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Brain Activation for Effort in Human Learning: A Critical and Systematic Review of fMRI Studies

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Abstract

This paper aims to review studies concerned on registering the activation of brain areas during the performance of tasks based on effort, as well as on determining specifically the role of the amygdala in such situations. The search was carried out in three databases: PubMed database, Neuroscience Information Framework, and PsycARTICLES section of the APA PsycNET database; 48 studies presented a methodological arrangement clearly oriented to analyze the effort during the performance of learning tasks. The studies reviewed employed tasks like memorization, decision-making, calculation, motor sequences, and spatial discrimination. Though some variability is found, the main key areas activated for such tasks were: a) *Prefrontal cortex*, *insula*, and *anterior cingulate cortex* in memorization tasks; (b) *Cerebellum*, *basal ganglia*, motor and pre-motor areas in specific motor tasks; (c) *Nucleus accumbens* and *striatum* when explicit reinforcing consequences and high effort were involved; (d) *Cingulate cortex* for effort requirements and persistent behavior; and (e) *Hypothalamus*, *hippocampus*, and related regions for the initial consolidation of memory, as well as for spatial discrimination. The *amygdala* was activated only under very specific conditions: in unpredictable contingencies (i.e., for superstitious behavior), and when the effort was far above the average. Thus, since the *amygdala* is the main area activated in aversive conditioning, we conclude that the performance of tasks based on effort, in general, cannot be considered equivalent to the aversive conditioning in neurological terms, accordingly to the review performed.
Key words: academic learning, *amygdala*, effort, *cingulate cortex*, *hippocampus*, *pre-frontal cortex*.

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Novelty and Significance

What is already known about the topic?

- Some brain areas like the pre-frontal cortex, the insula, the cingulate cortex, and the hippocampus are activated by different types of learning tasks.
- The activation of the amygdala is found in different experimental situations of aversive conditioning.

What this paper adds?

- This paper provides a systematic review of neuroimaging research concerned on the effort.
- The nucleus accumbens and the striatum are activated not only for positive reinforcement, but when such reinforcement is combined to high effort requirements.
- Only two conditions produce activation in the amygdala when the effort is present in a task: when the effort required is far above the average and under ambiguity conditions.

Recently, a growing interest on understanding the changes produced by the education in behavior and on the relation of these changes with the underlying modifications produced on the brain has appeared in the field of neuroimaging research (OECD, 2002). “Neuro-education” is the new term that has been created to label the studies derived from this research agenda (Howard-Jones, 2010). However, some transversal

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issues of the educative process have not been theoretically integrated in an appropriate way, or they have not been understood correctly (Ansari, De Smedt, & Grabner, 2012; Della Chiesa, 2013). This is what happens, to our view, with the effort. Besides, the attempts of popularizing brain mechanisms in their relation to different human facets, many times serve for confounding the role that the brain plays (Pérez Álvarez, 2011).

In addition, often effort is not explicitly defined even in the studies directly concerned on the matter, despite some degree of effort seems to be necessary for accomplishing whatever learning task. The effort is referred to the adjustment between task features and the behavioral repertoire of an individual, and can be defined from two conceptual perspectives: behavioral-contextual, and cognitive. On the one hand, in behavioral psychology effort has been treated as a form of response cost. A traditional experimental paradigm to study the effort has been the "matching law" (Herrnstein, 1970), which has analyzed the election between two concurrent schedules of reinforcement depending on the rate of responding and the rate of reinforcement programmed for each schedule. On the other hand, in cognitive psychology the effort has been usually analyzed in the study of human (declarative) memory. Craik and Tulving (1975) proposed that the effort was one of the three key variables responsible for long-term retention. The two other variables were the elaboration (i.e. the richness or amplitude of codification in a given dominion); and the distintivity (i.e. the amount of difference between two memory contents). However, these definitions are conceptually recursive, and ask for a principle provided in operational terms. Also from the cognitive viewpoint, Tyler, Hertel, McCallum, and Ellis (1979) defined "effort" as the amount of processing employed by a central processor of limited capability to execute a given task. But this definition is metaphorical, and does not specify who or what such central processor is, and tends to create a conceptual homunculus inside the brain.

Thus, we prefer the contextual definition to avoid explanations based on dualist metaphorical categories such as those of the information processing paradigm, or of the conceptual central nervous system (see Catania, 1998). Hence, this paper will talk of high effort when the response requirements are higher than the mean response rate that an individual is accustomed to perform for achieving a given rate of reinforcement, considering that such response requirements do not exceed the behavioral resources of the individual. But, even so, the pending question is if the effort (or high effort) involves aversive functions per se.

As we are living in a growing welfare state on the western world, the commodity and a non-suffering way of understanding life is invading our habits and values (Roales-Nieto, 2016; Segura & Roales-Nieto, 2016). Regarding the human learning, and specifically the academic learning, several pedagogic proposals (either academic or popular) have incorporated effortless-designed activities as procedures for prompting educative goals, because such theories consider that the effort can easily provoke anxiety, frustration, and other aversive states that are counterproductive for the learning (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Donovan, Bransford, & Pellegrino, 1999; Poplin, 1988; Robinson & Aronica, 2015). One of the latest academic reviews asserts that effort "causes an aversive state that corresponds in magnitude to the cost comported" (Kurzban, Duckworth, Kable, & Myers, 2013, p. 669); but is this true neurologically? Kurzban *et alii* (2013) provide disparate data regarding the relation between the effort and the task persistence, and do not answer such question directly. These authors identify "aversive" and "cost". However, task costs usually produce fatigue, but fatigue has been defined by Ishii, Tanaka, and Watanabe (2014) as a transitory state that activates brain areas like

Broadman areas 39-40 (e.g., *angular gyrus*) and the right *pulvinar*, and these areas do not coincide with those of the aversive conditioning (i.e. the *amygdala*).

A large amount of studies has demonstrated that the *amygdala* (AMYG) is the key brain area involved in aversive conditioning, due to its function for processing threatening stimuli and their relations to other events (Andreatta *et alii*, 2012; Bzdok, Laird, Zilles, Fox, & Eickhoff, 2013; Luan, Wager, & Liberzon, 2013; Morris, Buchel, & Dolan, 2001; Phelps, O'Connor, Gatenby, Gore, Grillon, & Davis, 2001; Riedel, Jacob, Müller, Vetter, Smolka, & Marxen, 2016). Indeed, some of the negative emotional states included as examples of such aversive conditioning are the evoked by stimuli like awful sounds, angry faces, electro-shocks, and even instructions about unpleasant upcoming events. This means that the AMYG is not activated only in fear-evoking conditions, but in relation to a wide range of negative emotional conditions. Even, AMYG does not appear involved only in aversive learning. For example, Floresco and Ghods-Sharifi (2007), through a procedure based on the infusion of a drug (e.g. *bupivacaine*) simulated the inactivation of the AMYG in a group of rats, and concluded that such area had a role on the evaluation of the rewards involved in a T-maze task. Notwithstanding, it is not clear if the effect was related to the costs of the task, instead of to the reward (Baxter & Murray, 2002 also discuss the role of the AMYG in relation to rewards). At any rate, if the effort would involve automatically aversive functions, we would probably find the activation of the AMYG.

Consequently, our aim is to see if the scientific literature finds that the tasks based on effort produces the activation of the AMYG in humans. The present study will examine the activation of brain areas during the performance of tasks that required some degree of effort, and that could be considered, in some way, analogues of academic tasks. The results of the review will be exposed thematically, i.e., by the type of task.

Method

Our method of analysis was descriptive, and was based on a systematic review. The search was carried out in three databases: the PubMed© database, the Neuroscience Information Framework©, and the PsycARTICLES section of the APA PsycNET® database. The search terms were "learning", "effort", and "magnetic resonance imaging", and the time interval was from an open date of beginning up to December 31, 2017. The three terms were introduced in English in a combined frame using "AND" or "&", and all of them were related to the value "any field". The search resulted in 1305 registers in total (se Figure 1). Although "magnetic resonance imaging" was one of the terms used for the search, the focus of this study was centered on the brain activation during the performance of different types of tasks, and hence, the studies selected were those using specifically functional magnetic resonance imaging (fMRI), because the goals, procedures, and measures of this technique are more appropriate than simple structural MRI for the study of dynamic brain activity correlated to behavioral phenomena. The use of structural MRI for experimental purposes is widely criticized, and such technique is recommended exclusively for the diagnosis of neurological damages (Illes *et alii*, 2006). Only 48 studies presented a methodological arrangement clearly oriented to analyze the effort during the performance of learning tasks, and therefore they were the studies finally selected. It was irrelevant for our purposes to make filters by the number of sessions, duration of the study, or number of trials. Studies whose participants

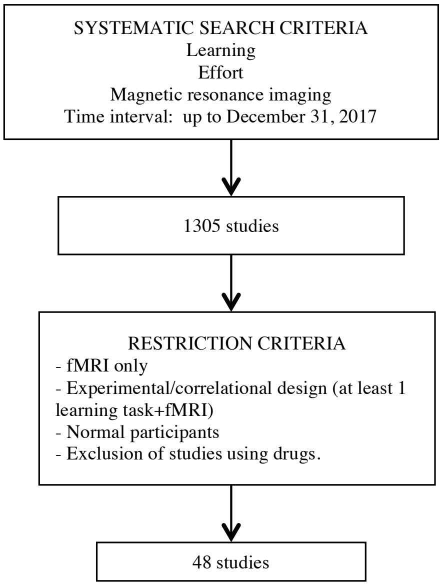

Figure 1. Schematic representation of the search criteria.

presented neurological damages or psychiatric diagnosis were excluded, because both clinical populations deserve their own consideration. And finally, studies using drugs were excluded as well to avoid masking effects over the effort.

Results

The main areas activated during these tasks were the *hippocampus* (HIP), *lingual gyrus*, *anterior cingulate cortex* (ACC), *hypothalamus* (HIPT), *anterior insula* (ant-INS), left-ventral pre-frontal *cortex* (lv-PFC), right-anterior pre-frontal *cortex* (ra-PFC), *cerebellum* (CER), *frontal gyrus*, and the *parietal lobe*. We find in this section tasks like the memorization of lists and pairs of words, of image-sound pairs, and even we find narrative comprehension tasks and the learning of words signaled by specific cues. Since whichever attempt of interpretation of the role of each brain area during learning must take into account the specific situation in which the activation is registered, a specific presentation of the results of the studies will be made (see Table 1).

Thus, in Buckner, Koutstaal, Schacter, Wagner, and Rosen (1998a) the participants had to study a list of words by establishing semantic relations, and after this, the participants had to remember if the items presented on the probe trials were old or new. The authors found a significant activation in the ra-PFC when the participants correctly identified new items. Though the effort criterion is not clear in this study, in a latter experiment the authors gave a further step. Buckner *et alii* (1998b) compared shallow and deep encoding, and found activation on the bilateral anterior *insula* (ba-INS) after shallow memorization, and on the ra-PFC in the condition of deep (or semantic) encoding, as in Buckner *et alii* (1998a).

In Iidaka, Sadato, Yamada, and Yonekura (2000) the participants had to learn one set of words and one set of patterns. The words activated the lv-PFC and the right

Table 1. Summary of the studies reviewed.

Category	Studies	Effort Criteria	Brain Areas Registered
Words/items Memorization	Buckner *et alii* (1998a)	Old/new semantic relations	ra-PFC
	Buckner *et alii* (1998b)	Shallow/deep enconding	Shallow= ba-INS; Deep= ra-PFC
	Iidaka *et alii* (2000)	Words/patterns	Words= lv-PFC;r-CER; Patterns= bmf-GYR;SPL; Visual cortex
	Katanoda *et alii* (2000)	Novel/viewed faces	PFC; fusiform GYR, right parietal
	Jenssen *et alii* (2001)	Novel words	Parahippocampus;f-GYR
	Chee *et alii* (2001)	Frequency of words Semantic/simple reading	l-PFC
	Heckers *et alii* (2002)	Nº of presentations Semantic vs. perceptual stim.	Right posterior HIP; la-HIP; Ventral tegmentum
	De Zubicaray *et alii* (2005)	Idem Chee et al.	li-PFC
	Reber *et alii* (2002)	Cues for remember/forgetfulness	li-PFC
	Miotto *et alii* (2006)	Semantic strategies	b-dl-PFC
	Jansma *et alii* (2007)	Nº of consonants	rv-PFC
	Allen *et alii* (2007)	Green's Word Test	dl-PFC;ant-INS;SPL;DCC
	Skinner *et alii* (2009)	Distraction	dl-PFC;r-HIP
	Leshikar *et alii* (2007)	Non-semantic relation	lif-GYR
	Larsen *et alii* (2010)	Idem	dl-PFC;mf-GYR;r-INS
	Bach *et alii* (2010)	Level of reading	Lif-GYR; INS
	Sachs *et alii* (2011)	Type of relation	lif-GYR;mf-GYR;r-INS
	Helie *et alii* (2011)	Nº of training trials	Striatum;Caudate;vl-PFC
	Reas & Brewer (2013)	Idem	Idem
	Wang & Holland (2013)	Pasive/active listening	dl-PFC;ACC;Sensorimotor cortex
	Hall *et alii* (2014)	Spatial localization	dl-PFC
	Rastle, & Davis (2014)	Non-semantic relation	lif-post-PFC;Parietal,temporal,occip.
	Engström *et alii* (2014)	Inspection time	ba-INS;ACC
Decision-making Tasks	Zyssets *et alii* (2006)	Nº of attributes	Pre-motor area;Parietal;lm-PFC;ant-INS;Caudate
	Botvinick *et alii* (2009)	Color and numerals from 1 to 9;	NAcc;PFC;dl-CC
	Croxson *et alii* (2009)	Conditional discriminations	ACC;Striatum;INS
	Kurniawan *et alii* (2010)	Levels of gripping and levels of reward	f-GYR;Caudate;Putamen;DCC;NAcc
	Enge *et alii* (2011)	Physical effort/delayed rewards	Striatum;vm-PFC;ACC;ant-INS
	Stoppel *et alii* (2011)	Idem	ACC:INS;Mesolimbic areas
	Burke *et alii* (2013)	Physical effort/risky rewards	MCC;ant-INS
	Kurniawan *et alii* (2013)	Chances of winning/losing	ACC;d-Striatum;v-Striatum
	LeBouc & Pessiglione (2013)	Competitive/collaborative decisions	v-BBGG;Temporal-Parietal
	Schouppe *et alii* (2014)	Voluntary/forced choices	Striatum;ACC
	Apps & Ramnani (2014)	Individual/Couple participation	ACC
	Skvortsova *et alii* (2014)	Physical effort/monetary reward	vm-PFC;ant-INS;DCC;Parietal
	Massar *et alii* (2015)	Backward typing	ACC;Caudate;CER;if-GYR;dl-PFC
	Scholl *et alii* (2015)	Level of reward/Real-hypothetical	AMYG;vm-PFC;ACC;ant-INS;la-PFC.
	Khader *et alii* (2016)	Nº of attributes/Automatic-controlled	dl-PFC;SPL
	Hauser *et alii* (2017)	Level of reward	v-Striatum; dm-PFC
	Dobryakova *et alii* (2017)	Nº of response options	v-Striatum
Arithmetic calculation	Hernández *et alii* (2014)	Levels of arithmetic calculation	ACC
	Vassena *et alii* (2014)	Delayed reward	ACC;Striatum
Motor Sequencing	Heun *et alii* (2004)	Sequence of finger tapping	mf-GYR;LPL;CER
	Remy *et alii* (2008)	Sequence complexity	dl-PFC; CER BB.GG.; HIP; lf-GYR
	Mochizuki *et alii* (2009)	Digits abduction	SMA;Premotor;Sensorimotor;Parietal; CER; Thalamus
	Watanabe *et alii* (2011)	Contact complexity between fingers and thumb	INS
	Kroemer *et alii* (2014)	Instrumental task/level of reward	d-Striatum;NAcc;AMYG
Spatial Discrimination	Menon *et alii* (2000)	Novelty of the stimuli/Spatial information	HIP;GYR;Parahippocampus

Notes: ra-PFC= right anterior prefrontal cortex; ba-INS= bilateral anterior insula; ra-PFC= right anterior prefrontal cortex; lv-PFC= left ventral prefrontal cortex; r-CER= right cerebellum; bmf-GYR= bilateral medial frontal gyrus; SPL= superior parietal lobe; l-PFC= left prefrontal contex; li-PFC= left inferior prefrontal cortex; b-dl-PFC= bilateral dorsolateral prefrontal cortex; rv-PFC= right ventral prefrontal cortex; ant-INS= anterior insula; DCC= dorsal cingulate cortex; r-HIP= right hippocampus; lif-GYR= left inferior frontal gyrus; mf-GYR= medial frontal gyrus; vl-PFC= ventro lateral prefrontal cortex; lif-post-PFC= left inferior frontal posterior prefrontal cortex; NAcc= nucleus accumbens; dl-CC= dorso lateral cingulate cortex; MCC= medial cingulate cortex; v-BBGG= ventral basal ganglia; AMYG= amygdala; LPL= lateral parietal lobe; SMA= supplemental motor area.

cerebellum (r-CER); and the patterns, the bilateral middle frontal *gyrus* (bmf-GYR), the *superior parietal lobe* (SPL), and the *occipital visual cortex*. We could presuppose that the remembering of patterns is more difficult than the remembering of words, however, the findings only appear to indicate to a particular specialization of the brain. In the same line, Heckers, Weiss, Alpert, and Schacter (2002) combined repetition times and the type of stimuli (semantic or perceptual), and found that the combination between words and repetitions activated la-HIP. And regarded with this matter, Katanoda, Yoshikawa , and Sugishita (2000) found that when the participants had to recognize previously viewed faces (low effort), the bilateral fusiform *gyrus* was activated, whereas when they were presented both novel and viewed faces (high effort), the right parietal and the PFC were activated, clarifying in some extent the question.

Jessen *et alii* (2001) designed a continuous verbal recognition task in which the items were repeated twice. This time a measure of effort was explicitly provided inasmuch as the authors tested for the amount of memorization, and they found that the memorization of novel words activated the *parahippocampal* and the *frontal* GYR during training and the *inferior parietal lobe* (IPL) during testing, showing apparently that responding in absence of continuous consequences (the testing phase), needs of the participation of areas where the learning has been consolidated.

Chee, Hon, Caplan, Ling Lee, and Goh (2001) chose to combine two conditions of effort: the frequency of word triplets, and the strategy of memorization (semantic or simple reading), and found again activation in the left PFC for the highest effort condition (low frequency and semantic memorization). De Zubicaray, McMahon, Eastburn, Finnigan, and Humphreys (2005) also found activation of the left inferior PFC (li-PFC), confirming the results of earlier studies.

When the effort was manipulated by indicating to the participants with two cues if they must remember or forget a word (i.e., through a discriminative stimulus), the words cued that were remembered activated the li-PFC during the training and the left *medial temporal lobe* (MTL) during the testing (Reber, Siwiec, Gitleman, Parrish, Mesulam, & Paller, 2002). Remember that Jensen *et alii* (2001) found activation in the parietal lobe during testing conditions, although they did not presented cues as discriminative stimuli. Similar results reported Miotto *et alii* (2006), who found that effort-based memorization using semantic organizational strategies, activated the bilateral dorsolateral PFC.

Jansma, Ramsey, de Zwart, van Gelderen, and Duyn (2007) instructed their participants to memorize a set of 1, 3 or 5 consonants, and found that the activation of the right ventral PFC (rv-PFC) changed as a function of effort, and conversely, the ACC, and the HIPT reduced their activity. Allen, Bigler, Larsen, Goodrich-Hunsaker, and Hopkins (2007) administered the Green's Word Memory Test as a probe of increasing effort, and found activation in the dorso-lateral PFC (dl-PFC), the ant-INS, the SPL, and the *dorsal cingulate cortex* (DCC). Likewise, Skinner, Fernandes, and Grady (2009) used a recognition task without distraction or interfered with a word, and the memory success in both conditions was correlated with the activation of the dl-PFC and the right HIP.

In Leshikar, Gutchess, Hebrank, Sutton, and Park (2007) the participants had to remember pairs of objects semantically related (low effort condition), or unrelated (high effort), and they found activation in the left inferior frontral GYR (lif-GYR) for the first condition, and in the left HIP for the second condition. Larsen, Allen, Bigler, Goodrich-Hunsaker, and Hopkins (2010) employed the same task and found activation also in the dl-PFC, the SPL, the ACC, the ant-INS, and the *bilateral lingual cortices* for the full effort trials, but not directly on the lif-GYR or the left HIP.

Bach, Bandeis, Hofstetter, Martin, Richardson, and Brem (2010) found that increased effort in poor readers in a task in which they had to substitute letters in words and non-words, activated bilateral GYR and INS, instead of lif-GYR, activated for good readers, which coincides with the results of Leshikar *et alii* (2007).

Similarly, in Sachs *et alii* (2011) the participants had to pair associated words, words related categorically, words without relation, or non-words, and found a diversity of areas activated (lif-GYR, medial frontal GYR, and right INS).

In Helie, Roeder, and Ashby (2011) the participants had to complete a categorization task composed of more than 10000 trials, and found increased subcortical activation with practice around the striatum and the caudate, and a cortical activation throughout the training phase (mainly in the *ventro-lateral* PFC), that became more *caudal* and *dorsal* along the training. Reas and Brewer (2013) found the same result, and added that failures at remembering were correlated with reduced activity in the HIP.

The effort on verbal comprehension has also been studied. Wang and Holland (2013) studied passive listening vs. active listening in a narrative comprehension task, and found activation in the left dl-PFC, the ACC, and in the *sensorimotor* networks in the active way of responding. When memorizing images-sounds pairs was combined with localizing spatially sounds presented without images, was found greater activity in the dl-PFC (Hall *et alii*, 2014).

Taylor, Rastle, and Davis (2014) conceived that the learning of non-words was more difficult than that of words, and found greater activation for words in the left angular GYR, as well as in the left posterior inferior frontal, parietal, and occipital-temporal cortices.

Finally, the effort in Engström, Karlsson, Landblom, and Craig (2014) was implemented through both a reading task and an inspection time task, and found that effort-related tasks elicited strong activation in the ba-INS and the ACC.

The areas activated by these tasks were the HIPT, HIP, *basal ganglia* (BB. GG.), the *striatum*, the *nucleus accumbens* (Nacc), and different regions of the *cortex*. Regarding specific experimental situations that lead to the activation of such areas, in Zyssets *et alii* (2006) the participants had to decide between two alternatives that had five attributes, and found activation in pre-motor areas, the *parietal lobe*, the lm-PFC, the ant-INS, and the *caudate* (a sub-area of the BB.GG. related to the movement and motor coordination).

Botvinick, Huffstetler, and McGuire (2009) investigated the relation between two effort levels (the correct response depended on the color in which a range of numerals was presented) and reward, and observed activation in the NAcc, orbito-frontal cortex, and a preceding activation in the dorsal-lateral cingulate cortex. Croxson, Walton, O'Reilly, Behrens, and Rushworth (2009) employed similar tasks that were oriented to attain secondary reinforcers and also found activation in the ACC, the ventral striatum, and INS.

Kurniawan, Seymour, Talmi, Yoshida, Chater, & Dolan (2010) mixed two levels of gripping (high and low) and two levels of monetary reward (high and low), and found activation in the *frontal* GYR, the *caudate*, and the *putamen* in relation to the level of effort, as well as in the DCC in those most persistent participants. The NAcc was activated for rewards only in trials in which the participants opted to a high effort option (i.e., as if the things that cost were the really valued).

Enge, Fleischhauer, Lesch, Reif, and Strobel (2011) designed a decision-making task based on different levels of physical effort and delayed rewards (erotic stimuli).

The authors found activation in the *striatum* and the vm-PFC for the increasing value of delayed rewards, and in the ACC and the ant-INS for the expected expense of energy in high effort trials. Stoppel, Boehler, Strumpf, Heinze, Hopf, & Schoenfeld (2011) reproduced this experimental procedure and found activity in the ACC, the INS, and *mesolimbic* regions.

Burke, Brünger, Kahnt, Park, and Tobler (2013) attempted to differentiate between physical effort costs and costs associated with risky rewards, and they found that the first condition produced activation in the *medial cingulate cortex* (MCC), and the second condition did it in the ant-INS. Likewise, Kurniawan, Guitart-Masip, Dayan, and Dolan (2013) combined two levels of effort and chances of winning or avoiding the loss of money, and they found activation in the ACC and the *dorsal striatum* for the anticipation of effort, and in the *ventral striatum* for outcomes better than expected.

When were explored the differences on brain activation during competitive vs. collaborative decision-making in the context of strategic games the activation was produced in the *ventral basal ganglia* (v-BBGG) for the condition of personal utility (competitive strategy), and in the temporal-parietal junction for the collaborative strategy (LeBouc & Pessiglione, 2013). Complementarily, Apps and Ramnani (2014) examined the reward magnitude and the level of effort when the participants had to accomplish alone the experimental tasks or when they had to do it accompanied by a social confederate, and the authors found activation in the *sulcus* of the ACC for response costs, and in the *gyral* of the ACC for the net value of rewards gained by others. Schouppe, Demanet, Boehler, Ridderinkhof, and Notebaert (2014) found that the *striatum* and the ACC activations were higher when participants chose voluntarily in the most effort option than when they responded on force-choice trials.

Skvortsova, Palminteri, and Pessiglione (2014) managed the amount of physical effort and monetary outcome, and they found that the vm-PFC was activated with expected and actual rewards, and the ant-INS, the DCC, and the *parietal cortex* with expected and actual efforts. In constrast, Massar, Libedinsky, Weiyan, Huettel, and Chee (2015) described that the value of the chosen options activated the ACC, the *caudate*, and the CER, and that cognitive efforts (to type backwards a specified number of words) activated the inferior frontal GYR and the dl-PFC.

More interestingly was the design employed by Scholl, Kolling, Nelissen, Wittmann, Harmer, & Rushworth (2015). They arranged a procedure that allowed them test for the effects of varying levels of reward and effort, as well as the real or hypothetical (but unknown) reward delivery. This procedure led to observe neurological patterns associated to a superstitious-like behavior. The authors found a pattern of behavior that they called “irrational chose bias”, and found activation in the AMYG and the vm-PFC in this condition; however, they found activation in the *dorsal* ACC, the ant-INS, and the la-PFC when the participants chose options in a defined way in the condition of being guided by a relation more predictable between their behavior and its consequences. In Khader, Pachur, Weber, and Jost (2016) the elections were associated with one, two or three attributes activated automatically, or controlled, and found that increasing efforts activated the dl-PFC, as well as the SPL only when remembering was controlled.

Finally, in Dobryakova, Jessup, and Tricomi (2017) the low effort condition was comprised of a single image that was presented with four response options, and the high effort condition was comprised of two images that were presented with two response options; correct feedback was presented only when the participants responded correctly to both of the images. The high effort condition correlated with activation in the ventral striatum. And Hauser, Eldar, and Dolan (2017) employed a similar decision-making task, and found that the amount of reward activated *ventral striatum*, and effort the dm-PFC. Obviously, these tasks do not need clarification about their parallelism with academic activities. Nonetheless, paradoxically these tasks do not appear to have been studied as much as others. Hernandez, Kuss, Trautner, Weber, Falk, Fliessbach (2014) designed an arithmetic calculation task with three levels of difficulty that, in addition, were differently rewarded. They found activation in the *subgenual* ACC only for the high effort condition. Vassena, Silvetti, Boehler, Achten, Fias, & Verguts (2014) added a delay in the reward delivery, and they found again that upcoming difficult tasks elicited activation in the ACC and in the *striatum*.

The main areas activated for these tasks were the GYR, supplemental motor area, LPL, CER, dl-PFC, *occipital cortices*, and BBGG. Specifically, Heun *et alii* (2004) used a finger tapping sequence as task, and they found strong bilateral activation in the mid-frontal GYR, the supplementary motor area, the LPL, and the CER, which is congruent with the employment of motor tasks.

Remy, Wenderoth, Lipkens, and Swinnen (2008) examined the acquisition of a complex bimanual coordination pattern, and found activation decreases along training in the dl-PFC, right middle *temporal* and *occipital cortices*, and in the posterior CER; and found increases in the BBGG, HIP, and frontal GYR.

Mochizuki *et alii* (2009) used as task the abduction of all digits (easy condition), and finger abduction with digits 2 and 3 abducted together, concurrently with digits 4 and 5 (hard condition). The authors found that the hard condition produced increased activation in the SMA, the pre-motor, sensorimotor, and parietal cortices, the CER, and the thalamus.

Watanabe, Watanabe, Kuruma, Murakami, Seno, and Matsuda (2011) presented four sequences of contact between different fingers and the thumb. The participants had to imitate them from one out of two perspectives. The authors found that the easiest sequence and perspective activated rp-INS.

Finally, Kroemer, Guevara, Ciocanea Teodorescu, Wuttig, Kobiella, and Smolka (2014) found that an average effort activated the *dorsal striatum*, that higher effort in an instrumental task was predicted by a higher activation in the NAcc, and that the AMYG was activated only when effort was far above the average.

At last, we can say that spatial discriminations are always present in whatever learning. For example, when somebody memorizes a schema, the spatial disposition of the verbal stimuli in such schema is a key element for remembering. However, there are not many works specifically centered on manipulating spatial difficulty. Menon, Rivera, White, Eliez, Glover, & Reiss (2000) combined the novelty of stimuli with the richness of their spatial information, and found greater activation in the HIP, the lingual GYR, and the *parahippocampal* GYR in accordance to the spatial complexity. The novelty only was correlated with activation in the lingual GYR.

Discussion

First of all, through the present review we can see the disparity of studies concerned on the matter, and we discover that there is not an organized agenda of research. The different learning tasks that can be employed to study the effort have not been examined in the same degree, which limits the conclusions that we can extract. In second place, the definition of effort is made a priori in the majority of the studies, or is made under the perspective of the experimenters. It would be advisable to define the effort according to the perspectives of the participants for assuring that effort is really implicated in a task. In fact, "semantic encoding" is sometimes understood as a strategy that requires high effort and other times low effort. And in third place, the results presented point out to certain variability in the areas involved, and even in the participation of different regions belonging to a same area along a given class of task, and the participation of a same area in different types of tasks. Moreover, some of the areas mentioned also participate in other matters. For example, the *caudate* and *ventral tegmentum* have been activated in relation to love-evoking stimuli, the INS when distributing reinforcers in accordance with criteria of "justice"; and the PFC in moral reasoning and during the practice of religious exercises (Pérez Álvarez, 2011). Hence, such crossed or multiple specializations of some brain areas can explicate the variability found. Other variables that could explicate the variability are certain methodological issues involved in fMRI, such as the specific timing of the registry, inappropriate parametrical statistical analysis, invalid cluster inferences, the methodological isolation of the relation between the oxigened blood levels that we call "activation" and the tasks employed, etc.; as pointed out by Eklund, Nichols, and Knutsson (2016).

At any rate, we can conclude that the most relevant areas related to the training of tasks based on effort were: (a) PFC, INS, and ACC in memorization tasks; (b) CER, BBGG, motor and pre-motor areas in specific motor tasks; (c) NAcc and *striatum* when explicit reinforcing consequences and high effort were involved; (d) *Cingulate cortex* for effort requirements and persistent behavior; (e) AMYG with unpredictable contingencies or superstitious behavior, and when the effort was far above the average; and (f) HIPT, HIP, and related regions for the initial consolidation of memory.

And another important conclusion that we can extract from this review, is that tasks that are based on effort do not activate automatically the fundamental area that is involved in aversive learning (i.e., AMYG). This area is only activated when the effort required is considerably higher than the average that an individual is accustomed to perform, as well as when the tasks consist of uncertainty conditions. The latter is congruent with other findings that connect the AMYG to behaving under conditions of ambiguity (DiChiara & Imperato, 1988; Whalen, 1998). Both the former and the latter have the same behavioral function, that is, both involve the withdrawal of positive reinforcement. In the former, the effort required exceeds an individual's resources to obtain such reinforcer, and in the latter there are not cues (discriminative stimuli) signaling criteria for attaining the reinforcement. Thus, the reinforcement "moves away" in both conditions.

Nonetheless, in accordance to the findings reported by others studies included in this review, a possible initial activation of the AMYG when the effort required was quite higher than the mean effort that an individual is accustomed to perform, could be moderated with a progressive adaptation to such level of effort. This process would finally lead to the activation of the striatum and NAcc (see Kroemer *et alii*, 2014; Kurniawan *et alii*, 2010), which would indicate that such activity passes by from an aversive function to a function of reinforcement (DiChiara & Imperato, 1988; Peciña & Berridge, 2005). This can be useful for programming more effective instructional procedures than the designed up to now, and for not forgetting the importance of effort in the process of the academic human learning, as has been remembered by some authors (Dweck, 2016; Enkvist, 2011). Furthermore, considering the results obtained by Segura and Roales Nieto (2016), that paradoxically show that a consolidated wellbeing when some social and intergenerational difficulties have been surmounted is related to a higher unhappiness, perhaps the best thing is not to dispense with the effort in the academic learning.

One method for the improvement of the instructional procedures would be programming tasks with successive levels of difficulty and effort, which has been successfully put into practice by Behavior Analysis since ever (Fredrick, Deitz, Bryceland, & Hummel, 2002; Luciano, 1995; Sulzer-Azaroff & Mayer, 1986). The trouble is that not all students are able to deploy initially the same level of effort. Consequently, such programming should be individualized in some extent, and the different social agencies involved in the development of an individual should be concerned on helping to achieve such growing level of effort tolerance (parents included). What is clear is that effort per se is not equivalent to aversive conditioning in neurological terms, and is restricted to very specific conditions, which contradicts proposals like that by Kurzban *et alii* (2013). Even more, it seems that, under some conditions, only when the effort is explicitly required to achieve a given amount of rewards, are activated the brain areas involved in positive reinforcement (see Kurniawan *et alii*, 2010). As Plato (c. 390 BC) wrote in Hippias Major (p. 304e), “beautiful things are difficult”.

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