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# Framing decision-making: the role of executive functions, cognitive bias and reward

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## ABSTRACT

*Decision-making is described as a cognitive and emotional process that allows an individual to select a certain action from a multitude of choices and possibilities. This process is commonly seen as a complicated interaction of high-level processes. It is engaged in a wide range of executive operations, concerning which it is possible to hypothesize how the decision-making is located in the continuum between hot and cool processes, involving a multifaced brain areas network. Besides the contextual influences in which decisions are taken this proposal highlights and investigates the relationship between decision-making and cognitive – attentional and perceptual – bias. Moreover, this article takes into exam the association between cost-benefit decisions underpinning executive performance and reward responsiveness. All these factors are considered highly relevant in explaining human behaviour.*

*Keywords: executive functions; decision-making; cognitive bias; reward sensitivity*

## 1. EXPLORING THE RELATIONSHIP BETWEEN EXECUTIVE FUNCTIONS AND DECISION-MAKING: A NEUROSCIENTIFIC APPROACH

The purpose of this article is to introduce the concept of decision-making – which is defined as a process consisting of cognitive and emotional factors that assist an individual in selecting a particular action from a variety of alternatives and options (Gonzalez Aguilar et al., 2021) – with a greater emphasis on their contextualization within the construct of executive functions (EFs).

According to some evidence, the decision-making process, which is generally conceived as a complex interaction of high-level processes, is involved in a variety of executive processes (Del Missier et al., 2010). Furthermore, patient studies (Balconi & Campanella, 2021; Nigg, 2017; Snyder et al., 2015), behavioral experiments (Snyder et al., 2015), and neuroimaging studies (Gonzalez et al., 2005) have indeed suggested a connection between the decision-making process and EFs.

Even though these topics are typically considered to be closely interrelated, the relationship between executive control and decision-making procedures is rarely adequately explained.

Therefore, we provide a summary of the cognitive and emotional processes involved in the complexity of decision-making mechanisms with an overview of the EFs. Literature analysis showed that EFs have an important role in the performance of an individual in relation to a variety of different circumstances. This can be attributed to the fact that EFs are required for improving cognitive and social skills in addition to high-functioning skills (Bailey, 2007; Willoughby & Blair, 2016).

In fact, it has been theorized that EFs can provide support for social competencies, emotional regulation, and psychological development, and are necessary for the management of social dynamics and interpersonal interactions, as well as for the adaptive regulation of stress (Cacioppo & Cacioppo, 2020; Diamond, 2013). Scholars, furthermore, identify EFs as extremely important for adaptive behavior, which is crucial in contemporary society, characterized by a constantly changing environment (Jurado & Rosselli, 2007; Norman & Shallice, 1986).

In fact, society increasingly requires adaptability, a willingness to change, and the capacity to rapidly adapt to new situations, as well as quickness in finding creative solutions to problems, the ability to manage stress factors associated with different contexts (Chandola et al., 2010), and proficiency in communicating and establishing positive interpersonal relationships (Balconi et al., 2017; Balconi & Bortolotti, 2012; Crivelli & Balconi, 2017).

Although the processes involved in those functions are acknowledged, there is still disagreement regarding the definition of EFs (Duncan & Owen, 2000): a recent proposal describes them as a set of top-down, high-level mental processes that encourage behaviours geared toward the accomplishment and achievement of goals (Balconi et al., 2020).

Consistent with this definition, Ward (2019) highlighted how, although EFs are commonly described as a way of processing information or, in general, as cognitive functions, it is important considering EFs properly as a *meta-cognitive*, supervisory, or controlling system.

### *1.1 Attentional and perceptual biases in the decision-making process*

The concepts proposed in the first paragraph resonate widely in the definition of the decision-making construct, whose connection to the executive functions has been amply demonstrated (Brand et al., 2008; Delazer et al., 2007; Euteneuer et al., 2009). Over the past 50 years, substantial theoretical and experimental advances have been made to describe how humans control their actions by selecting, elaborating, and giving priority to the stimuli relevant to the achievement of a specific objective and how they are able to adapt flexibly to changes resulting from environmental demands (Kahneman & Tversky, 1973).

In this regard, it is worth mentioning that human decision-making is characterized by limited rationality. In general, it is feasible to express how individuals adopt numerous heuristics or short-cut strategies in order to develop reasonable or viable solutions to dilemmas.

Indeed, everyday life is characterized by decisional processes - deliberate or not aware – that lead to certain outcomes. Especially in situations where people need to make quick decisions, cognitive shortcuts – heuristics – allow them to make good and accurate judgements (Ehrlinger et al., 2016) although they make people vulnerable to the so-called cognitive biases (Tversky & Kahneman, 1974). Cognitive biases may be quite pervasive, persistent, and also systematic (Korteling et al., 2018): in fact, not only are people keen to apply similar heuristics, but they may also show the same cognitive biases (Shafir & LeBoeuf, 2003). Over time, three different perspectives tried to explain the origin of heuristics and cognitive biases: (i) cognitive-psychological; (ii) ecological; and (iii) evolutionary, which will be now shortly addressed (Korteling et al., 2018). According to the Cognitive-psychological perspective (i), since humans are able to process only a limited part of the available information when in complex, uncertain, time-constrained scenarios they are prone to use simple heuristics (Kahneman, 1973). The latter although, may lead to decision errors or biases, for example, because of relevant information being ignored (Kahneman, 2003; Evans, 2008).

In this context, it is proposed the distinction between two distinct types of thinking processes: Type 1 and Type 2. Type 1 (automated or System 1) is fast, intuitive, automatic, heuristic, and emotionally charged; it might be compared to intuition (Ehrlinger et al., 2016) and comes into play when a quick decision is required. Type 2 (deliberate or System 2) is analytic, deliberate, effortful, and part of rational decision-making, but it needs enough time and information to successfully engage. Basically, when there's a failure of System 2 in engaging (Kahneman, 2003) or overriding System 1 that's when a bias occurs (Evans & Stanovich, 2013).

According to the ecological perspective (ii), instead, behind the cognitive prejudices, there is a discrepancy between heuristics and environment (Klein, 2008). This perspective posits that heuristics might be useful in natural and practical contexts (Gigerenzer & Gaissmaier, 2011).

Finally, according to the evolutionary perspective (iii), a bias occurs whenever an ancestor heuristic (Haselton et al., 2009) used in a natural environment is maladaptively applied to our current (artificial) environment (Tooby & Cosmides, 2005). However, according to Korteling and colleagues (2018) not only these three perspectives don't explain the occurrence of biases and their consistency among distinct people and conditions but also, they lack to provide a conceptual framework that is congruent with known principles or mechanisms in neuroscience.

For the abovementioned reasons, they postulated a new perspective on cognitive biases, the Neural Network perspective (iv), that complements the other ones. According to this framework, "human decision-making is determined by the basic design characteristics of neural information processing itself" (Korteling et al., 2018) and biases – that are also named hard-wired and present the same neural mechanism of perceptual illusions (Reeves & Pinna, 2017) – derived from a discrepancy between the nature of many conceptual or analytical problems and our brain's original design features as a neural network for executing perceptual – motor operations and sustaining biological integrity.

Four are the basic principles that characterize the working of biological neural networks: association (Bar, 2007) of unrelated information, compatibility between information and our current knowledge and expectations, retainment of not-so-relevant information, and focus on some information while ignoring those not immediately available.

### *1.2 Cool versus hot executive functions: comparison between different decision-making strategies*

What is described in the previous paragraph can also be traced and contextualized within well-established theoretical frameworks. Indeed, the first cognitive models introduced the hypothesis that at the basis of the cognitive architecture of decision-making processes, as well as for EF, there is a hypothetical "central executive" (Baddeley & Hitch, 1974).

This system is located at the apex of the cognitive architecture hierarchy; it is not merely involved in decision-making processes, but it also governs all higher-order computation, including monitoring and planning, and led directly to the selection and regulation of lower-level subsystems (De Gardelle & Kouider, 2009).

Taking up a model proposed by Brand and colleagues (2007), it is possible to highlight the existence of two distinct pathways involved in the decision-making process: (i) a path involving non-declarative knowledge, recalling the pool of emotions experienced as a result of previous positive or negative feedback; and (ii) a more cognitive pathway involved in the processing of available information, in the comparison between different decision-making strategies, and the formulation of a final decision. In fact, the role of emotions and motivation in modulating neural and behavioural cognitive responses related to decision-making has also been studied. In this regard, a widely known classification highlights the distinction between cool EFs and hot EFs (Zelazo et al., 2005).

Precisely, cool EFs consist of all those functions that involve the execution of exclusively cognitive processes positioned along the continuum of cool and hot EFs, demonstrating a preponderance of more cool or hot characteristics depending on the specific situation in which the individual must decide.

In particular, neuroimaging research showed that the prefrontal cortex (PFC) is one of the most involved areas in both cool EFs and hot EFs (Friedman & Robbins, 2021). In this connection, it is assumed that the involvement of hot and cool EF depends on the nature of the task, specifically the degree of implicated cognitive control and emotional aspects (Fernández García et al., 2021).

Cold EF involves cognitive or emotionally neutral processes, such as set shifting, working memory, and inhibition. In accordance with this classification, neuroimaging studies demonstrated, at the cerebral level, that cool EFs are supported by a cognitive control network consisting of the lateral portion of the prefrontal cortex (lPFC), the dorsal anterior cingulate cortex (dACC), and the parietal cortex (Colautti et al., 2022).

On the other hand, as mentioned above, specifically, hot EFs are implicated in social and emotional circumstances that elicit emotion and motivation, as well as conflict between instant satisfaction and higher long-term reward (Balconi & Canavesio, 2016; Fernández García et al., 2021).

Hot EFs are generally associated with the medial (mPFC), ventromedial (vmPFC), and orbital (OFC) components of the prefrontal cortex (PFC) or subcortical structures involved in motivation and emotions (Matyi & Spielberg, 2021; Sharpe & Schoenbaum, 2016). These areas have significant connections with the amygdala and other limbic system structures linked with emotional processing and motivation management (Happaney et al., 2004). It is necessary to emphasize how individual disparities in reward/punishment reactivity might result in variances in the subjective cost of enforcement operations and cost-benefit choices (Franken & Muris, 2005; Suhr & Tsanadis, 2007).

Accordingly, an interesting avenue of future studies, as described in the following paragraph, is to evaluate the possible association between reward responsiveness and cost-benefit decisions underpinning executive performance, for example, by analyzing the combined impacts of task complexity and reward sensitivity according to the individuals' motivational tendencies (Balconi et al., 2015; Capa & Bouquet, 2018).

### *1.3 Reward sensitivity and decision-making*

The brain's association between certain kinds of stimulus (e.g., situations, activity, or events) and positive outcomes can be defined as reward, that leads a person to modify and adjust his/her behaviour in order to look for that particular positively evaluated stimulus (Lewis et al., 2021). Rewards imply beneficial hedonic outcomes (physiological pleasure), learning cues, and giving both internal and external stimuli a value and motivational status (salience) (Myles, 2021).

The brain network underlying this mechanism – known as the reward system – that mediates reward cognitive and physiological processing is the mesolimbic system. The latter includes projections of midbrain dopamine neurons of the ventral tegmental area (VTA) to the striatum, nucleus accumbens prefrontal cortex, amygdala, and hippocampus, among other structures of the limbic system (Lewis et al., 2021).

The reward system also allows individuals to label the valence of a stimulus by evaluating whether it is rewarding (approachable) or aversive (to avoid) (Berridge & Kringelbach, 2015) and defines the relative importance of some stimuli by prioritizing one over another.

The way the reward system may influence behaviour has been studied by the reinforcement sensitivity theory (RST) (Gray, 1982): according to RST, our behaviour is the interrelation of three systems: the behavioural inhibition system (BIS), behavioural approach/activation system (BAS), and fight-flight system (FFS).

Specifically, BIS is a general avoidance system that prevents behaviour in unfamiliar, risky or dangerous situations in order to improve risk assessment and attention. This system is activated by punishment and fear, and BIS functionality is linked to anxiety (Corr & Perkins, 2006; Smillie et al., 2006); BAS on the other hand, is an approach system that drives behaviour towards a goal or reward and encourages exploration to meet biological demands, and is linked to impulsivity (Espinoza Oyarce et al., 2021). Finally, FFS is related to flight-or-fight behaviour.

Thus, according to the RST individual with high BIS are more sensitive to punishment, while individuals with high BAS are more sensitive to rewards (Franken & Muris, 2005); both systems drive and explain motivational behaviour and are connected to emotional behaviours regulation in healthy individuals (Balconi et al., 2017; Pace-Schott et al., 2019) and clinical conditions, such as substance and behavioral addictions (Balconi et al., 2014a; 2014b; Balconi & Finocchiaro, 2016; Balconi et al., 2018).

The BIS/BAS model is well-established from a neuroscientific perspective due to several evidence showing a correlation between BIS/BAS activity intensity and the PFC electrophysiological resting-state activity lateralization. Indeed, Davidson (2004) showed how left PFC is linked to reward processes, positive emotions and appetitive system, while right PFC is connected with withdrawal processes, negative emotions and aversive system. Moreover, EEG studies demonstrated a cortical asymmetry during resting state in frontal areas: thus, greater frontal left activity (and reduced left frontal alpha activity) is connected to approach motivation (BAS), while greater frontal right activity (and reduced right frontal alpha activity) is connected to withdrawal behaviour (BIS) (Davidson, 1993; Harmon-Jones & Allen, 1998; Sutton & Davidson, 1997).

As regards emotions (and emotions regulation), they can affect, influence, and predict successful and advantageous decision-making. Indeed, emotions may be considered a powerful decision-making motor, that can produce unwanted influences difficult to reduce (Morelli et al., 2022). A vivid example of this influence is represented by the so-called ‘framing effect’ which causes large and seemingly inexplicable changes in preference as a result of little variations in how a choice problem is presented (Roberts et al., 2022). Indeed, Druckman and McDermott (2008) found that emotions have a substantial impact on risk-taking behaviours, as well as how a frame affects dangerous decisions (e.g., emotions can either magnify or reduce the impact of a frame). The precise function of emotions relies on the issue at hand – such as a life-or-death or financial decision – and the particular emotional state under investigation.

Finally, emotions play a pivotal role also in the successful use of ‘nudging’ defined as a decision-context intervention that ‘alters people’s behavior in a predictable way without forbidding any options’ leveraging on people’s cognitive biases to influence their decisions (Congiu & Moscati, 2022). Indeed, when emotions’ influence is not accounted for, some nudges can be ineffective or even unsuccessful.

## 2. CONCLUSIONS

This work underlines the substantial association between decision-making and executive functions, taking up the distinction between cool and hot EFs and placing decision-making along this continuum, depending on the context decisions are taken. Indeed, decisions can be affected and biased by situational context and environment as well as by emotions that can also help the decisional process by warning individuals of the consequences of their actions. We also focused on neuroimaging studies showing that the frontal area is fundamental in decision-making, including mPFC, vmPFC and OFC. Although decision-making and its neural correlates have been widely studied, at present, further research might be useful to better understand this process and integrate current theories.

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