acquired resources, depending on their necessities, thus giving place to different networks activation. At the same time, and to avoid mutually interfering, innate general-purpose attentional capacities will be silenced through an active inhibition mechanism, also developed as a necessary part of new cognitive responses. Thus, a shifting process from innate to acquired attentional capacities, together with automaticity of those acquired capacities, could give account of several observed phenomena (See Domínguez-Borrás & Vuilleumier, 2013 for a review).

1.11. Cognitive systems

According to our model, cognitive systems are responsible to find new, more specific, effective and efficient responses when the available ones, whether innate, cognitive or even automated, are not able to effectively resolve a stimulus, that is, to completely match stimulus and expectation representations. This means that, as we will later reason in more depth, cognitive systems are in charge to minimize the emotional tensions paired with active stimulative processes, whether exogenous or endogenous.

Within the category of cognitive systems we include those neural networks capable of implementing different strategies, more or less advanced, to process information in a dynamic and innovative way, generating solutions of varying complexity, allowing the living being to effectively respond to stimuli. To do so, these systems use sensory and previously represented conceptual information (Mahon & Caramazza, 2009; Martin, 2007; Patterson, Nestor, & Rogers, 2007), and their relationships, to combine them and create new representations that minimize the emotional tension. Within cognitive systems we include from

implicit learning or imitation, to decision making, going through working memory, logic, planning and prediction systems, theory of mind, language, imagination or deception.

Once a stimulus gains access to cognitive systems, we must re-apply the principles of efficacy and efficiency. The brain must find an effective response, while minimizing the time and resources to do so. To do that, it must explore the appropriate cognitive strategies according to the criticality and complexity of the proposed task, and only those. The existence of multiple subsystems (Norman & Bobrow, 1975; Miyake et al., 2000), with different degrees of expertise and consumption of resources and time, generate a hierarchical structure for cognitive systems that define the order in which they will get into action to solve a particular problem (Miyake et al., 2000). Sometimes several of them may operate in parallel on the same stimulus, while other times they will operate sequentially (Paas, Renkl, & Sweller, 2004; Paas, van Gog, & Sweller, 2010; Bapi et al., 2005).

Thus, and according with our reasoning, the meaning of *cognition* do not depends on how sophisticated are the systems used to solve the stimuli, but the right balance between the problem, the constrains, the system applied and the quality of the response in terms of need, effectiveness, time and resources used to find it (R. J. Sternberg & Pretz, 2005; Neubauer & Fink, 2009; Deary, Penke, & Johnson, 2010). This will have important implications for the behavior to be discussed later.

It is worth noting that, as cognitive responses are experientially-acquired responses, their effective range of operation will be restricted within the limits of the already experienced stimuli. In case a stimulus exceeds that range, the cognitive response could become ineffective, and the emotional response will take the control again. This, for example, is the main reason for airplane pilots to get trained in a wide number of unlikely risky situations in flight simulators, thus widening the range for which learnt emergency responses are valid. The operative range of cognitive responses can also be widen through mental imagery pre-training, as many combatants and professional athletes usually do (Milton et al., 2008; MacIntyre et al., 2013; Guillot et al., 2012; Héту et al., 2013).

At the neuroanatomical level, and aligned with our reasoning about the necessity of emotional-cognitive loops, the “networks” approach is showing that we can’t identify specific brain regions as “cognitive” or “emotional” given that both, cortical and subcortical pathways massively participate in the diffusion-integration processing of information (Swanson, 2000; Modha & Singh, 2010). Thus, some brain regions take part in numerous functions, while the same function can be executed by different regions, giving place to conjunctural dynamic assemblies of different circuitry, innate and acquired, to produce a behavior (Pessoa, 2014b). Accordingly, we don’t differentiate emotional from cognitive processes by the regions involved on their processing, but only on the kind of bottom-up and top-down operations that must be run on the stimulus, together with contextual and internal state information, to elicit the primer or the latter (Lamme, 2003). Therefore, we displace from the circuit concept to the network concept, where different necessities recruit different sets of functions that temporally conform a network (Pessoa, 2014c). In that sense, Pessoa recently affirmed that “the neural basis of emotion and cognition should be viewed as governed less by properties that are intrinsic to specific sites and more by contextually determined interactions among multiple brain regions. In this sense, emotion and cognition are functionally integrated systems, namely, they more or less continuously impact each other’s operations” (Pessoa, 2014a).

As an example of our approach both, an amazonian indigene and an urban man will respond the same, with a startle reflex, when they are suddenly exposed to an unknown and unexpected loud noise, while the indigene will not respond the same than the urban man before an aimed gun. In the first example, will be reflexive networks which completely execute the response, while in the second case the urban man’s brain will recruit innate and cognitively-developed representations to assess the stimulus and identify it as a threat, thus eliciting an emotional response (Phelps, 2006). A firearm is a meta-concept whose stimulative pattern has to be associatively related to its killing capacities and risks through a cognitive process and, therefore, initially it has no meaning for the indigene. It is obvious that, though both stimulus, the loud noise and the firearm, may elicit a fear response to the urban man, the networks recruited to reach that response are not the same.

1.12. Consciousness and free will

Although this issue goes beyond the focus of this paper and we do not intend to give an explanation for the “hard problem” of what consciousness is (Blackmore, 2004), we have made an operational approach to this phenomena. In that sense, and apart from wider philosophical considerations, for the scope of this paper we consider that there exist two different realities; the “*objective reality*” which represents the exogenous information that is captured and transduced through our senses, and the “*subjective reality*” which is the one we finally perceive when the sensory information has been filtered, integrated, modulated, combined, modified and feedback through an unnumbered set of emotional, attentional and cognitive processes. Thus, we consider that both realities are very different. The first one, we suppose, has a material entity but, where does reside the second one? We suppose in our brain. Therefore, we need a system, or a set of systems, where subjective reality is finally built, whether it is localized or distributed along several networks. Thus, our model does not provide an explanation for what consciousness is or where it resides, but it does provide a reasoned explanation for what are the contents that access the conscious level, which will be described in depth when introducing the dynamic model, given that some reasoning still need to be introduced. Up to then, consciousness will be considered as an emergent phenomena and a final stage in the information processing, which “shows” the results of lower levels of processing (Libet, Gleason, Wright, & Pearl, 1983; Libet, 1999, 2004; Haynes & Rees, 2006; Soon, Brass, Heinze, & Haynes, 2008; Haynes, 2011).

1.13. Summary

The fundamental physical laws together with evolutionary and adaptive processes, sustained for long periods of time, have shaped the nervous system as a highly optimized mechanism in the processing of information, allowing the development of responses that facilitate effective and efficient interaction of living beings with its environment, thereby improving their chances of survival and reproduction. As part of the optimization mechanism, due to uncertainties about the characteristics and simultaneity of stimuli that an individual will face, evolution has selected the emotional system like the responsible for carrying out three major functions:

1. Deploy broad-spectrum innate responses that allow exploration and rapidly address of novel or unexpected stimuli for which there is no a specific response.
2. Activate cognitive systems, responsible for the search and development of new responses, when really needed, thus improving response time and resource consumption.
3. Indicate the criticality of stimuli to be solved, allowing priority access to the most advanced and scarce resources, if concurrency with other processes occurs.

Thus, and according to our model, the emotional system has control over the activation and dynamics of attention, which regulates and prioritizes the access of stimuli information to advanced cognitive systems and these, in turn, are able to operate over different functional elements the emotional system utilizes to assess the necessity of displaying an emotion. According to this, emotion and cognition do not compete but collaborate, mutually complementing to achieve a complete and the most efficient way to resolve the challenges the individual has to face.

Section 2: Functional Structure

2.1. Introduction

In the first section of this paper we have presented the evolutionary reasoning which allowed us to understand the fundamental role that emotions have for optimizing the brain functioning. In this section, we present the functional structure that emerges from this reasoning. To do so, we will first introduce some basic concepts that will allow us to further address a clearer reasoning.

2.2. Information sources

As we have seen, the information that the nervous system processes comes from a variety of sources which include:

- **Exogenous or Exteroceptive**, in the case of sensory stimuli coming from the interaction with the physical world.
- **Endogenous**, which can be of two types:
 - o **Physiological**, such as the information received through the sensors located inside the body, like those present in the muscles and viscera (proprioceptive & interoceptive).
 - o **Neural**, information that is already represented within different neural systems (e.g. memory), or that can be internally generated in the absence of additional sensory information (e.g. imagery and thoughts), and which can be cognitively processed and reprocessed through different networks to give place to new internal representations (Baron, 2012; Kohn, Paulus, & Korde, 2011; Mahon & Caramazza, 2009; Martin, 2007; Middleton, Rawson, & Wisniewski, 2011; Patterson et al., 2007).

2.3. Processes

Except for a few cases, such as some inborn reflexes and innate responses, that have specific circuits to recognize and manage their associated stimuli, the nervous system cannot know a priori what stimuli the

individual will face. This, together with the fact that stimuli can range from single nociceptive sensor activation up to complex integration of multimodal information, gives our model the form of a process-oriented structure, where the afferent information is simultaneously processed through different networks composed of different specialized systems (Lamme & Roelfsema, 2000; Pessoa, 2013). A double **diffusion - Integration** process (Modha & Singh, 2010; Swanson, 2000) along different brain regions gradually explores the saliency of the stimulus together with the context where it is onset (Fanselow, 2000; Rudy, Huff, & Matus-Amat, 2004), both modulated by the expectations previously elaborated, or not (Siegel, Hinson, Krank, & McCully, 1982), and generate new or the same responses depending on the input information (Edelman & Gally, 2001).

Our model also includes the need for information processing networks to have the potential to be dynamically activated or silenced by other networks, thus allowing the incorporation or selectively blocking of information from different pathways, without the need to change the physical connectivity therewith.

2.4. Levels of processing

In our model, the data from different sources of information are combined using the diffusion-integration process, and are gradually evaluated through a functional hierarchy (Lamme & Roelfsema, 2000) in which we distinguish six main levels (Fig.3.a) that, starting at the lower levels (neuronal level), integrates and processes information, transferring the responses generated in each of these levels to different destinations, and gradually reaching the top level (relational or associative level).

At each level, the information is analyzed by different networks (Lamme & Roelfsema, 2000; Martin, 2007; Patterson et al., 2007), evaluated and, if necessary, one of the various types of possible responses is elicited. Thus, all the information is gradually assessed as it is relayed in a back and forth process, bottom-up and top-down (Kveraga et al., 2007; Lamme, 2003; Lamme & Roelfsema, 2000) through the different levels of processing to identify those stimuli that are meaningful to the living being. This process is what we call **Pattern Recognition** and is one of the main functions of the nervous system (Scherer, 2009).

But this structure is not static. Our model considers this structure of levels as dynamic, especially during childhood and adolescence, where brain plasticity mechanisms continually creates and prunes neural circuits in order to optimize the critical variables and the operation of the whole system as a set (Chklovskii et al., 2004; Low & Cheng, 2006). Thus, new neural pathways allow information at a certain level to be feedback to previous levels, like when we imagine or recall, send it in advance (feedforward) to more advanced levels in the processing chain, or even in a lateral way, as all have been observed in visual information processing (Lamme & Roelfsema, 2000). This model thus incorporates two main concepts for understanding brain structure, recursion and fractal structure of its components.

2.5. Corollary discharge

Our model naturally incorporates the mechanism of **Corollary Discharge** (Fig.3.b) that, at some levels, can suppress the information generated by the individual's own responses. From the **efferent copy** of the response, this system generates a proprioceptive expectation that, appropriately subtracted from re-afferent signal, allows isolating the actual stimulus information from the response information self-generated by the individual.

2.6. Assessment and response

As we previously saw, this model predicts the existence, at each level, of two parallel networks responsible for processing information (Fig. 3-c):

- A first **Emotional system**, genetic and that is always present, in charge of processing all stimuli, using innate and stereotyped responses (**emotions**), able to quickly respond to generic and novel or unexpected stimuli, in addition to activating cognitive systems and to indicate the criticality of the stimulus they represent.
- A second **Expectation-Response system**, which can exist since the beginning in the case to be genetic (innate response), or may be partially or fully developed (cognitive response / automated), or otherwise does not exist at all, as in the case of exposure to a completely novel stimulus (Fig 3.d - B).

These two networks are interconnected (Evgeniy N. Sokolov, 1963) but, in our model, the emotional system is the by default response network, and the expectation-response system is in charge to control the Emotional system activation through mechanisms of inhibition (Fig.3-c). This inhibitory mechanism is an important subtask of all available responses, whether innate or acquired, and is effective for a limited range of stimulus' values, out of which the inhibition becomes ineffective. We will see in more detail its operations in the next section.

Thus, a certain stimulative pattern can either trigger an emotional response and being "tagged" with an emotion (Fig.3-d - A), or produce an "active" response (Fig. 3-d), or both at once if the response is not completely effective, is not available, or it doesn't exist at all (Fig.3-d - B).

Once a response is found and whether the stimulus is repetitive, the automaticity process allows it to be optimized (Fig. 3-d). Through the mechanisms of plasticity, the nervous system adjusts and modifies the neural pathways that generate the responses to achieve the best balance between the critical variables that define their quality.

In turn, responses may be constituted by two complementary components (Fig.3-e):

- A neural component that sends information to other brain systems.
- A physiological component, which may consist of motor actions and / or endocrine ones.

In any case, the displayed response can generate a feedback that can be physiological, as postulated by the emotion embodiment theories (James, 1884, 1890; Lange, 1885; A. R. Damasio, 1994, 2001; A. Damasio & Carvalho, 2013), or neural, activating other networks on the same or on different processing levels. We are now working on a new approach for embodiment of emotions (Garcés & Finkel, 2014b, submitted for publication).

2.7. Attention

As attention topic has been widely introduced in the first section, here we only summarize that previous reasoning. Once a stimulus, whose associated response doesn't exist or it's not completely effective, has

been "tagged" with its corresponding emotion, both enter the **Attentional Competition** process (Fig.3-f). According to this model, the focus and width of the **attentional window** is thus controlled by the characteristics of different emotion-stimulus pairs that, at a given time, act on the **attentional model** (Fig.3-f). In our theory, attentional model is a dynamic element that processes emotional information according with priority maps codified in both, lateral frontal cortex and parietal cortex (Fecteau & Munoz, 2006).

Depending on the needs, number, complexity, and criticality of active stimuli at a given time, the attentional systems regulates the range and shifts the focus of the attentional windows, allowing information concerning to stimuli with higher priority to access the cognitive systems.

2.8. Cognitive systems

Cognitive systems (Fig. 3-g) process information following a hierarchical pattern, starting with simpler or more probable strategies (according to previous experience) and applying more advanced strategies consecutively if the previous one are not able to effectively solve the stimulus that triggered the emotional-cognitive process.

2.9. Cognitive responses

This model gives rise to three different types of cognitive responses the brain can deploy to solve stimuli.

They are:

- Responses which act on the stimulus or modify the relationship of the individual with regard to it (e.g. fight or flight).
- Responses acting on the reference model, modifying the expectation the stimulus is compared with (e.g. acceptance).
- Responses acting on functional elements of the system, thus modifying its global dynamics (e.g. somatic silencing by anxiolytic consumption).

It is important to note that we consider stored representations and memory recall as endogenous stimuli that must be treated as independent stimuli which can, by themselves, maintain an emotional-cognitive

process active even when the original sensory stimulus has already disappeared (e.g remembering a beloved). This fact will be of critical importance in describing some extreme psychological phenomena, such as Body Dismorphic Dissorder (BDD), as normal responses of a dynamic system exposed to possible, though unlikely, context conditions (Garcés & Finkel, 2014b, submitted for publication). Anyway, these three kinds of cognitive responses will be developed in more detail when we introduce the dynamic model in the next section.

2.10. Automaticity

Once a response has been found, and as reasoned in the first section, the brain will try to automatize it as much as possible as a way to balance the three critical variables relationships, thus giving place to skills, and in some cases also to habits and even addictions.

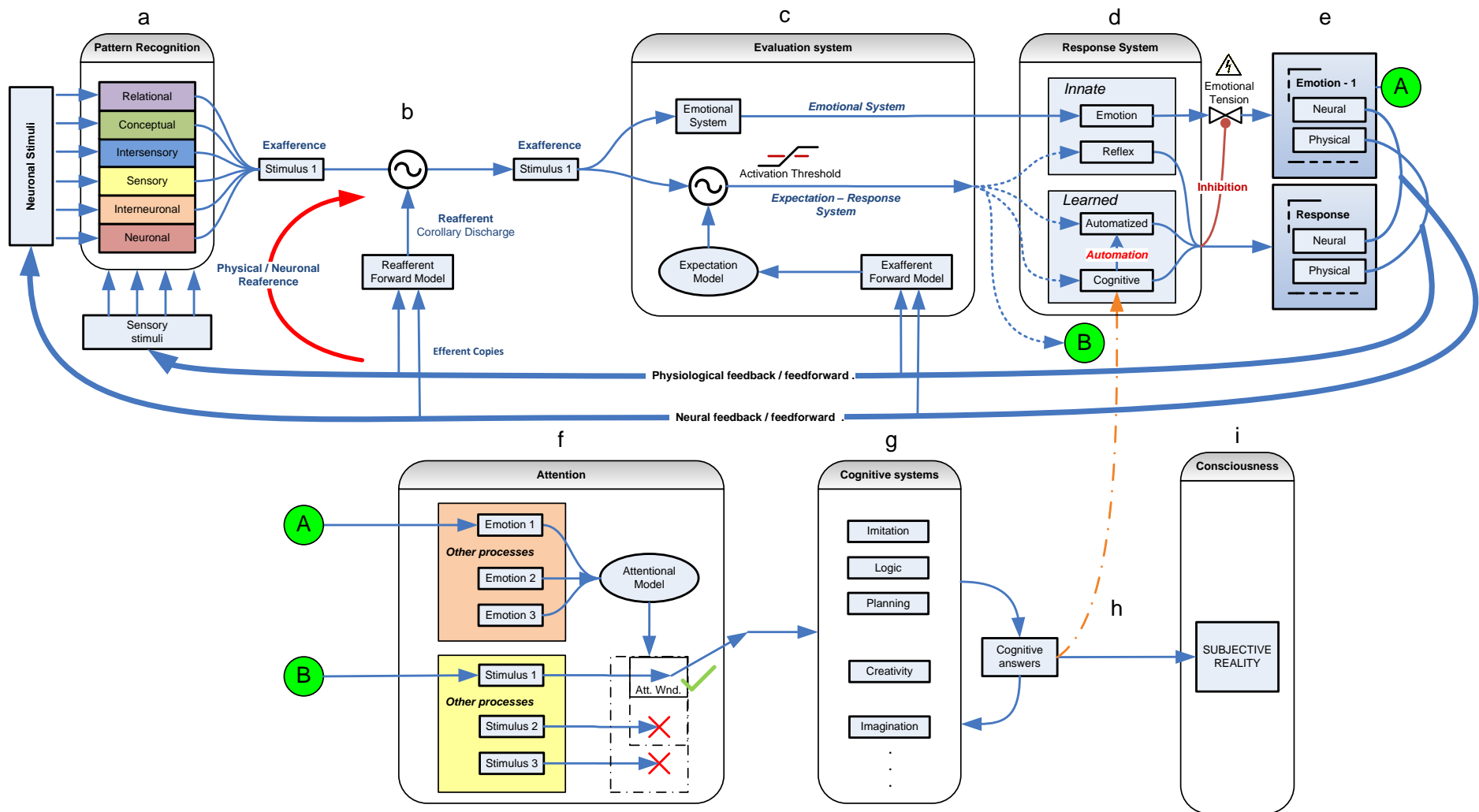


Figure 3. Emotional-Cognitive model.

Section 3: Dynamic model

3.1. Introduction

In the first two sections we have presented the evolutionary reasoning leading to our model and the functional structure that emerges from this reasoning. In this section we analyze the dynamic model, which describes the way the various parts of the functional structure interact to generate the sensory, emotional, perceptual, cognitive and behavioral phenomena.

3.2. Pattern recognition

As we reasoned, the first step to face a significant stimulus is to be able to recognize the characteristics that identify it unambiguously. In that sense, once sensory information is captured and encoded, one of the most important tasks of the nervous system is to recognize the arising patterns (Scherer, 2009).

Since the nervous system doesn't know a priori what stimuli or combinations of them (patterns) are going to be significant, it initially needs to run a comprehensive strategy capable of analyzing all the information it receives, especially that for which it doesn't have innate circuits to process and response. Some few stimulative patterns are innately represented and can be automatically recognized and processed through innate networks such as reflexes or fixed action patterns (e.g. sucking the nipple). From those innate patterns, more complex ones are associatively developed in a dynamic learning process, thus giving place to capacities like dynamic pattern recognition (e.g. text reading independently of the font it is written in) (Mahon & Caramazza, 2009; Martin, 2007; Patterson et al., 2007) .

It is worth noting that, as significant stimulative patterns can be mono or multimodal, and can arise at many different times, forms and sizes, multiple different components can be recruited in parallel networks and in back and forth loops to allow recognizing them (Martin, 2007; Pessoa & Adolphs, 2010). Thus, the nervous system gradually integrates, through successive functional levels and recursive bottom-up and top-down loops (Lamme & Roelfsema, 2000), the data from the various sources of multimodal information available, both external and internal. In parallel with the creation and optimization of physical network, the


vast initial network of neurons and connections will be optimized through the mechanisms of synaptic pruning and plasticity (LTP, LTD, iLTP, iLTD, STDP), reinforcing those networks encoding functions necessary to recognize and respond to significant patterns the living being is exposed to (Johansen et al., 2014).

3.3. Corollary discharge

In addition, the corollary discharge process filters and separates the information concerning the stimulus from the self-generated one as a part of the individual's own response. An example of this system is the inability to tickle ourselves, because the brain uses the efferent motor copy to generate a proprioceptive sensory expectation (Blakemore et al., 2000). As an example, a malfunction of this system could be behind the hallucinations experienced by patients with schizophrenia. In these cases, a failure of this mechanism would prevent them from recognizing the voices they hear inside their head as generated by its own brain, then interpreting the "inner voice" as if they were induced by an outside agent (Ford & Mathalon, 2004).

3.4. Emotional and expectation-response systems interaction

According with our previous reasoning, at birth, few, if any, cognitive representations or responses are available, and so the stimuli are responded through very specific or very general innate reflexive networks (Viding et al., 2013). While those innate responses are effective, emotional activation is not needed. If those responses become ineffective or out of range, emotional information will regulate the innate attentional mechanisms indicating the need to intensify the response or to search for another one. Given the limited number and range of efficacy of innate responses, as the time goes on and the interaction with the environment and sensory experiences accumulate, it is logical to think that the number of episodes where innate responses becomes ineffective also grows, thus forcing the activation of the emotional system to regulate the development of new cognitive responses. Those new cognitive responses gradually give place to the appearance of advanced capacities, mainly cognitive, attentional, more accurate expectation generation, and more complex pattern recognition. In that sense, at every developmental moment we identify two complementary networks:

The first one is the **emotional system**. This network is always present as it is innate and, by default, processes the sensory information in search for emotional-laden patterns. As those significant patterns can be either simple or complex, they can arise at every level of information integration and processing. Thus, a hierarchical loop should exist to systematically explore multimodal information as it is gradually combined. This implies that the emotional response is always the first to be available, though not necessarily executed. (Garvert, Friston, Dolan, & Garrido, 2014) 

The second one is the **Expectation-Response system**. This network can exist since the beginning if innate, can be acquired if cognitive or automated, or might not exist, like in the case of a novel stimulus. If it exists, it can be effective in solving the stimulus, or not (e.g. out of range).

It is important to note that both systems refer to dynamic networks formed by recruiting heterogeneous subsystems (Pessoa, 2013). This dual analysis configuration ensures that, if the stimulus is novel and/or if the available response is or becomes ineffective, the emotional response is always ready to run, without delay, deploying a stereotyped strategy that initially allows to tackle the stimulus while, in parallel, prioritizes and regulates the attentional mechanisms to compete for the access to cognitive systems and find a more effective response, thus optimizing the overall functioning of the nervous system.

But, as we expose in the first section, when two parallel networks assume the task of solving the same stimuli, it makes no sense that both act at a time. For example, if both simultaneously would run two different motor actions using the same muscle groups, their effectiveness would be greatly reduced as both responses would mutually interfere (Klein, Petitjean, Olivier, & Duque, 2014; Morsella, Godwin, Jantz, Krieger, & Gazzaley, 2015). To avoid it, these two networks should be **inversely connected through an inhibition mechanism (Fig. 3.c)**. It stands to reason that this inhibition signal should be generated from the network that implements the more specific response to solve the stimulus, the expectation-response system, to the network that displays the less specific response, the emotional one. Furthermore, because of the importance the emotional responses have for the survival of living organisms, inhibition signal must be active, that is, by default the emotional system will not be inhibited. Thus, the inhibiting function of the

emotional system will become an important subtask of specific responses, whether innate, cognitive or automated.

The best way to clarify the role of emotions in our theory is to use as an example the "**dead-man button**". This mechanism is used in trains as a safety measure to prevent accidents. The system repeatedly asks the driver to actively push a button after a random time interval. Pressing the button inhibits the action of the emergency brake, which is active by default. Thus, if the driver suffers a mishap and does not respond to the request to press the button, then there is no inhibition of the brake, which is automatically activated, stopping the train and avoiding an accident. Importantly, pressing the button maintains active the inhibition of the emergency system.

In our model, the execution of a completely effective response would be equivalent to pressing the "dead-man button", thus inhibiting the activation of the emotional system, which is active by default after stimulus onset. Conversely, if there is no a completely effective response, the inhibition over the emotional network will not be complete, executing the emotional response. In this case, emotions are the default response that mobilizes physiological and cognitive resources, but only while really needed, thus optimizing the functioning of the nervous system (Bassett et al., 2009). This dynamic could give account of the stress curve (Fig.4) indicating when the cognitive response is out of range, whether due to cognitive available capacity or to the intensity of the stimulus (Yerkes & Dodson, 1908; Diamond, Campbell, Park, Halonen, & Zoladz, 2007).

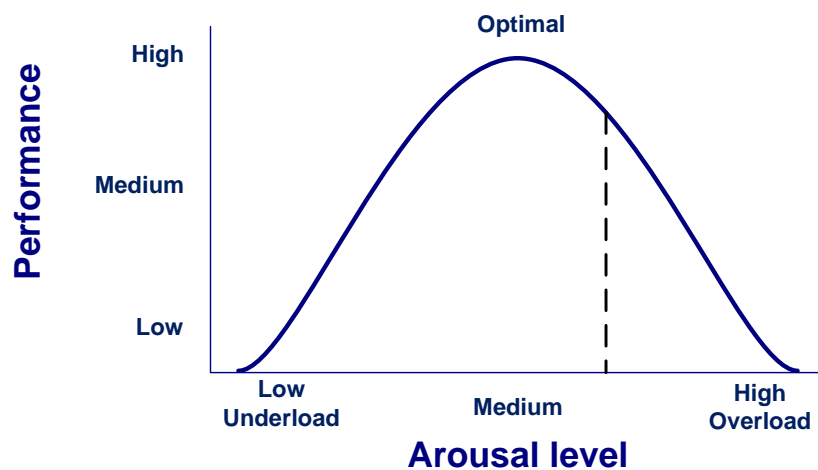


Figure 4. Stress curve.

If we look again for the neuroanatomical and physiological correlates, we found that this mechanism has been observed at cellular level in fear-conditioning and extinction experiments. As the conditioned response (CR) can return after extinction under different conditions (e.g. spontaneous recovery, renewal, reinstatement, external disinhibition), it is thought that conditioned memory survives the extinction process, being actively inhibited by new memories (Maren, 2014). In that sense, the CR not only is partially depotentiated by the extinction process (LTD), but also actively inhibited in the basolateral nucleus of the amygdala (BLA), either potentiating LTP at excitatory synapses among conditioned stimulus (CS) afferents that terminate on inhibitory interneurons, or limiting excitatory transmission between the BLA and central amygdala (CEA) through synaptic plasticity, induced by afferents coming from the ventromedial prefrontal cortex (vmPFC) to inhibitory intercalated cells (ITC), thereby suppressing the generation of learned fear responses (Maren, 2014; Furini, Myskiw, & Izquierdo, 2014; Hartley & Phelps, 2009; Quirk & Mueller, 2007). In the same sense, experiments with cognitive inhibition of fear have also shown the active inhibition of the amygdala by the dorsolateral prefrontal cortex (DLPFC) through the same vmPFC region thought to mediate the inhibition of fear response during extinction process (Delgado, Nearing, LeDoux, & Phelps, 2008; Hartley & Phelps, 2009; Phelps, Delgado, Nearing, & LeDoux, 2004). This mechanism of inhibition can also be observed in the startle reflex regulation when subjects are exposed to positive, neutral and negative valence stimuli (Speed, 2012).

Thus, the neural mechanisms implied in extinction and cognitive regulation of fear seems to follow the same scheme we propose, where a pathway codifies the parameters of the emotional stimulus and its response, while other circuitry, more specific and more effective, actively inhibits that response.

This model is thus consistent with more experimental models like “dual competition” (Pessoa, 2009), where emotional information, whether stimulus-driven or motivational, impairs neurophysiological and behavioral responses (Yang et al., 2014). Those experimentally observed interferences are naturally explained within our model as “transient states” that exist in the process that leads, from the completely ineffective response state (novel stimulus), where a pure emotional response is displayed, to the completely effective

response state, where the emotional response is completely inhibited. Therefore, our model explains the reason for the gradual changes that affective information processing suffers, as the attentional and behavioral components are shifted from innate processing networks to more cognitively acquired and automated ones. In that sense, the impact of emotional stimulus on behavioral impairment is not only linked to the stimulus' level of threat (intensity, complexity, etc...), but also to the repeated experience with the stimulus (memory) and the degree of efficacy reached in solving it. Therefore, and once again, a multifactor function will define the set of resources, innate and acquired, to be recruited into a dynamic network to face a specific stimulus.

We can see this graphically using a simplified diagram (Fig. 5):

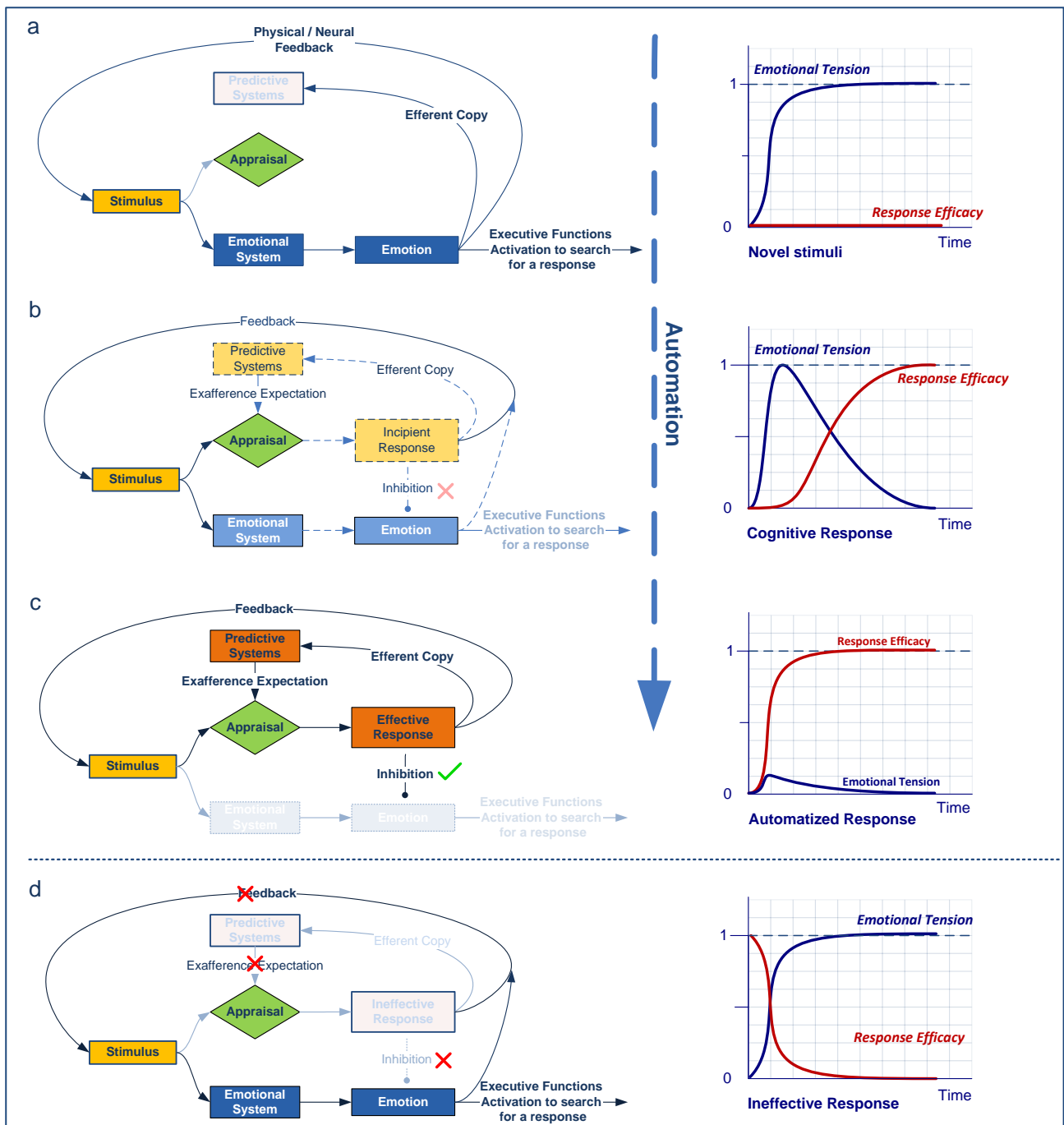


Figure 5. Emotional-Cognitive simplified dynamic model.

This figure shows the scheme to process stimuli. **(a)** If the stimulus is novel, both for the species and for the individual, there will not exist an innate expectation-response network. In that case, the inhibition signal for the emotional system will be disabled, which in turn will display an emotion to activate the advanced cognitive systems, thus starting the search for a new and more effective response. **(b)** The emotion stays active throughout the response searching process, but is gradually inhibited as the expectation-response set becomes more and more effective. **(c)** Once an effective expectation-response is developed, the more it is automated or the more the predictive systems are fine tuned for expectations generation, the more the emotion becomes unnecessary and, therefore, it will be completely inhibited. **(d)** But the emotional network doesn't disappear. It stays inhibited as a contingency element whether the response could newly become ineffective.

- a) According to our model, all stimuli are always simultaneously processed in parallel by two dynamic networks, the emotional one and, if it exists, also the expectation-response one. When an organism is exposed to a novel stimulus, both for himself and for his species (Fig. 5-a), there is not an innate and specific neural circuitry to solve it, nor an expectation to compare with. Thus, the stimulus is processed necessarily through the emotional system, displaying an emotion. This emotional response, with its physiological and/or neural components, activates and prioritizes the attentional access to advanced cognitive systems to search or develop a new response, while in parallel it executes a stereotyped behavior, more or less accurate (e.g. fight or flight).
- b) As cognitive systems increasingly develop and refine an effective response to resolve the stimulus (Fig. 5-b), predictive systems also generate new increasingly accurate expectations for both, the expected change in the characteristics of the stimulus (exaference), and the expected change in the system's proprioceptive state (reaference)(Stahl & Feigenson, 2015). This allows performing the appraisal process, which compares the stimulus information as it is modified by the response, and the body's proprioceptive state, with the internally developed expectation. This structure allows the nervous system to check the effectiveness of their own responses (Friston, Kilner, & Harrison, 2006).
- c) In addition, as a result of the repeated experience and through the automaticity process, the efficacy of the response can be gradually improved, thus inhibiting the emotional system to optimize brain functioning (Fig. 5-c).
- d) But, what if the response ceases to be effective? In this case the inhibition over the emotional network stops again, thus triggering the emotion as the stereotyped and the best available contingency response (Fig 5-d).

This model definitely solves the intense debate that has existed for decades about the concepts and the primacy between emotion and cognition (Zajonc, 1980, 1984; Lazarus, 1984, 1991; Leventhal & Scherer, 1987; C. A. Smith & Lazarus, 1990; Scherer, 2009; Frijda, 2009). In our model there is no place for such a discrepancy, since it considers that all these statements are true and complementary, and are the

characteristics of the stimulus, its previous history on both, the individual and the species, the context in which it occurs and the brain optimization mechanisms which define whether the process performed on the sensory information will be emotional, reflexive, cognitive or just an automated expectation-response one.

Also, unlike the theories that consider emotion as an element that provides flexibility allowing isolating stimuli from responses (Lazarus, 1991), this theory regards emotions as a system optimizer and contingency response mechanism. The flexibility function is thus delegated to cognitive systems (cognition and metacognition) that, as one of the possible solutions they can deploy, allow to dynamically create and delete associations, schemes and representations (Conceptual combination, see Martin, 2007; and Patterson et al., 2007 for a review) which are subsequently processed by the emotional network as if they were new stimuli, conducting a dual bottom-up and top-down process.

In the same sense, a similar model was already proposed by Sokolov in the 60s of last century in his work about the **orienting reflex** and the **habituation** process (Evgeniy N. Sokolov, 1963; Evgeniy N. Sokolov et al., 2002). Our model re-contextualizes that work from a more global systems perspective. Thus, the gradual process of finding an effective and increasingly automatic response, or the development of an increasingly precise expectation for the stimulus is known as **habituation**. (Groves & Thompson, 1970; R. F. Thompson, 2009)

3.5. Attentional process

The following stage in the information processing is attentional competition, which is continuously assessing the full set of stimulus-emotion pairs that are active at every moment, and actively assigning the available resources according to their criticality. Thus, as the active stimuli-emotion pairs dynamically vary their criticality, the attentional windows are refocused and expanded or narrowed to reassign the access to cognitive systems.

One of the main problems when exploring the emotional regulation of attention is the fact that diverse experiments show a great disparity in their results, some of which seems to show a “hard automaticity” of

emotional regulation over attention, others that show “soft automaticity” (depending on the available resources) (Pessoa, 2013). Our model gives a framework to explain those different results by taking into account the definition of emotion, attention and the automaticity process we have already introduced. Thus, a set of different alternatives to attend to a stimulus can be deployed, depending once again on novelty, context, response availability, response efficacy, stimuli concurrency, criticality, etc... As an example, different attentional processes can be deployed to the same stimulus (e.g. light), from a natural stimulus within a limited range (e.g. soft daylight), that is unattended and unconsciously managed through a specific reflex circuit (e.g. pupillary reflex), to a completely out of range stimulus (e.g. High beams at night) which is emotionally attended to be faced with a spontaneous defensive behavior (e.g. raising the hand before the eyes and turning the head) or deploying a cognitively learnt strategy (e.g. deviating gaze to the road’s sideline).

3.6. Dynamic model variables

At this point, it is worth noting the relationship that arises between the different variables, functions and factors when we explore the dynamic model. In that sense, a graphical summary is shown in figure 6.

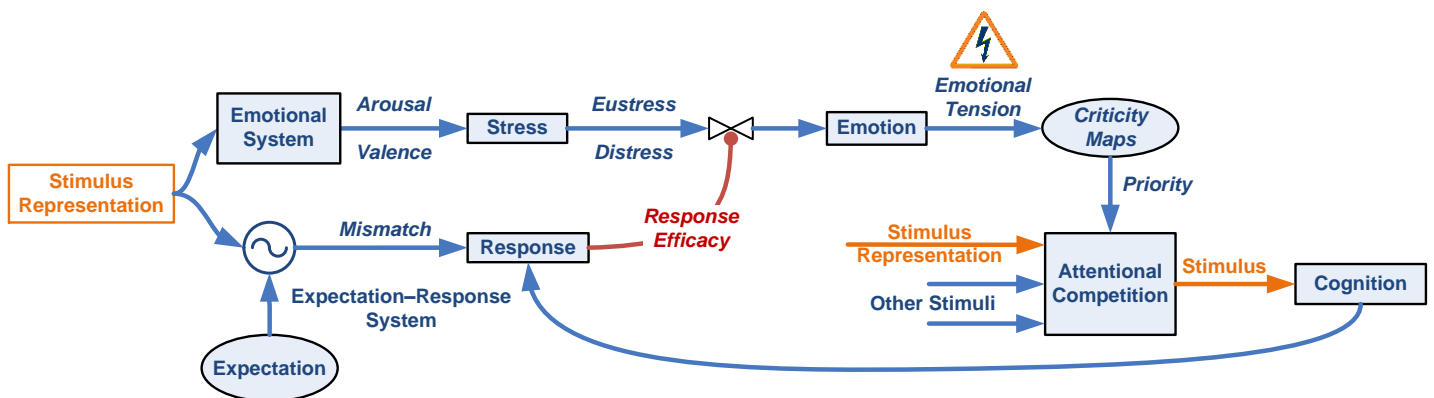


Figure 6. Dynamic model variables and relationships

According to that, the first variable we find is **Mismatch** which indicates the degree of disagreement between stimulus and expectation representations. If the difference surpasses the activation threshold, the response, if available, is executed by the expectation-response system.

In parallel, we find the variables that characterize the emotional system (arousal and valence). **Arousal** refers to the level of physiological and psychological activation. **Valence**, in turn, indicates the approach-avoidance behavioral tendency. If we go on through the emotional system we find **Stress**, which is the primary emotional response, and represents a multidimensional function that combines the arousal and valence variables to give place to **distress** (negative stress) or **eustress** (positive stress).

The next step shows the **Response Efficacy** (or Emotional Inhibition) parameter that, according with our reasoning, codifies the degree of inhibition the expectation-response system (if exists) exerts over the emotional system, thus regulating its expression according with the level of efficacy achieved. Therefore, and as we have previously exposed, we define **Emotional Tension** as a function that results of applying the response efficacy parameter over the stress function.

Once the emotional tension for a given stimulus is processed, it must be weighted using **Criticality** maps as a reference model towards assigning a **Priority** to the stimulus representation.

Finally, through the **Attentional Competition** process, the brain uses the “relative” priority (dependent of current workload) of all concurrent processes, together with the stimuli representations, to dynamically manage the shared access to the overlapped cognitive resources.

3.7. Cognitive responses

Once a stimulus successfully goes through the attentional competition process, it access cognitive systems that will be responsible to find or develop an effective response.

Before going on exploring cognitive capacities, we should briefly contextualize our work with regard to previous definitions of “coping” and classifications of coping strategies identified by other authors (Lazarus, 1993), in which the term is defined as “efforts to prevent or diminish threat, harm, and loss, or to reduce associated distress. Some prefer to limit the concept of coping to voluntary responses; others include automatic and involuntary responses within the coping construct” (Carver & Smith, 2010, p. 685).

As exposed, our model postulates that an ineffective or inexistent response to face a stimulus does not inhibit the elicitation of an emotional-cognitive process in charge to search for an effective response capable to minimize its emotional tension. In that sense, and given that in our model emotion always regulates cognition, and cognition always pursue minimizing emotion, we consider the term “coping” in a wider manner than previous authors, thus including not only the strategies directed to resolve stressful or threatening stimuli, but also those positive and rewarding ones. For example, we consider that both, a reverie about how to seduce a beloved and a rumination about the possibility of being fired at work, are coping processes, with different characteristics (novelty, intensity, valence, criticality, etc...) looking to minimize its own emotional tension through the same functional structure and competing for the same cognitive resources. Using a metaphor, they are different input values for the same equation. Thus, we do not distinguish them by their focus (problem vs. emotion), volition (engagement vs. disengagement), valence (negative vs positive), nor awareness, or even automaticity, given that according with our model we can deploy automated though ineffective responses (e.g. compulsive gambling) (see Carver & Smith, 2010 for a review). See also “habituation and sensitization” below.

In this sense, and depending on the **degree of efficacy**, we identified two different groups of responses:

- A. Effective responses:** completely resolve the emotional tension associated with the stimulus.
- B. Cyclic responses:** the emotional tension is not fully resolved, so that the emotional-cognitive process is still active, though it could stay latent if more critical processes take control of attentional resources.

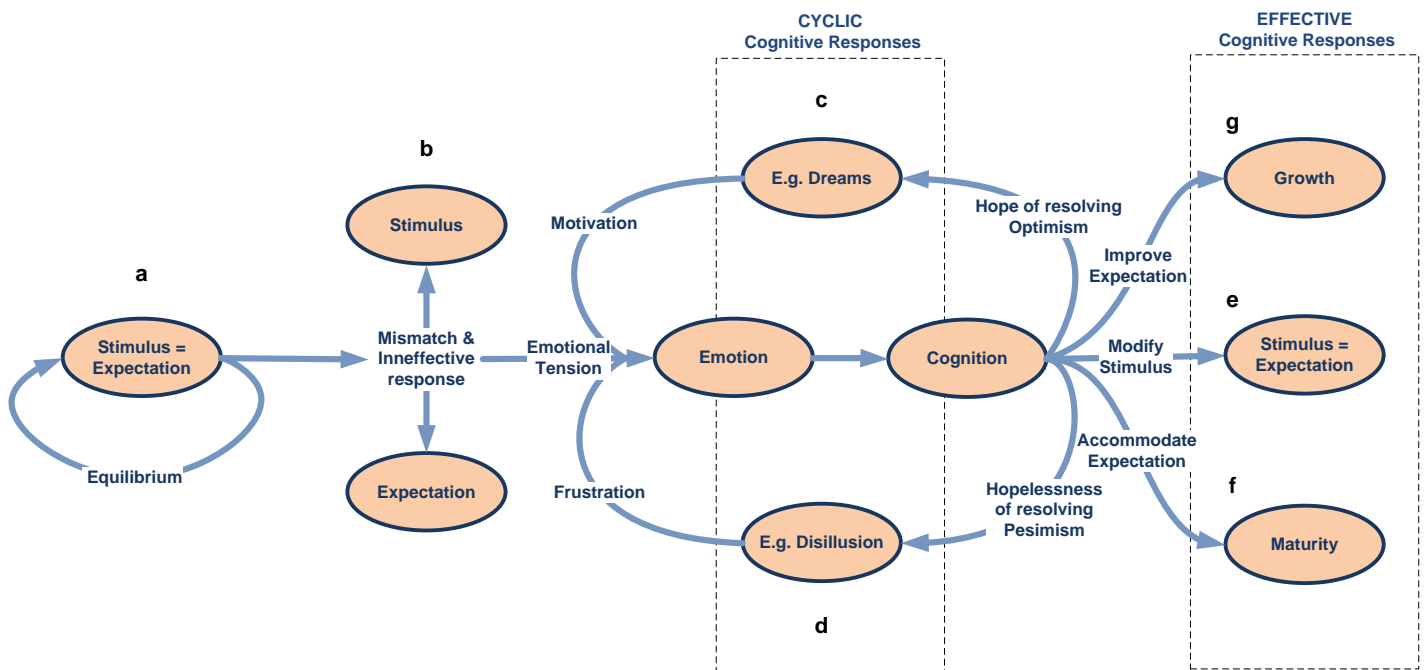


Figure 7. Cognitive responses. This figure shows some of the different cognitive possibilities the nervous system can find to face a stimulus. **a)** As far as the stimulus matches the expectation, a response is not necessary. **b)** If a mismatch occurs and an effective response is not available, an emotion is disinhibited, which in turn regulates the attentional competition to access the cognitive systems. While searching for an effective response, but not yet found, those advanced systems can **c)** positively (optimism) or **d)** negatively (pessimism) shape the expectation (Carver, 2006; Carver & Scheier, 1998), or alternate between both in a cyclic process (e.g. motivation and then frustration...). When finally an effective response is found it can **e)** modify the stimulus or the relationship regarding to it **f)** modify the expectation to match the stimulus or **g)** reframing the stimulus through conceptual combination to create a new interpretation, and therefore a new expectation, about it. There are, however, other possibilities (not shown in this figure) that can modify the operation of the global system by acting upon different functional elements, thus giving place to singular psychological and behavioral phenomena (see text in 3.7 - 3 for details).

Furthermore, as mentioned in Section II, this theory considers three different areas on which cognitive responses can act:

1. Modify the stimulus.

This kind of responses solves the emotional tension by acting on the sensory information that is received. To do that it can follow two different strategies:

- I. **Modify the stimulus to match the expectations.** In the fight or fly paradigm, the fight option would be an example of stimulus modification. This also happens, for example,

when we change our physical appearance, for example cutting our hair or wearing makeup to get a (subjectively) more enjoyable look.

- II. **Modify the individual's relationship with the stimulus.** Thus, within this category we can include the responses of **avoidance** (e.g. fly) or **approach**. An example of this kind of responses would be the approaching behavior a small child usually shows toward his mother, and the antagonistic behavior of rejection he deploys toward strangers.

2. **Modify the expectations.**

This kind of cognitive responses modifies or create new representations or new relationships between previously existing ones, and are usually englobed under “emotion regulation” capacities (Gross & Ochsner, 2013; Viviani, 2013) Thus, under this category we can distinguish two different strategies:

- I. **Modify the expectations to exactly match the stimulus.** We call this strategy "**Maturity**". Acceptance would be such a kind of cognitive responses. An example would be the process of accepting death as an inevitable and unpredictable fact of life.
- II. **Create a new concept or find a new relationship between concepts that expand the expectations (Reappraisal),** allowing the stimulus fit within this new framework (Mahon & Caramazza, 2009; Martin, 2007; Middleton et al., 2011; Patterson et al., 2007). We call this process "**Growth**". An example of this type would be to consider the fact of the inevitability and unpredictability of death as elements that make life, today, here and now, something valuable and exceptional, worthy of being intensely enjoyed. As discussed below, this process of re-contextualization of the same phenomenon is one of the best examples to ratify the emotional-cognitive structure proposed by this theory.

Also, and unlike other models which only consider the possibility to modify the stimulus or the expectation (Friston et al., 2006), our model incorporates a third option that follow and let us to explain a lot of different observed psychological and behavioral phenomena.

3. Modify the system dynamics.

Such responses can be varied and act directly on any of the functional elements of the model, thereby changing the way in which stimulus' information is processed through the system. Without wishing to be exhaustive there are a lot of different strategies:

- I. **Modify the activation threshold of a stimulative pattern.** This generates a greater or lesser activation response to the same stimulus. A simple example would be the priming effect where the rapid presentation of a stimulus bias the subsequent response to related or unrelated stimulus (Murphy & Zajonc, 1993; Suslow et al., 2013)
- II. **Saturate the available resources.** If we look for new and very innovative or intense stimuli so that they have greater criticality, they will compete with advantage in the attentional competition process and prevent other less priority processes from accessing cognitive systems and also consciousness. An example of this strategy would be the compulsive activity and intense sensation-seeking behavior that some people show after a painful breakup.
- III. **Silence the somatic stimuli associated with the emotional response.** Thus eliminating the physiological feedback that, together with neural activation, comprises the elements defining criticality, thereby minimizing attentional priority again. An example for this strategy would be the use or abuse of anxiolytics or chemicals such as alcohol or drugs.
- IV. **Generate alternative stimuli.** One of the most fascinating strategies postulated by this theory is the possibility of internally generating, through mental imagery, alternative stimuli that offer a better solution to minimize the overall emotional tension. Thus, these imagined stimuli will compete for the same perceptual channel, outperforming the original stimulus to provide a better solution. This strategy could be on the foundations of multiple perceptual phenomena of reality distortion, and their associated behaviors (e.g. deception). One of the most extreme areas where we are currently conducting research is

the phenomenon of body image distortion (Body Dismorphic Disorder), which is particularly important in conditions such as anorexia nervosa (Garcés & Finkel, 2014a submitted for publication).

- V. **Time dissociation.** Changing the temporal correlation of different related stimuli can dissociate them from belonging to the same event, thus reducing again the overall emotional tension.

As exposed before, cognitive responses are developed within a certain range, according to the characteristics, intensity and frequency of the stimulus that elicits the search, as well as the emotion associated with it. If a new stimulus is beyond the range of effectiveness of a previously developed response, the emotional response becomes disinhibited again. A dynamic decision-tree can be found in the next figure (Fig. 8)

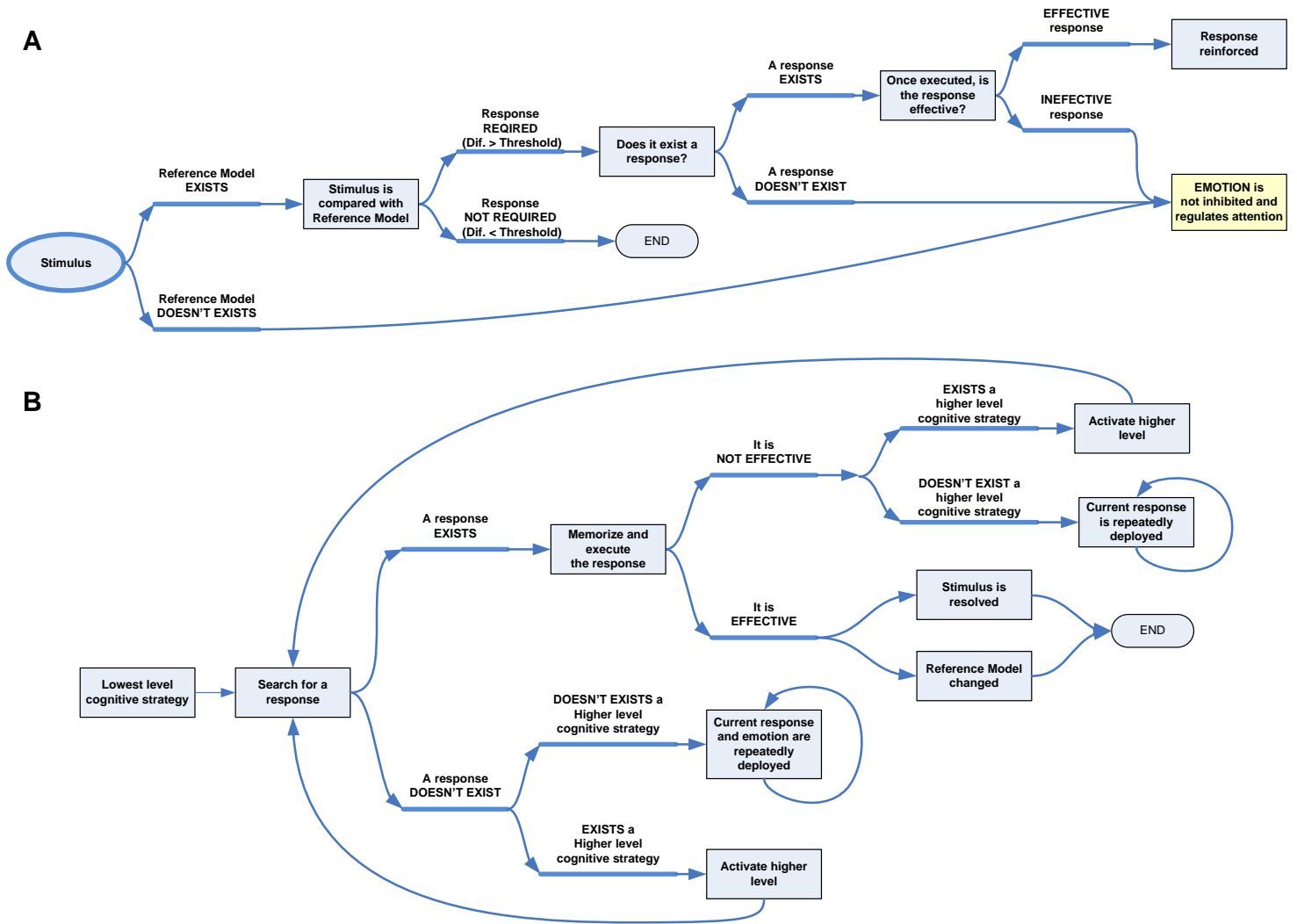


Figure 8. Decision tree for emotional and cognitive responses

3.8. Cognition heuristics

To be effective in solving problems, cognitive systems need to work with a number of elements, and according to certain rules, which follow:

1. For cognitive systems to get into action there must exist an emotional tension due to absence of an effective response to resolve a discrepancy between the stimulus and the expectations.
2. The stimulus should have sufficient priority to be selected in the attentional competition. The more critical it is, the more time and resources allocated to process it.
3. It must have access to the various concepts and relationships that will be combined to find a new response. To manage and create a new concept, cognitive systems must find or create new

relationships between previously developed concepts stored in memory. As soon as a new concept or metaconcept is created, it is stored and becomes itself a new element that can be combined. The greater the number of conceptual elements and their relations:

- The more flexible, advanced and creative are the new responses.
 - The longer the process to find a new solution.
 - The greater the consumption of resources and energy.
4. It's necessary to have different cognitive strategies that can be hierarchically applied to the conceptual elements to find those new relationships and associations.
- The more a cognitive system or strategy is used, the faster and more effective it will become.
 - The more advanced, the higher the quality and accuracy of their responses.
5. To find effective solutions cognitive systems need time.
- The greater the time available to look for alternatives, the greater the number and quality of the options found.
6. Emotional-cognitive processes are not disabled while they don't have a totally effective response, maintaining emotional tension even outside the attentional focus. Thus, all the unsolved stimuli stay latent until attentional competition becomes unloaded, and resources are available again.

3.9. Habituation and sensitization

But what happens if cognitive systems are not able to find an effective response?

Given this situation, the only option the brain has to cope with the stimulus is to increase the intensity of the best response available at that time, whether emotional or specific (Silvers, Weber, Wager, & Ochsner, 2014). Thus, in our model, to promote the search for alternatives, the intensity curve of the emotional

response associated to a stimulus should follow a growing path (Fig.9b), as a mechanism to increase the criticality of the stimulus and gradually giving it a greater priority in the process of attentional competition. As a result of this process the phenomenon of **sensitization** can arise (Groves & Thompson, 1970), which intensifies the emotional response, and so the perception, and may even completely take control before a low intensity stimulus, a phenomenon also known as "**emotional hijacking**".

Thus, our model integrates the principles reasoned by Groves and Thompson (1970), considering the variable **S** as the activation of the emotional network, and the variable **H** as the efficacy of the expectation-response network, and both are related through the mechanism of inhibition postulated by Sokolov (Evgeniy N. Sokolov, 1963).

Habituation does not occur if the response is not completely effective. The unresolved stimulus may see how its criticality becomes gradually reduced, so it doesn't get access to cognitive resources, being relegated but not disabled.

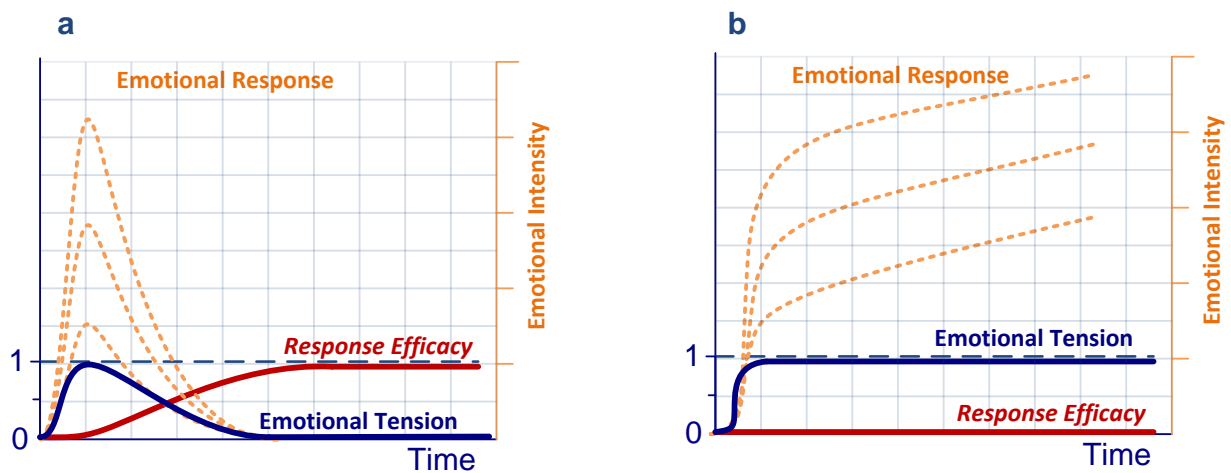


Figura 9. (a) The intensity of emotional response is regulated by emotional tension, and this in turn by the efficacy of the response available. **(b)** When cognitive systems are not able to find a completely effective response, the only option is to increase the intensity of both, the emotional response to give greater priority to its associated stimuli in the process of attentional competition, and the best response available to address the stimulus.

3.10. Learning, automaticity and control

When a new cognitive response is developed, it is stored by the new relationships between concepts and the activation timing thereof or Short Time Potentiation (STP). Thus, the learning process together with the automaticity process will consolidate the new relationship as the stimulus occurs repeatedly. But the brain always took advantage of previous work. From an evolutionary standpoint, the efficacy principle tells us that there must always be at least one basic response to address or explore any stimulus. That means that, even when you find a new response for a stimulus, the older should be preserved. Thus, new pathways would be a kind of "short-circuit" that bypass the old response above for the benefit of the new one. While effective, the new responses are executed but, if they fail, the brain gives way to the old one, less effective, while the emotional process associated reactivate the search for a new and more effective cognitive response. This approach gives account of the irrationality of many behaviors that arise when people are exposed to stimuli that exceed the range of application of already developed cognitive responses.

Thus, and according to the theory and functional model exposed, the control systems are themselves cognitive responses that naturally emerge as a result of creating, through learning processes, new relationships between cognitive responses and stimuli patterns that elicited its development.

As it happen with other cognitive responses, some control responses could also be automated, thus optimizing their execution. This has important implications for trying to understand and explain the evolution and development of behaviors, whether individual or social.

3.11. Emotion-cognition systemic dynamics

This point is one of the fundamental keys of this theory, and has important implications that must be explored to understand psychological phenomena, behavior and decision-making process.

So far, we have focused on the dynamics of a single emotional - cognitive process that tries to minimize its own emotional tension. But we cannot forget that all emotional - cognitive processes work on a common space we call conceptual space, i.e. all use information stored in different memory systems to create cognitive alternatives that allows them to effectively solve their own emotional tension. This means that

different processes can modify the existing conceptual relationships and create new ones within that shared conceptual space. These changes may in turn cause that other processes, whose emotional tension was inactive, to be activated or reactivated as a result of dynamically modifying the already existing associations. This will cause these processes, previously inactive, begin again their own emotional - cognitive cycle to find a new response that enables them to return to its minimum tension state.

At this point we must consider two things:

- According to our model, the most primary and basic a concept is, the greater the number of meta-concepts and relationships built over it (Qin et al., 2014). Thus, we can assume that the modification of a very primary concept triggers the reactivation of more processes dependent on it, which in turn will generate a greater overall emotional tension in the system.
- On the other hand, we must not forget that emotional - cognitive processes do not stop until there is a fully effective response to face the stimuli that elicited them.

Considering this, the theory predicts that the brain will try to find the most balanced response possible for the system as a whole, i.e. the one that minimizes the **overall emotional tension** of all processes concerned. That means that, in the process of assessing different options to face the same stimulus, the brain decides between them in terms of overall emotional tension associated with each possible response, including all partial tensions generated along the thinking chain (Kahneman & Tversky, 1979; Tversky & Kahneman, 1981, 1992).

So, if we take the sensations, perceptions, concepts, meta - concepts and their associations, and consider the different emotional-cognitive processes that act on them as "**agents**" competing to minimize their own emotional tension, we can postulate that the brain process of decision-making takes the form of what in game theory is known as a Nash equilibrium (Nash, 1950, 1951). This means that, once found a response, none of the processes involved can unilaterally reduce its emotional tension by changing its own response.

By adding this new systemic level, oscillatory phenomena such as sensation seeking, altruism or self-harmful behaviors can be explained, laying the foundations for a new paradigm in the study of motivation,

decision making and behavior, whether in individuals as in social groups (Myers, 2012). These consequences of the theory may have important implications which we are now investigating in collaboration with the Interdisciplinary Group of Complex Systems GISC, in the Carlos III University of Madrid, and the Political sciences & Sociology Faculty in the Complutense University of Madrid.

3.12. Theory implications

This theory and its associated model let us open important hypothesis, which should be explored in more depth in the future, for understanding and scientifically explaining many psychological and behavioral phenomena, including the following:

- Allows us to have a functional model which, through its own dynamics and without resorting to malfunction assumptions, can cause the individual display behaviors contrary to their own biological fitness (Garcés & Finkel, 2014b).
- Generates plausible hypothesis to explain the contents that access consciousness, helping to explain the mechanisms that underlie perception and the construction of subjective reality. In this sense, the theory generates a model to explain phenomena such as Body Dysmorphic Disorder that occurs in diseases such as anorexia nervosa (Garcés & Finkel, 2014a).
- Let's to scientifically redefine, in a solid and well-founded way, psychological concepts far unbounded like the construction of self-concept and mainly self-esteem (Garcés & Finkel, 2014c), fundamental topic given its influence in the psychological development of individuals, in education and social relationships.
- Allows addressing, from a systems perspective, the study of phenomena such as habits, ruminations and addictions, especially those in which there is not involved the use of external chemicals (e.g. gambling addiction).
- It provides a solid framework that can be taken into the field of simulation, in which to fit the phenomena studied in neuroeconomics and neuromarketing such as decision making and the emotional impact on them.

- Provides a new approach to address phenomena such as violence from a cognitive point of view, being able to frame the emotional intensity within a structure that can be described and justified to the aggressive subject as part of a cognitive therapy.
- Provides a framework in which to study the evolution of emotional processes with important implications for the understanding of so important psychological phenomena such as motivation, learning, creativity and innovation.
- It lays the foundations to extend the theory to its social dimension.
- Gives some well-founded clues to better understand the development of cognition and the relevance of the emotional stimulation for a correct improvement of education programs.
- Provides a model for understanding the development of cognitive and control systems based on emotional arousal to which the person is exposed.

3.13. Conclusions

Along this paper we have followed a logical reasoning to support our hypothesis that emotions are an innate resource for nervous system optimization. As such, and by default, they are in charge to manage all the stimuli for which there is not an effective response available, whether innate, cognitive or automated, also regulating the activation of cognitive mechanisms and prioritizing the access to them to find a new and more effective response. In turn, effective responses actively inhibits the expression of emotions, as they are not necessary, thus self-regulating the functioning of the system. Once responses are found, architectural strategies (e.g. memory, pattern recognition, expectations, etc...) together with automaticity also optimizes their execution. As the number of simultaneous stimuli, both exogenous and endogenous, can become numerous, and given that all of them work over the same “conceptual space”, they can mutually influence, forcing the brain to find the best option among available responses to minimize the overall emotional tension. All this mechanisms makes the nervous system to be able to deploy a wide set of different solutions, most of which are adaptive, while others are not, thus giving place to some more or less extreme biased psychological and behavioral phenomena (eg. Body Dysmorphic Disorders)

Bibliography

- Abzhanov, A., Extavour, C. G., Groover, A., Hodges, S. A., Hoekstra, H. E., Kramer, E. M., & Monteiro, A. (2008). Are we there yet? Tracking the development of new model systems. *Trends in Genetics*, 24(7), 353–360. <http://doi.org/10.1016/j.tig.2008.04.002>
- Adolphs, R., Tranel, D., Damasio, H., & Damasio, A. (1994). Impaired recognition of emotion in facial expressions following bilateral damage to the human amygdala. *Nature*, 372(6507), 669–72.
- Alcock, J., & Farley, P. (2001). *Animal behavior: an evolutionary approach*. Sinauer Associates Massachusetts.
- Armony, J., & Vuilleumier, P. (Eds.). (2013). *The Cambridge Handbook of Human Affective Neuroscience*. Cambridge: Cambridge University Press. Retrieved from <http://ebooks.cambridge.org/ebook.jsf?bid=CBO9780511843716>
- Artwohl, A. (2002). Perceptual and memory distortion during officer-involved shootings. *FBI Law Enforcement Bulletin*, 71(10), 18–24.
- Ashby, F. G., & Crossley, M. J. (2012). Automaticity and multiple memory systems. *Wiley Interdisciplinary Reviews: Cognitive Science*, 3(3), 363–376.
- Ashby, F. G., Turner, B. O., & Horvitz, J. C. (2010). Cortical and basal ganglia contributions to habit learning and automaticity. *Trends in Cognitive Sciences*, 14(5), 208 – 215. <http://doi.org/http://dx.doi.org/10.1016/j.tics.2010.02.001>
- Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. *The Psychology of Learning and Motivation: Advances in Research and Theory*, 2, 89–195.
- Attwell, D., & Laughlin, S. B. (2001). An energy budget for signaling in the grey matter of the brain. *Journal of Cerebral Blood Flow and Metabolism*, 21(10), 1133–1145. <http://doi.org/10.1097/00004647-200110000-00001>
- Baddeley, A. (1992). Working memory. *Science*, 255(5044), 556–559.
- Badyaev, A. V. (2005). Stress-induced variation in evolution: from behavioural plasticity to genetic assimilation. *Proceedings of the Royal Society B: Biological Sciences*, 272(1566), 877–886. <http://doi.org/10.1098/rspb.2004.3045>

- Bapi, R. S., Pammi, V. S., Miyapuram, K. P., & Ahmed, A. (2005). Investigation of sequence processing: A cognitive and computational neuroscience perspective. *Current Science*, 89(10). Retrieved from <http://cogprints.org/4640/>
- Barabási, A.-L., & Oltvai, Z. N. (2004). Network biology: understanding the cell's functional organization. *Nature Reviews Genetics*, 5(2), 101–113. <http://doi.org/10.1038/nrg1272>
- Bar, M. (2011). *Predictions in the Brain: Using Our Past to Generate a Future*. OUP USA.
- Baron, S. G. (2012). *The neural basis of compositionality: Functional magnetic resonance imaging studies of conceptual combination*. PRINCETON UNIVERSITY. Retrieved from http://dspace.princeton.edu/jspui/bitstream/88435/dsp01w08929975/1/Baron_princeton_0181D_10201.pdf
- Barrett, K. E., & Ganong, W. F. (2010). *Ganong's review of medical physiology*. New York: McGraw-Hill Medical. Retrieved from <http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=284144>
- Barton, N. H., Briggs, D. E. G., Eisen, J. A., Goldstein, D. B., & Patel, N. H. (2007). *Evolution* (1st ed.). Cold Spring Harbor Laboratory Press.
- Bassett, D. S., Bullmore, E. T., Meyer-Lindenberg, A., Apud, J. A., Weinberger, D. R., & Coppola, R. (2009). Cognitive fitness of cost-efficient brain functional networks. *Proceedings of the National Academy of Sciences*, 106(28), 11747–11752.
- Bateson, P., & Mamerli, M. (2007). The innate and the acquired: Useful clusters or a residual distinction from folk biology? *Developmental Psychobiology*, 49(8), 818–831. <http://doi.org/10.1002/dev.20277>
- Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: Impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied*, 8(1), 6–16. <http://doi.org/http://0-dx.doi.org.cisne.sim.ucm.es/10.1037/1076-898X.8.1.6>

- Belin, D., Jonkman, S., Dickinson, A., Robbins, T. W., & Everitt, B. J. (2009). Parallel and interactive learning processes within the basal ganglia: Relevance for the understanding of addiction. *Behavioural Brain Research, 199*(1), 89–102. <http://doi.org/10.1016/j.bbr.2008.09.027>
- Bell, K. F., & Hardingham, G. E. (2011). The influence of synaptic activity on neuronal health. *Current Opinion in Neurobiology, 21*, 299–305. <http://doi.org/10.1016/j.conb.2011.01.002>
- Blackmore, S. J. (2004). *Consciousness: an introduction*. Oxford ; New York: Oxford University Press.
- Blakemore, S. J., Wolpert, D., & Frith, C. (2000). Why can't you tickle yourself? *Neuroreport, 11*(11), R11.
- Boffelli, D., Nobrega, M. A., & Rubin, E. M. (2004). Comparative genomics at the vertebrate extremes. *Nature Reviews Genetics, 5*(6), 456–465.
- Bosman, C. A., Schoffelen, J.-M., Brunet, N., Oostenveld, R., Bastos, A. M., Womelsdorf, T., ... Fries, P. (2012). Attentional Stimulus Selection through Selective Synchronization between Monkey Visual Areas. *Neuron, 75*(5), 875–888. <http://doi.org/10.1016/j.neuron.2012.06.037>
- Burggren, W. W., & Crews, D. (2014). Epigenetics in Comparative Biology: Why We Should Pay Attention. *Integrative and Comparative Biology, icu013*. <http://doi.org/10.1093/icb/icu013>
- Burra, N., Hervais-Adelman, A., Kerzel, D., Tamietto, M., Gelder, B. de, & Pegna, A. J. (2013). Amygdala Activation for Eye Contact Despite Complete Cortical Blindness. *The Journal of Neuroscience, 33*(25), 10483–10489. <http://doi.org/10.1523/JNEUROSCI.3994-12.2013>
- Butler, A., & Hodos, W. (1996). *Comparative vertebrate neuroanatomy*. New York: Wiley-Liss.
- Caroni, P., Donato, F., & Muller, D. (2012). Structural plasticity upon learning: regulation and functions. *Nature Reviews Neuroscience, 13*(7), 478–490. <http://doi.org/10.1038/nrn3258>
- Carroll, N. C., & Young, A. W. (2005). Priming of emotion recognition. *The Quarterly Journal of Experimental Psychology Section A, 58*(7), 1173–1197. <http://doi.org/10.1080/02724980443000539>
- Carroll, S. P., Hendry, A. P., Reznick, D. N., & Fox, C. W. (2007). Evolution on ecological time-scales. *Functional Ecology, 21*(3), 387–393. <http://doi.org/10.1111/j.1365-2435.2007.01289.x>
- Carver, C. S. (2006). The concepts of optimism and pessimism concern people's expectations for the.
- Carver, C. S., & Scheier, M. F. (1998). *On the self-regulation of behavior*. Cambridge University Press.

Retrieved from

<http://books.google.es/books?hl=es&lr=&id=U9xi8wlfWccC&oi=fnd&pg=PR17&dq=On+the+self-regulation+of+behavior&ots=gNgsdL22cv&sig=zYAvuPwYrdGYLopFAI0sJ4c56q8>

Carver, C. S., & Smith, J. C. (2010). Personality and Coping. *Annual Review of Psychology*, *61*(1), 679–704.

<http://doi.org/10.1146/annurev.psych.093008.100352>

Charlton, S. G., & Starkey, N. J. (2011). Driving without awareness: The effects of practice and automaticity on attention and driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *14*(6),

456–471. <http://doi.org/10.1016/j.trf.2011.04.010>

Charnov, E. L. (1976). Optimal foraging, the marginal value theorem. *Theoretical Population Biology*, *9*(2), 129–136.

Chechik, G., Meilijson, I., & Ruppin, E. (1998). Synaptic Pruning in Development: A Computational Account.

Neural Computation, *10*(7), 1759–1777. <http://doi.org/10.1162/089976698300017124>

Chica, A. B., Bartolomeo, P., & Lupiáñez, J. (2013). Two cognitive and neural systems for endogenous and exogenous spatial attention. *Behavioural Brain Research*, *237*, 107–123.

<http://doi.org/10.1016/j.bbr.2012.09.027>

Chittka, L., Skorupski, P., & Raine, N. E. (2009). Speed–accuracy tradeoffs in animal decision making. *Trends in Ecology & Evolution*, *24*(7), 400–407.

Chklovskii, D. B., Mel, B. W., & Svoboda, K. (2004). Cortical rewiring and information storage. *Nature*, *431*(7010), 782–788. <http://doi.org/10.1038/nature03012>

Ciocchi, S., Herry, C., Grenier, F., Wolff, S. B. E., Letzkus, J. J., Vlachos, I., ... Lüthi, A. (2010). Encoding of conditioned fear in central amygdala inhibitory circuits. *Nature*, *468*(7321), 277–282.

<http://doi.org/10.1038/nature09559>

Cisek, P., & Kalaska, J. F. (2010). Neural mechanisms for interacting with a world full of action choices. *Annual Review of Neuroscience*, *33*, 269–298.

Citri, A., & Malenka, R. C. (2007). Synaptic plasticity: multiple forms, functions, and mechanisms.

Neuropsychopharmacology, *33*(1), 18–41.

- Corbetta, M., Patel, G., & Shulman, G. L. (2008). The Reorienting System of the Human Brain: From Environment to Theory of Mind. *Neuron*, 58(3), 306–324.
<http://doi.org/10.1016/j.neuron.2008.04.017>
- Crapse, T. B., & Sommer, M. A. (2008). Corollary discharge across the animal kingdom. *Nat Rev Neurosci*, 9(8), 587–600. <http://doi.org/10.1038/nrn2457>
- Damasio, A., & Carvalho, G. B. (2013). The nature of feelings: evolutionary and neurobiological origins. *Nature Reviews Neuroscience*, 14(2), 143–152. <http://doi.org/10.1038/nrn3403>
- Damasio, A. R. (1994). *Descartes' error: emotion, reason, and the human brain*. New York: Putnam.
- Damasio, A. R. (2001). Emotion and the human brain. *Annals of the New York Academy of Sciences*, 935(1), 101–106.
- Danchin, É., Charmantier, A., Champagne, F. A., Mesoudi, A., Pujol, B., & Blanchet, S. (2011). Beyond DNA: integrating inclusive inheritance into an extended theory of evolution. *Nature Reviews. Genetics*, 12(7), 475–86. <http://doi.org/http://0-dx.doi.org.cisne.sim.ucm.es/10.1038/nrg3028>
- Darwin, C. (1859). *On the origin of species, 1st edition with anotations*. London: John Murray.
- Davidson, P. R., & Wolpert, D. M. (2005). Widespread access to predictive models in the motor system: a short review. *Journal of Neural Engineering*, 2, S313.
- Dawkins, R. (2006). *The selfish gene*. Oxford University Press, USA.
- Dawkins, R. (2009). *The greatest show on Earth : the evidence for evolution*. New York: Free Press.
- Deary, I. J., Penke, L., & Johnson, W. (2010). The neuroscience of human intelligence differences. *Nature Reviews. Neuroscience*, 11(3), 201–211. <http://doi.org/10.1038/nrn2793>
- Decety, J. (1996). Do imagined and executed actions share the same neural substrate? *Cognitive Brain Research*, 3(2), 87–93.
- Decety, J., & Grèzes, J. (2006). The power of simulation: Imagining one's own and other's behavior. *Brain Research*, 1079(1), 4–14. <http://doi.org/10.1016/j.brainres.2005.12.115>
- DeFelipe, J. (2010). From the Connectome to the Synaptome: An Epic Love Story. *Science*, 330(6008), 1198–1201. <http://doi.org/10.1126/science.1193378>

- Delgado, M. R., Nearing, K. I., LeDoux, J. E., & Phelps, E. A. (2008). Neural Circuitry Underlying the Regulation of Conditioned Fear and Its Relation to Extinction. *Neuron*, *59*(5), 829–838.
<http://doi.org/10.1016/j.neuron.2008.06.029>
- Denk, W., Briggman, K. L., & Helmstaedter, M. (2012). Structural neurobiology: missing link to a mechanistic understanding of neural computation. *Nature Reviews Neuroscience*, *13*(5), 351–358.
<http://doi.org/10.1038/nrn3169>
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*(1), 193–222.
- Dezfouli, A., Lingawi, N. W., & Balleine, B. W. (2014). Habits as action sequences: hierarchical action control and changes in outcome value. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1655), 20130482–20130482. <http://doi.org/10.1098/rstb.2013.0482>
- Diamond, D. M., Campbell, A. M., Park, C. R., Halonen, J., & Zoladz, P. R. (2007). The temporal dynamics model of emotional memory processing: a synthesis on the neurobiological basis of stress-induced amnesia, flashbulb and traumatic memories, and the Yerkes-Dodson law. *Neural Plasticity*, *2007*, 60803. <http://doi.org/10.1155/2007/60803>
- Dias, B. G., & Ressler, K. J. (2014). Parental olfactory experience influences behavior and neural structure in subsequent generations. *Nature Neuroscience*, *17*(1), 89–96. <http://doi.org/10.1038/nn.3594>
- DiCarlo, J. J., Zoccolan, D., & Rust, N. C. (2012). How Does the Brain Solve Visual Object Recognition? *Neuron*, *73*(3), 415–434. <http://doi.org/10.1016/j.neuron.2012.01.010>
- Dixon, T. (2012). “Emotion”: The History of a Keyword in Crisis. *Emotion Review*, *4*(4), 338–344.
<http://doi.org/10.1177/1754073912445814>
- Domínguez-Borrás, J., & Vuilleumier, P. (2013). Affective Biases in Attention and Perception. In *The Cambridge Handbook of Human Affective Neuroscience*. Cambridge University Press. Retrieved from <http://dx.doi.org/10.1017/CBO9780511843716.018>
- Donders, F. C. (1969). On the speed of mental processes. *Acta Psychologica*, *30*, 412–431.
- Doya, K. (2008). Modulators of decision making. *Nature Neuroscience*, *11*(4), 410–416.
<http://doi.org/10.1038/nn2077>

- Drzewiecki, S. (2002). Survival Stress in Law Enforcement. *An Applied Research Project Submitted to the Department of Interdisciplinary Technology as Part of the School of Police Staff and Command Program, Retrieved June, 28(2008), 339–345.*
- Eagleman, D. M. (2008). Human time perception and its illusions. *Current Opinion in Neurobiology, 18*, 131–136. <http://doi.org/10.1016/j.conb.2008.06.002>
- Edelman, G. M., & Gally, J. A. (2001). Degeneracy and complexity in biological systems. *Proceedings of the National Academy of Sciences, 98(24)*, 13763–13768. <http://doi.org/10.1073/pnas.231499798>
- Eldredge, N., & Gould, S. J. (1972). Punctuated equilibria: an alternative to phyletic gradualism. *Models in Paleobiology, 82*, 115.
- Elith, J., & Leathwick, J. R. (2009). Species distribution models: ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution, and Systematics, 40*, 677–697.
- Estes, S., & Arnold, S. J. (2007). Resolving the paradox of stasis: models with stabilizing selection explain evolutionary divergence on all timescales. *The American Naturalist, 169(2)*, 227–244.
- Fanselow, M. S. (2000). Contextual fear, gestalt memories, and the hippocampus. *Behavioural Brain Research, 110(1)*, 73–81.
- Fecteau, J., & Munoz, D. (2006). Saliency, relevance, and firing: a priority map for target selection. *Trends in Cognitive Sciences, 10(8)*, 382–390. <http://doi.org/10.1016/j.tics.2006.06.011>
- Fedoroff, N. V. (2012). Transposable Elements, Epigenetics, and Genome Evolution. *Science, 338(6108)*, 758–767. <http://doi.org/10.1126/science.338.6108.758>
- Fischer, A. (2014). Epigenetic memory: the Lamarckian brain. *The EMBO Journal, 33(9)*, 945–967. <http://doi.org/10.1002/emboj.201387637>
- Ford, J. M., & Mathalon, D. H. (2004). Electrophysiological evidence of corollary discharge dysfunction in schizophrenia during talking and thinking. *Journal of Psychiatric Research, 38(1)*, 37–46. [http://doi.org/10.1016/S0022-3956\(03\)00095-5](http://doi.org/10.1016/S0022-3956(03)00095-5)
- Franks, B. (2005). The role of “the environment” in cognitive and evolutionary psychology. *Philosophical Psychology, 18(1)*, 59–82.

- Free, A., & Barton, N. H. (2007). Do evolution and ecology need the Gaia hypothesis? *Trends in Ecology & Evolution*, 22(11), 611–619.
- Fries, P. (2009). Neuronal Gamma-Band Synchronization as a Fundamental Process in Cortical Computation. *Annual Review of Neuroscience*, 32(1), 209–224.
<http://doi.org/10.1146/annurev.neuro.051508.135603>
- Frijda, N. H. (2009). Emotions, individual differences and time course: Reflections. *Cognition & Emotion*, 23(7), 1444–1461. <http://doi.org/10.1080/02699930903093276>
- Friston, K. J. (2010). The free-energy principle: a unified brain theory? *Nature Reviews Neuroscience*, 11, 127–138. <http://doi.org/10.1038/nrn2787>
- Friston, K. J., Kilner, J., & Harrison, L. (2006). A free energy principle for the brain. *Journal of Physiology-Paris*, 100(1-3), 70–87. <http://doi.org/10.1016/j.jphysparis.2006.10.001>
- Fritz, J. B., Elhilali, M., David, S. V., & Shamma, S. A. (2007). Auditory attention — focusing the searchlight on sound. *Current Opinion in Neurobiology*, 17(4), 437–455.
<http://doi.org/10.1016/j.conb.2007.07.011>
- Furini, C., Myskiw, J., & Izquierdo, I. (2014). The learning of fear extinction. *Neuroscience & Biobehavioral Reviews*, 47, 670–683. <http://doi.org/10.1016/j.neubiorev.2014.10.016>
- Fussmann, G. F., Loreau, M., & Abrams, P. A. (2007). Eco-evolutionary dynamics of communities and ecosystems. *Functional Ecology*, 21(3), 465–477. <http://doi.org/10.1111/j.1365-2435.2007.01275.x>
- Gamez, D. (2012). From Baconian to Popperian Neuroscience. *Neural Systems & Circuits*, 2(1), 2.
<http://doi.org/10.1186/2042-1001-2-2>
- Garcés, M. (2003). *Long term persistence of unattended and involuntary capacity for detecting palindromic car plates.*
- Garcés, M., & Finkel, L. (2014a). Body Image Distortion in Anorexia and Bulimia: An Emotional Approach. *Unpublished Manuscript.*
- Garcés, M., & Finkel, L. (2014b). Emotional Selection: A new systems approach for non-adaptive conserved behaviors. *Unpublished Manuscript.*

- Garcés, M., & Finkel, L. (2014c). Exo-esteem vs. Self-esteem: Origin, dynamics and definition. *Unpublished Manuscript*.
- Garrett, H. E. (1922). *A study of the relation of accuracy to speed*. Archives of psychology.
- Garvert, M. M., Friston, K. J., Dolan, R. J., & Garrido, M. I. (2014). Subcortical amygdala pathways enable rapid face processing. *NeuroImage*, *102*, 309–316.
<http://doi.org/10.1016/j.neuroimage.2014.07.047>
- Goda, Y., & Sabatini, B. L. (2011). Synaptic function and regulation. *Current Opinion in Neurobiology*, *21*, 205–207. <http://doi.org/10.1016/j.conb.2011.03.004>
- Godnig, E. C. (2003). TUNNEL VISION - Its causes & treatment strategies. *Journal of Behavioral Optometry*, *14*(4), 99.
- González-Pardo, H., & others. (2013). Epigenetics and its implications for psychology. *Psicothema*, *25*(1), 3–12.
- Gould, S. J. (2002). *The structure of evolutionary theory*. Belknap Press.
- Gould, S. J., & Vrba, E. S. (1982). Exaptation—a missing term in the science of form. *Paleobiology*, 4–15.
- Graybiel, A. M. (2008). Habits, Rituals, and the Evaluative Brain. *Annual Review of Neuroscience*, *31*(1), 359–387. <http://doi.org/10.1146/annurev.neuro.29.051605.112851>
- Grill-Spector, K. (2003). The neural basis of object perception. *Current Opinion in Neurobiology*, *13*(2), 159–166. [http://doi.org/10.1016/S0959-4388\(03\)00040-0](http://doi.org/10.1016/S0959-4388(03)00040-0)
- Grossberg, S., & Levine, D. S. (1987). Neural dynamics of attentionally modulated Pavlovian conditioning: blocking, interstimulus interval, and secondary reinforcement. *Applied Optics*, *26*(23), 5015–5030.
<http://doi.org/10.1364/AO.26.005015>
- Gross, J. J., & Ochsner, K. (2013). The neural bases of emotion and emotion regulation: A valuation perspective. In *Handbook of Emotion Regulation, Second Edition* (pp. 87–109). Guilford Publications.
- Groves, P. M., & Thompson, R. F. (1970). Habituation: A dual-process theory. *Psychological Review*, *77*(5), 419–450. <http://doi.org/http://dx.doi.org/10.1037/h0029810>

- Guillot, A., Di Rienzo, F., & Collet, C. (2012). The neurofunctional architecture of motor imagery. *Functional Magnetic Resonance imaging/Book, 1*. Retrieved from <http://cdn.intechopen.com/pdfs-wm/46103.pdf>
- Hairston Jr, N. G., Ellner, S. P., Geber, M. A., Yoshida, T., & Fox, J. A. (2005). Rapid evolution and the convergence of ecological and evolutionary time. *Ecology Letters, 8*(10), 1114–1127.
- Hamann, S. B., Stefanacci, L., Squire, L. R., Adolphs, R., & al, et. (1996). Recognizing facial emotion. *Nature, 379*(6565), 497.
- Hartley, C. A., & Phelps, E. A. (2009). Changing fear: the neurocircuitry of emotion regulation. *Neuropsychopharmacology, 35*(1), 136–146.
- Hassabis, D., Kumaran, D., Vann, S. D., & Maguire, E. A. (2007). Patients with hippocampal amnesia cannot imagine new experiences. *Proceedings of the National Academy of Sciences, 104*(5), 1726.
- Haynes, J. D. (2011). Decoding and predicting intentions. *Annals of the New York Academy of Sciences, 1224*(1), 9–21.
- Haynes, J. D., & Rees, G. (2006). Decoding mental states from brain activity in humans. *Nature Reviews Neuroscience, 7*(7), 523–534.
- Hebb, D. O. (1949). *The Organization of Behavior: A Neuropsychological Theory* (New edition). Psychology Press.
- Hélie, S., Ell, S. W., & Ashby, F. G. (2015). Learning robust cortico-cortical associations with the basal ganglia: An integrative review. *Cortex, 64*, 123–135. <http://doi.org/10.1016/j.cortex.2014.10.011>
- Helton, W. S. (2007). Expertise acquisition as sustained learning in humans and other animals: commonalities across species. *Animal Cognition, 11*(1), 99–107. <http://doi.org/10.1007/s10071-007-0093-4>
- Hétu, S., Grégoire, M., Saimpont, A., Coll, M.-P., Eugène, F., Michon, P.-E., & Jackson, P. L. (2013). The neural network of motor imagery: An ALE meta-analysis. *Neuroscience & Biobehavioral Reviews, 37*(5), 930–949. <http://doi.org/10.1016/j.neubiorev.2013.03.017>
- Hick, W. E. (1952). On the rate of gain of information. *Quarterly Journal of Experimental Psychology, 4*(1), 11–26. <http://doi.org/10.1080/17470215208416600>

- Hikosaka, O., Yamamoto, S., Yasuda, M., & Kim, H. F. (2013). Why skill matters. *Trends in Cognitive Sciences*, 17(9), 434–441. <http://doi.org/10.1016/j.tics.2013.07.001>
- Holliday, R. (2006). Epigenetics: a historical overview. *Epigenetics*, 1(2), 76–80.
- Hurst, L. D. (2009). Genetics and the understanding of selection. *Nature Reviews Genetics*, 10(2), 83–93. <http://doi.org/10.1038/nrg2506>
- Iacoboni, M. (2009). Imitation, Empathy, and Mirror Neurons. *Annual Review of Psychology*, 60(1), 653–670. <http://doi.org/10.1146/annurev.psych.60.110707.163604>
- Inokuchi, K. (2011). Adult neurogenesis and modulation of neural circuit function. *Current Opinion in Neurobiology*, 21, 360–364. <http://doi.org/10.1016/j.conb.2011.02.006>
- Jablonka, E., & Raz, G. (2009). Transgenerational epigenetic inheritance: prevalence, mechanisms, and implications for the study of heredity and evolution. *Quarterly Review of Biology*, 84(2), 131–176.
- James, W. (1884). What is an Emotion? *Mind*, 9(34), 188–205.
- James, W. (1890). *The principles of psychology*. Retrieved from http://89.253.247.156/_files/product/pdf/92/910451.pdf
- Jensen, A. R. (2006). *Clocking the mind mental chronometry and individual differences*. Amsterdam [u.a.: Elsevier. Retrieved from <http://www.sciencedirect.com/science/book/9780080449395>
- Johansen, J. P., Diaz-Mataix, L., Hamanaka, H., Ozawa, T., Ycu, E., Koivumaa, J., ... LeDoux, J. E. (2014). Hebbian and neuromodulatory mechanisms interact to trigger associative memory formation. *Proceedings of the National Academy of Sciences*, 201421304. <http://doi.org/10.1073/pnas.1421304111>
- Kahneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, 47(2), 263–291. <http://doi.org/10.2307/1914185>
- Kaiser, T. F., & Peters, F. J. (2009). *Synaptic plasticity new research*. New York: Nova Science Publishers. Retrieved from <http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=28491>

- Kandel, E. (1999). *Principles of neural science* (4th ed.). East Norwalk Conn. ;Hemel Hempstead: Appleton & Lange ;;Prentice Hall.
- Kastner, S., O'Connor, D. H., Fukui, M. M., Fehd, H. M., Herwig, U., & Pinsk, M. A. (2004). Functional Imaging of the Human Lateral Geniculate Nucleus and Pulvinar. *Journal of Neurophysiology*, *91*(1), 438–448. <http://doi.org/10.1152/jn.00553.2003>
- Kastner, S., & Ungerleider, L. G. (2001). The neural basis of biased competition in human visual cortex. *Neuropsychologia*, *39*(12), 1263–1276. [http://doi.org/10.1016/S0028-3932\(01\)00116-6](http://doi.org/10.1016/S0028-3932(01)00116-6)
- Kersten, D., Mamassian, P., & Yuille, A. (2004). Object Perception as Bayesian Inference. *Annual Review of Psychology*, *55*, 271–304.
- Kleidon, A., Lorenz, R., & Lorenz, R. D. (2005). *Non-equilibrium thermodynamics and the production of entropy: life, earth, and beyond*. Springer Verlag.
- Klein, P.-A., Petitjean, C., Olivier, E., & Duque, J. (2014). Top-down suppression of incompatible motor activations during response selection under conflict. *NeuroImage*, *86*, 138–149. <http://doi.org/10.1016/j.neuroimage.2013.08.005>
- Kohn, N. W., Paulus, P. B., & Korde, R. M. (2011). Conceptual Combinations and Subsequent Creativity. *Creativity Research Journal*, *23*(3), 203–210. <http://doi.org/10.1080/10400419.2011.595659>
- Kooijman, S. A. L. M. (2010). *Dynamic energy budget theory for metabolic organisation*. Cambridge [u.a.]: Cambridge University Press.
- Koonin, E. V., & others. (2007). The Biological Big Bang model for the major transitions in evolution. *Biol Direct*, *2*, 21.
- Koonin, E. V., & Wolf, Y. I. (2006). Evolutionary systems biology: links between gene evolution and function. *Current Opinion in Biotechnology*, *17*(5), 481–487. <http://doi.org/10.1016/j.copbio.2006.08.003>
- Kosinski, R. J. (2008). A literature review on reaction time. *Clemson University*, *10*.
- Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2001). Neural foundations of imagery. *Nature Reviews Neuroscience*, *2*(9), 635–642.
- Kumar, S. (2005). Molecular clocks: four decades of evolution. *Nature Reviews Genetics*, *6*(8), 654–662. <http://doi.org/10.1038/nrg1659>

- Kveraga, K., Ghuman, A. S., & Bar, M. (2007). Top-down predictions in the cognitive brain. *Brain and Cognition*, 65(2), 145–168. <http://doi.org/10.1016/j.bandc.2007.06.007>
- Lamme, V. A. F. (2003). Why visual attention and awareness are different. *Trends in Cognitive Sciences*, 7(1), 12–18. [http://doi.org/10.1016/S1364-6613\(02\)00013-X](http://doi.org/10.1016/S1364-6613(02)00013-X)
- Lamme, V. A. F. (2010). How neuroscience will change our view on consciousness. *Cognitive Neuroscience*, 1(3), 204–220.
- Lamme, V. A. F., & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing. *Trends in Neurosciences*, 23(11), 571–579.
- Lange, C. G. (1885). The mechanism of the emotions. *The Classical Psychologists*. Boston: Houghton Mifflin, 1912. Retrieved from <http://psychclassics.yorku.ca/Lange/>
- Lang, P. J. (2014). Emotion's Response Patterns: The Brain and the Autonomic Nervous System. *Emotion Review*, 6(2), 93–99. <http://doi.org/10.1177/1754073913512004>
- Lang, P. J., & Davis, M. (2006). Emotion, motivation, and the brain: Reflex foundations in animal and human research. In *Progress in Brain Research* (Vol. 156, pp. 3–29). Elsevier. Retrieved from <http://linkinghub.elsevier.com/retrieve/pii/S0079612306560017>
- Lan, G., Sartori, P., Neumann, S., Sourjik, V., & Tu, Y. (2012). The energy-speed-accuracy trade-off in sensory adaptation. *Nature Physics*, 8(5), 422–428. <http://doi.org/10.1038/nphys2276>
- Lazarus, R. S. (1984). On the primacy of cognition.
- Lazarus, R. S. (1991). Cognition and motivation in emotion. *American Psychologist*, 46(4), 352–367. <http://doi.org/10.1037/0003-066X.46.4.352>
- LeDoux, J. (2012). Rethinking the Emotional Brain. *Neuron*, 73(4), 653–676. <http://doi.org/10.1016/j.neuron.2012.02.004>
- Lellis, V., Mariani, M., Ribeiro, A., Cantiere, C., Teixeira, M., & Carreiro, L. (2013). Voluntary and automatic orienting of attention during childhood development. *Psychology and Neuroscience*, 6(1), 15–21. <http://doi.org/10.3922/j.psns.2013.1.04>

- Lerner, Y., Hendler, T., Ben-Bashat, D., Harel, M., & Malach, R. (2001). A Hierarchical Axis of Object Processing Stages in the Human Visual Cortex. *Cerebral Cortex*, *11*(4), 287–297.
<http://doi.org/10.1093/cercor/11.4.287>
- Leventhal, H., & Scherer, K. R. (1987). The relationship of emotion to cognition: A functional approach to a semantic controversy. *Cognition and Emotion*, *1*, 3–28.
- Libet, B. L. (1999). Do we have free will? *Journal of Consciousness Studies*, *6*, 8(9), 47–57.
- Libet, B. L. (2004). *Mind time : the temporal factor in consciousness*. Cambridge Mass.: Harvard University Press.
- Libet, B. L., Gleason, C. A., Wright, E. W., & Pearl, D. K. (1983). Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential). The unconscious initiation of a freely voluntary act. *Brain: A Journal of Neurology*, *106* (Pt 3), 623–642.
- Llinás, R. R., & Roy, S. (2009). The “prediction imperative” as the basis for self-awareness. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1521), 1301–1307.
<http://doi.org/10.1098/rstb.2008.0309>
- Logan, G. D. (1979). On the use of a concurrent memory load to measure attention and automaticity. *Journal of Experimental Psychology: Human Perception and Performance*, *5*(2), 189.
- Logan, G. D. (1985). Skill and automaticity: Relations, implications, and future directions. *Canadian Journal of Psychology/Revue Canadienne de Psychologie*, *39*(2), 367.
- Logan, G. D. (1997). Automaticity and reading: Perspectives from the instance theory of automatization. *Reading & Writing Quarterly: Overcoming Learning Difficulties*, *13*(2), 123–146.
- Logan, G. D., Cowan, W. B., & Davis, K. A. (1984). On the ability to inhibit simple and choice reaction time responses: a model and a method. *Journal of Experimental Psychology: Human Perception and Performance*, *10*(2), 276.
- Logothetis, N. K. (2008). What we can do and what we cannot do with fMRI. *Nature*, *453*(7197), 869–878.
<http://doi.org/10.1038/nature06976>

- Low, L. K., & Cheng, H.-J. (2006). Axon pruning: an essential step underlying the developmental plasticity of neuronal connections. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 361(1473), 1531–1544. <http://doi.org/10.1098/rstb.2006.1883>
- Lu, U., Roach, S. M., Song, D., & Berger, T. W. (2012). Nonlinear Dynamic Modeling of Neuron Action Potential Threshold During Synaptically Driven Broadband Intracellular Activity. *IEEE Transactions on Biomedical Engineering*, 59(3), 706–716. <http://doi.org/10.1109/TBME.2011.2178241>
- MacArthur, R. H., & Pianka, E. R. (1966). On optimal use of a patchy environment. *American Naturalist*, 603–609.
- MacIntyre, T. E., Moran, A. P., Collet, C., & Guillot, A. (2013). An emerging paradigm: a strength-based approach to exploring mental imagery. *Frontiers in Human Neuroscience*, 7, 104. <http://doi.org/10.3389/fnhum.2013.00104>
- MacLeod, C. M. (1991). Half a century of research on the Stroop effect: an integrative review. *Psychological Bulletin*, 109(2), 163.
- MacLeod, C. M., & MacDonald, P. A. (2000). Interdimensional interference in the Stroop effect: uncovering the cognitive and neural anatomy of attention. *Trends in Cognitive Sciences*, 4(10), 383–391. [http://doi.org/10.1016/S1364-6613\(00\)01530-8](http://doi.org/10.1016/S1364-6613(00)01530-8)
- Maher, B. (2012). ENCODE: The human encyclopaedia. *Nature*, 489(7414), 46–48. <http://doi.org/10.1038/489046a>
- Mahon, B. Z., & Caramazza, A. (2009). Concepts and Categories: A Cognitive Neuropsychological Perspective. *Annual Review of Psychology*, 60(1), 27–51. <http://doi.org/10.1146/annurev.psych.60.110707.163532>
- Mameli, M., & Bateson, P. (2011). An evaluation of the concept of innateness. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366(1563), 436–443.
- Mani, A., Mullainathan, S., Shafir, E., & Zhao, J. (2013). Poverty Impedes Cognitive Function. *Science*, 341(6149), 976–980. <http://doi.org/10.1126/science.1238041>
- Manoli, D. S., Meissner, G. W., & Baker, B. S. (2006). Blueprints for behavior: genetic specification of neural circuitry for innate behaviors. *Trends in Neurosciences*, 29(8), 444–451.

- Maren, S. (2014). Out with the old and in with the new: Synaptic mechanisms of extinction in the amygdala. *Brain Research*. <http://doi.org/10.1016/j.brainres.2014.10.010>
- Marois, R., & Ivanoff, J. (2005). Capacity limits of information processing in the brain. *Trends in Cognitive Sciences*, 9(6), 296–305. <http://doi.org/10.1016/j.tics.2005.04.010>
- Marshall, C. R. (2006). Explaining the Cambrian “explosion” of animals. *Annu. Rev. Earth Planet. Sci.*, 34, 355–384.
- Martin, A. (2007). The Representation of Object Concepts in the Brain. *Annual Review of Psychology*, 58(1), 25–45. <http://doi.org/10.1146/annurev.psych.57.102904.190143>
- Martyushev, L. M., & Seleznev, V. D. (2006). Maximum entropy production principle in physics, chemistry and biology. *Physics Reports*, 426(1), 1–45.
- Mattick, J. S. (2009). Deconstructing the Dogma. *Annals of the New York Academy of Sciences*, 1178(1), 29–46. <http://doi.org/10.1111/j.1749-6632.2009.04991.x>
- Mattick, J. S. (2009). Has evolution learnt how to learn? *EMBO Reports*, 10(7), 665–665.
- McEwen, B. S., & Wingfield, J. C. (2003). The concept of allostasis in biology and biomedicine. *Hormones and Behavior*, 43(1), 2–15.
- Mendizabal, I., Keller, T. E., Zeng, J., & Yi, S. V. (2014). Epigenetics and Evolution. *Integrative and Comparative Biology*, icu040. <http://doi.org/10.1093/icb/icu040>
- Meyer, D. E., Irwin, D. E., Osman, A. M., & Kounois, J. (1988). The dynamics of cognition and action: Mental processes inferred from speed-accuracy decomposition. *Psychological Review; Psychological Review*, 95(2), 183.
- Meyer, D. E., Osman, A. M., Irwin, D. E., & Yantis, S. (1988). Modern mental chronometry. *Biological Psychology*, 26(1), 3–67.
- Michaelian, K. (2009). Thermodynamic origin of life. *Arxiv Preprint arXiv:0907.0042*.
- Middleton, E. L., Rawson, K. A., & Wisniewski, E. J. (2011). How do we process novel conceptual combinations in context? *The Quarterly Journal of Experimental Psychology*, 64(4), 807–822. <http://doi.org/10.1080/17470218.2010.520414>

- Milton, J., Small, S. L., & Solodkin, A. (2008). Imaging motor imagery: Methodological issues related to expertise. *Methods*, *45*(4), 336–341. <http://doi.org/10.1016/j.ymeth.2008.05.002>
- Missenard, O., & Fernandez, L. (2011). Moving faster while preserving accuracy. *Neuroscience*, *197*(0), 233–241. <http://doi.org/10.1016/j.neuroscience.2011.09.020>
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100.
- Modha, D. S., & Singh, R. (2010). Network architecture of the long-distance pathways in the macaque brain. *Proceedings of the National Academy of Sciences*, *107*(30), 13485–13490. <http://doi.org/10.1073/pnas.1008054107>
- Molenberghs, P., Cunnington, R., & Mattingley, J. B. (2009). Is the mirror neuron system involved in imitation? A short review and meta-analysis. *Neuroscience & Biobehavioral Reviews*, *33*(7), 975–980. <http://doi.org/10.1016/j.neubiorev.2009.03.010>
- Monfardini, E., Gazzola, V., Boussaoud, D., Brovelli, A., Keysers, C., & Wicker, B. (2013). Vicarious Neural Processing of Outcomes during Observational Learning. *PLoS ONE*, *8*(9), e73879. <http://doi.org/10.1371/journal.pone.0073879>
- Moors, A., & De Houwer, J. (2006). Automaticity: A Theoretical and Conceptual Analysis. *Psychological Bulletin*, *132*(2), 297–326. <http://doi.org/10.1037/0033-2909.132.2.297>
- Morsella, E., Godwin, C. A., Jantz, T. K., Krieger, S. C., & Gazzaley, A. (2015). Homing in on Consciousness in the Nervous System: An Action-Based Synthesis. *Behavioral and Brain Sciences*. Retrieved from <http://online.sfsu.edu/morsella/images/ForFriendsBBS.pdf>
- Murphy, S. T., & Zajonc, R. B. (1993). Affect, cognition, and awareness: Affective priming with optimal and suboptimal stimulus exposures. *Journal of Personality and Social Psychology*, *64*(5), 723–739. <http://doi.org/http://0-dx.doi.org.cisne.sim.ucm.es/10.1037/0022-3514.64.5.723>
- Myers, D. G. (2012). *Exploring social psychology*. New York: McGraw-Hill.
- Nagasako, E. M., Oaklander, A. L., & Dworkin, R. H. (2003). Congenital insensitivity to pain: an update. *Pain*, *101*(3), 213–219. [http://doi.org/10.1016/S0304-3959\(02\)00482-7](http://doi.org/10.1016/S0304-3959(02)00482-7)

- Nash, J. F. (1950). Equilibrium Points in N-Person Games. *Proceedings of the National Academy of Sciences of the United States of America*, 36(1), 48–49.
- Nash, J. F. (1951). Non-Cooperative Games. *The Annals of Mathematics*, 54(2), 286–295.
<http://doi.org/10.2307/1969529>
- Neubauer, A. C., & Fink, A. (2009). Intelligence and neural efficiency. *Neuroscience & Biobehavioral Reviews*, 33(7), 1004–1023. <http://doi.org/10.1016/j.neubiorev.2009.04.001>
- Niedenthal, P. M. (1990). Implicit perception of affective information. *Journal of Experimental Social Psychology*, 505–527. [http://doi.org/10.1016/0022-1031\(90\)90053-O](http://doi.org/10.1016/0022-1031(90)90053-O)
- Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, 7(1), 44–64.
- Norman, D. A., & Shallice, T. (1986). Attention to Action: Willed and Automatic Control of Behavior
Technical Report No. 8006.
- O'Neill, R. V., Johnson, A., & King, A. (1989). A hierarchical framework for the analysis of scale. *Landscape Ecology*, 3(3), 193–205.
- Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive Load Theory: Instructional Implications of the Interaction between Information Structures and Cognitive Architecture. *Instructional Science*, 32(1), 1–8.
<http://doi.org/10.1023/B:TRUC.0000021806.17516.d0>
- Paas, F., van Gog, T., & Sweller, J. (2010). Cognitive Load Theory: New Conceptualizations, Specifications, and Integrated Research Perspectives. *Educational Psychology Review*, 22(2), 115–121.
- Padmala, S., & Pessoa, L. (2008). Affective Learning Enhances Visual Detection and Responses in Primary Visual Cortex. *The Journal of Neuroscience*, 28(24), 6202–6210.
<http://doi.org/10.1523/JNEUROSCI.1233-08.2008>
- Parker, G. A., & Smith, J. M. (1990). Optimality theory in evolutionary biology. *Nature*, 348(6296), 27–33.
- Patterson, K., Nestor, P. J., & Rogers, T. T. (2007). Where do you know what you know? The representation of semantic knowledge in the human brain. *Nature Reviews Neuroscience*, 8(12), 976–987.
<http://doi.org/10.1038/nrn2277>

- Paulus, M. P., Potterat, E. G., Taylor, M. K., Van Orden, K. F., Bauman, J., Momen, N., ... Swain, J. L. (2009). A neuroscience approach to optimizing brain resources for human performance in extreme environments. *Neuroscience & Biobehavioral Reviews*, *33*(7), 1080–1088.
<http://doi.org/10.1016/j.neubiorev.2009.05.003>
- Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences*, *13*(4), 160–166. <http://doi.org/10.1016/j.tics.2009.01.006>
- Pessoa, L. (2010a). Emergent processes in cognitive-emotional interactions. *Dialogues in Clinical Neuroscience*, *12*(4), 433–448.
- Pessoa, L. (2010b). Emotion and cognition and the amygdala - From “what is it?” to “what’s to be done?.” *Neuropsychologia*, *48*(12), 3416–3429. <http://doi.org/10.1016/j.neuropsychologia.2010.06.038>
- Pessoa, L. (2013). *The Cognitive-Emotional Brain: From Interactions to Integration*. The MIT Press.
- Pessoa, L. (2014a). Emotion beyond brain regions: Networks generate cognitive–emotional interactions. Retrieved June 1, 2014, from <http://emotionresearcher.com/the-emotional-brain/pessoa/>
- Pessoa, L. (2014b). Précis of The Cognitive-Emotional Brain. *Behavioral and Brain Sciences*, *FirstView*, 1–66. <http://doi.org/10.1017/S0140525X14000120>
- Pessoa, L. (2014c). Understanding brain networks and brain organization. *Physics of Life Reviews*. Retrieved from <http://www.sciencedirect.com/science/article/pii/S1571064514000451>
- Pessoa, L., & Adolphs, R. (2010). Emotion processing and the amygdala: from a ‘low road’ to ‘many roads’ of evaluating biological significance. *Nature Reviews Neuroscience*, *11*(11), 773–783.
- Pessoa, L., Kastner, S., & Ungerleider, L. G. (2002). Attentional control of the processing of neutral and emotional stimuli. *Cognitive Brain Research*, *15*(1), 31–45. [http://doi.org/10.1016/S0926-6410\(02\)00214-8](http://doi.org/10.1016/S0926-6410(02)00214-8)
- Petersen, S. E., Mier, H. van, Fiez, J. A., & Raichle, M. E. (1998). The effects of practice on the functional anatomy of task performance. *Proceedings of the National Academy of Sciences*, *95*(3), 853–860.
- Petersen, S. E., & Posner, M. I. (2012). The Attention System of the Human Brain: 20 Years After. *Annual Review of Neuroscience*, *35*(1), 73–89. <http://doi.org/10.1146/annurev-neuro-062111-150525>

- Phelps, E. A. (2006). Emotion and Cognition: Insights from Studies of the Human Amygdala. *Annual Review of Psychology*, 57(1), 27–53. <http://doi.org/10.1146/annurev.psych.56.091103.070234>
- Phelps, E. A., Delgado, M. R., Nearing, K. I., & LeDoux, J. E. (2004). Extinction learning in humans: role of the amygdala and vmPFC. *Neuron*, 43(6), 897–905.
- Phelps, E. A., O'Connor, K. J., Gatenby, J. C., Gore, J. C., Grillon, C., & Davis, M. (2001). Activation of the left amygdala to a cognitive representation of fear. *Nature Neuroscience*, 4(4), 437–441.
- Platkiewicz, J., & Brette, R. (2010). A Threshold Equation for Action Potential Initiation. *PLoS Computational Biology*, 6(7), e1000850. <http://doi.org/10.1371/journal.pcbi.1000850>
- Poldrack, R. A., Sabb, F. W., Foerde, K., Tom, S. M., Asarnow, R. F., Bookheimer, S. Y., & Knowlton, B. J. (2005). The neural correlates of motor skill automaticity. *The Journal of Neuroscience*, 25(22), 5356–5364.
- Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, 13(1), 25–42. <http://doi.org/10.1146/annurev.ne.13.030190.000325>
- Posner, M. I., & Snyder, C. R. R. (1975). Attention and Cognitive Control. In *Information Processing and Cognition: The Loyola Symposium*. Lawrence Erlbaum.
- Pourtois, G., Grandjean, D., Sander, D., & Vuilleumier, P. (2004). Electrophysiological Correlates of Rapid Spatial Orienting Towards Fearful Faces. *Cerebral Cortex*, 14(6), 619–633. <http://doi.org/10.1093/cercor/bhh023>
- Prigogine, I. (1997). *The end of certainty : time, chaos, and the new laws of nature* (1st Free Press ed.). New York: Free Press.
- Purves, D. (2004). *Neuroscience*. Sunderland, Mass.: Sinauer Associates, Publishers.
- Qin, S., Cho, S., Chen, T., Rosenberg-Lee, M., Geary, D. C., & Menon, V. (2014). Hippocampal-neocortical functional reorganization underlies children's cognitive development. *Nature Neuroscience*, 17(9), 1263–1269. <http://doi.org/10.1038/nn.3788>
- Quartz, S. R., & Sejnowski, T. J. (1997). The neural basis of cognitive development: A constructivist manifesto. *Behavioral and Brain Sciences*, 20(04), 537–556. <http://doi.org/10.1017/S0140525X97001581>

- Quirk, G. J., & Mueller, D. (2007). Neural Mechanisms of Extinction Learning and Retrieval. *Neuropsychopharmacology*, 33(1), 56–72. <http://doi.org/10.1038/sj.npp.1301555>
- Raichle, M. E., Fiez, J. A., Videen, T. O., MacLeod, A.-M. K., Pardo, J. V., Fox, P. T., & Petersen, S. E. (1994). Practice-related Changes in Human Brain Functional Anatomy during Nonmotor Learning. *Cerebral Cortex*, 4(1), 8–26. <http://doi.org/10.1093/cercor/4.1.8>
- Raz, A., & Buhle, J. (2006). Typologies of attentional networks. *Nature Reviews Neuroscience*, 7(5), 367–379. <http://doi.org/10.1038/nrn1903>
- Rizzolatti, G., & Craighero, L. (2004). THE MIRROR-NEURON SYSTEM. *Annual Review of Neuroscience*, 27(1), 169–192. <http://doi.org/10.1146/annurev.neuro.27.070203.144230>
- Rudy, J. W., Huff, N. C., & Matus-Amat, P. (2004). Understanding contextual fear conditioning: insights from a two-process model. *Neuroscience & Biobehavioral Reviews*, 28(7), 675–685. <http://doi.org/10.1016/j.neubiorev.2004.09.004>
- Santesso, D. L., Meuret, A. E., Hofmann, S. G., Mueller, E. M., Ratner, K. G., Roesch, E. B., & Pizzagalli, D. A. (2008). Electrophysiological correlates of spatial orienting towards angry faces: A source localization study. *Neuropsychologia*, 46(5), 1338–1348. <http://doi.org/10.1016/j.neuropsychologia.2007.12.013>
- Schaal, S. (1999). Is imitation learning the route to humanoid robots? *Trends in Cognitive Sciences*, 3(6), 233–242.
- Scherer, K. R. (2009). The dynamic architecture of emotion: Evidence for the component process model. *Cognition & Emotion*, 23(7), 1307–1351. <http://doi.org/10.1080/02699930902928969>
- Schneider, E. D., & Sagan, D. (2005). *Into the cool: Energy flow, thermodynamics, and life*. University of Chicago Press.
- Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review*, 84(1), 1.
- Schoener, T. W. (2011). The Newest Synthesis: Understanding the Interplay of Evolutionary and Ecological Dynamics. *Science*, 331(6016), 426–429. <http://doi.org/10.1126/science.1193954>

- Serre, T., Oliva, A., & Poggio, T. (2007). A feedforward architecture accounts for rapid categorization. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(15), 6424–6429. <http://doi.org/10.1073/pnas.0700622104>
- Shaffer, L. H. (1975). Multiple attention in continuous verbal tasks.
- Shapiro, J. A. (2002a). A 21 st century view of evolution. *Journal of Biological Physics*, *28*(4), 745–764.
- Shapiro, J. A. (2002b). Genome organization and reorganization in evolution. *Annals of the New York Academy of Sciences*, *981*(1), 111–134.
- Shapiro, J. A. (2005). A 21st century view of evolution: genome system architecture, repetitive DNA, and natural genetic engineering. *Gene*, *345*(1), 91–100.
- Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, *84*(2), 127–190. <http://doi.org/10.1037/0033-295X.84.2.127>
- Shiffrin, R. M., & Schneider, W. (1984). Automatic and controlled processing revisited.
- Siegel, S., Hinson, R. E., Krank, M. D., & McCully, J. (1982). Heroin “overdose” death: Contribution of drug-associated environmental cues. *Science (Washington)*, *216*(4544), 436–437.
- Silvers, J. A., Weber, J., Wager, T. D., & Ochsner, K. N. (2014). Bad and worse: Neural systems underlying reappraisal of high and low intensity negative emotions. *Social Cognitive and Affective Neuroscience*, nsu043.
- Simon, H. A. (1967). Motivational and emotional controls of cognition. *Psychological Review; Psychological Review*, *74*(1), 29.
- Smith, C. A., & Lazarus, R. S. (1990). Emotion and adaptation.
- Smith, J. (1983). The genetics of stasis and punctuation. *Annual Review of Genetics*, *17*, 11.
- Smith, J. M. (1978). Optimization Theory in Evolution. *Annual Review of Ecology and Systematics*, *9*(1), 31–56. <http://doi.org/10.1146/annurev.es.09.110178.000335>
- Sokolov, E. N. (1963). Higher nervous functions: The orienting reflex. *Annual Review of Physiology*, *25*(1), 545–580.

- Sokolov, E. N., Spinks, J. A., Näätänen, R., & Lytinen, H. (2002). *The orienting response in information processing*. Lawrence Erlbaum Associates Publishers. Retrieved from <http://psycnet.apa.org/?fa=main.doiLanding&uid=2002-00156-000>
- Soon, C. S., Brass, M., Heinze, H.-J., & Haynes, J.-D. (2008). Unconscious determinants of free decisions in the human brain. *Nature Neuroscience*, *11*(5), 543–545. <http://doi.org/10.1038/nn.2112>
- Soressi, M., McPherron, S. P., Lenoir, M., Dogandžić, T., Goldberg, P., Jacobs, Z., ... Texier, J.-P. (2013). Neandertals made the first specialized bone tools in Europe. *Proceedings of the National Academy of Sciences*. <http://doi.org/10.1073/pnas.1302730110>
- Sousa, T., Domingos, T., & Kooijman, S. (2008). From empirical patterns to theory: a formal metabolic theory of life. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1502), 2453.
- Speed, B. C. (2012). Startle reflex as a physiological measure of emotion regulation. *University of British Columbia's Undergraduate Journal of Psychology*, *1*. Retrieved from <http://prophet.library.ubc.ca/ojs/index.php/ubcuyp/article/view/2368>
- Sporns, O. (2011). *Networks of the brain*. Cambridge, MA: MIT Press.
- Stahl, A. E., & Feigenson, L. (2015). Observing the unexpected enhances infants' learning and exploration. *Science*, *348*(6230), 91–94. <http://doi.org/10.1126/science.aaa3799>
- Sterelny, K. (2001). *Dawkins, Gould and the nature of evolution*. Cambridge: Icon.
- Sternberg, R. J., & Pretz, J. E. (2005). *Cognition and intelligence: identifying the mechanisms of the mind*. Cambridge Univ Pr.
- Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica*, *30*, 276–315.
- Stewart, L. (2005). A neurocognitive approach to music reading. *Annals of the New York Academy of Sciences*, *1060*(1), 377–386.
- Striedter, G. F. (2005). *Principles of brain evolution*. Sunderland, Mass: Sinauer Associates.
- Suslow, T., Kugel, H., Ohrmann, P., Stuhmann, A., Grotegerd, D., Redlich, R., ... Dannlowski, U. (2013). Neural correlates of affective priming effects based on masked facial emotion: An fMRI study.

- Psychiatry Research: Neuroimaging*, 211(3), 239–245.
<http://doi.org/10.1016/j.psychresns.2012.09.008>
- Swanson, L. W. (2000). Cerebral hemisphere regulation of motivated behavior. *Brain Research*, 886(1–2), 113–164. [http://doi.org/10.1016/S0006-8993\(00\)02905-X](http://doi.org/10.1016/S0006-8993(00)02905-X)
- Takahata, N. (2007). Molecular clock: An anti-neo-Darwinian legacy. *Genetics*, 176(1), 1–6.
- Tau, G. Z., & Peterson, B. S. (2009). Normal Development of Brain Circuits. *Neuropsychopharmacology*, 35(1), 147–168. <http://doi.org/10.1038/npp.2009.115>
- Thompson, J. N. (1998). Rapid evolution as an ecological process. *Trends in Ecology & Evolution*, 13(8), 329–332.
- Thompson, R. F. (2009). Habituation: A History. *Neurobiology of Learning and Memory*, 92(2), 127–134.
<http://doi.org/10.1016/j.nlm.2008.07.011>
- Tsuchiya, N., Moradi, F., Felsen, C., Yamazaki, M., & Adolphs, R. (2009). Intact rapid detection of fearful faces in the absence of the amygdala. *Nature Neuroscience*, 12(10), 1224–1225.
<http://doi.org/10.1038/nn.2380>
- Tversky, A., & Kahneman, D. (1981). The Framing of Decisions and the Psychology of Choice. *Science*, 211(4481), 453–458. <http://doi.org/10.2307/1685855>
- Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty*, 5(4), 297–323. <http://doi.org/10.1007/BF00122574>
- Ungerleider, L. G., & Bell, A. H. (2011). Uncovering the visual “alphabet”: Advances in our understanding of object perception. *Vision Research*, 51(7), 782–799. <http://doi.org/10.1016/j.visres.2010.10.002>
- Viding, E., Sebastian, C. L., & McCrory, E. J. (2013). Development of Affective Circuitry. In *The Cambridge Handbook of Human Affective Neuroscience*. Cambridge University Press. Retrieved from <http://dx.doi.org/10.1017/CBO9780511843716.034>
- Viviani, R. (2013). Emotion regulation, attention to emotion, and the ventral attentional network. *Frontiers in Human Neuroscience*, 7. <http://doi.org/10.3389/fnhum.2013.00746>
- Vogt, J., De Houwer, J., & Crombez, G. (2011). Multiple Goal Management Starts With Attention: Goal Prioritizing Affects the Allocation of Spatial Attention to Goal-Relevant Events. *Experimental*

Psychology (formerly Zeitschrift Für Experimentelle Psychologie), 58(1), 55–61.

<http://doi.org/10.1027/1618-3169/a000066>

Vogt, J., De Houwer, J., Crombez, G., & Van Damme, S. (2013). Competing for attentional priority:

Temporary goals versus threats. *Emotion*, 13(3), 587–598. <http://doi.org/10.1037/a0027204>

Vuilleumier, P. (2005). How brains beware: neural mechanisms of emotional attention. *Trends in Cognitive*

Sciences, 9(12), 585–594. <http://doi.org/10.1016/j.tics.2005.10.011>

Wedel, M. J. (2012). A Monument of Inefficiency: The Presumed Course of the Recurrent Laryngeal Nerve in

Sauropod Dinosaurs. *Acta Palaeontologica Polonica*, 57(2), 251–256.

<http://doi.org/10.4202/app.2011.0019>

Whalen, P. J., & Phelps, E. A. (2009). *The human amygdala*. Guilford Press. Retrieved from

<http://books.google.com/books?hl=en&lr=&id=275mEq72pkUC&oi=fnd&pg=PA3&dq=%22Phelps,+Elizabeth%22+%22amygdala+to+facial+expressions+of+emotion+to+assess+normal%22+%221.+Amygdala%E2%80%94physiology.+2.%22+%22A.+Phelps,+PhD,+is+Silver+Professor+of+Psychology+and+Neural%22+%22and+Brain+Sciences+at+Dartmouth+College.+The+focus+of+his+research+is%22+%22&ots=nbkWi-wBuR&sig=lc6XbvQB9Ebv5fMdGWEBfINBMaI>

Wickelgren, W. A. (1977). Speed-accuracy tradeoff and information processing dynamics. *Acta*

Psychologica, 41(1), 67–85.

Wolpert, D. M., & Flanagan, J. R. (2001). Motor prediction. *Current Biology*, 11(18), 729.

Wolpert, D. M., Miall, R. C., & Kawato, M. (1998). Internal models in the cerebellum. *Trends in Cognitive*

Sciences, 2(9), 338–347.

Wu, T. (2004). How Self-Initiated Memorized Movements Become Automatic: A Functional MRI Study.

Journal of Neurophysiology, 91(4), 1690–1698. <http://doi.org/10.1152/jn.01052.2003>

Yang, S., Luo, W., Zhu, X., Broster, L. S., Chen, T., Li, J., & Luo, Y. (2014). Emotional content modulates

response inhibition and perceptual processing. *Psychophysiology*, 51(11), 1139–1146.

<http://doi.org/10.1111/psyp.12255>

Yarrow, K., Brown, P., & Krakauer, J. W. (2009). Inside the brain of an elite athlete: the neural processes

that support high achievement in sports. *Nature Reviews Neuroscience*, 10(8), 585–596.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation.

Journal of Comparative Neurology and Psychology, 18(5), 459–482.

<http://doi.org/10.1002/cne.920180503>

Yin, H. H., & Knowlton, B. J. (2006). The role of the basal ganglia in habit formation. *Nature Reviews*

Neuroscience, 7(6), 464–476. <http://doi.org/10.1038/nrn1919>

Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist*, 35(2),

151–175. <http://doi.org/10.1037//0003-066X.35.2.151>

Zajonc, R. B. (1984). On the primacy of affect. *American Psychologist*, 39(2), 117–123.

<http://doi.org/10.1037/0003-066X.39.2.117>

Zhang, T. Y., & Meaney, M. J. (2010). Epigenetics and the Environmental Regulation of the Genome and Its

Function. *Annual Review of Psychology*, 61(1), 439–466.

<http://doi.org/10.1146/annurev.psych.60.110707.163625>