

A Review: Psychophysiology of Tool Use in Non-Human Primates

Manuel Alejandro Cruz-Aguilar^{1,2}, Miguel Angel Guevara², Marisela Hernández-González³, Ignacio Ramírez-Salado¹, Francisco García-Orduña⁴

¹Instituto Nacional de Psiquiatría “Ramón de la Fuente Muñiz”, Dirección de Investigaciones en Neurociencias. Laboratorio de Cronobiología y Sueño, CDMX, México

²Instituto de Neurociencias, CUCBA, Universidad de Guadalajara. Laboratorio de Correlación Electroencefalográfica y Conducta. Guadalajara, Jalisco, México

³Instituto de Neurociencias, CUCBA, Universidad de Guadalajara. Laboratorio de Neurofisiología de la Conducta Reproductiva. Guadalajara, Jalisco, México

⁴Instituto de Neuroetología. Universidad Veracruzana. Xalapa, Veracruz, México

Abstract: *The main aim of this work was to conduct a systematic review of the scientific contributions to understanding the psychophysiological mechanisms related to tool use in non-human primates. Results showed that tool use is observed in several species of non-human primates, which use tools to obtain food, even sequentially. In macaque and human species, it has been observed prefronto-parietal circuit activation. The intrinsic properties of this circuit are linked to the tool use in primates. Specific activation in the parietal lobe observed in humans could be a recent evolutionary feature in the primate order.*

Keywords: executive functions, primates, evolution, brain, tool use

1. Introduction

Approximately 55 million years ago, primates appeared on the earth. Arboreal in nature and with pensive tail, these mammals evolved through the geological eras, at the end of which arose the *Homo sapiens*[1]. The transition from arboreal life to the semi-arboreal life observed throughout the primate order, required adaptations in the central nervous system (CNS). Thus, diverse morphological and functional changes occurred during this process. Today, it is known that the development of the prefrontal cortex (PFC) and the associative areas of the encephalon in the primates are related with the performance of the superior cognitive functions [2]. As the result of the development of these cortical regions in these mammals there are complex behaviors such as the tool use. Tools can be defined as mechanical instruments that permit reaching goals that, in other manner, would be difficult or impossible to achieve [3,4]. Historically, the appearance of this behavior has been considered an important step in the evolution of primates and even for defining the genus *Homo*[5]. The tool use was considered for a long time as an exclusively human characteristic [6], however, currently there is evidence that other species, in particular non-human primates, can also use tools [7]. Primates are mammals adapted to life in the tropical forest. The presence of a basically primitive skeleton; especially in dentition, combined with arboreal life style and social organization, gave rise to the evolution of fingers and hands and well as to the evolution of language and telescopic vision. At present, nearly 175 species of primates are known, distributed in the tropical zones of America, Asia, and Africa. Phylogenetically, the primate order could be divided into three suborders: *Strepsirrhini* (formerly called Prosimians), *Tarsioidae* (tarsiers) and *Anthropoidea* (anthropoids)[8-10]. In turn, the anthropoids are divided into three superfamilies: *Hominoidea*, which the great apes and

humans are found; *Cercopithecoidea*, made up of the Old World monkeys, and *Ceboidea*, comprising the New World monkeys [1].

The living species of the great apes are divided into three families: Hylobatidae, gibbons and the siamangs belong; *Pongidae*, which includes the orangutans, gorillas, and chimpanzees, which are the currently existing anthropomorphic great apes, and *Hominidae*, which is composed of numerous genera, of which all but one have been extinguished at present: *Homo*, which at present, possesses a unique species: *Homo sapiens*[11]. On the other hand, the Old World monkeys live in tropical and subtropical regions in Asia and Africa, except for the macaque, which lives in Japan. The Old World monkeys do not have prehensile tails, but they do have ischial callosities around the tail and on the underside. These species preserve the tail (with the unique exception of the *Macaca sylvanus*), presents more prominent faces, and their locomotion is basically quadruped [9, 10]. Among the Old World monkeys, there are twelve species of macaques, two species of mandrills, and four species of boons papions, also known as baboons, and the distinct species of macaques, the *Macaca arctoides* that most utilized primate in a broad gamma of areas of knowledge, among which psychology, medicine, and the neurosciences are highlighted.

The New World monkeys are divided into two families: *Callitricidae*, which includes the titis and the tamarins, and the *Cebidae*, which includes the spider monkeys and the howler monkeys. The habitats of the New World monkeys are the tropical and subtropical zones of South America and Central America. These monkeys present long tails in relation to their body mass and that are frequently prehensile as well as flattened snouts, with nostrils in a lateral position. They are very well adapted to tree life, possess long limbs,

Volume 6 Issue 9, September 2017

www.ijsr.net

Licensed Under Creative Commons Attribution CC BY

delicate hands, and a tail apt for balancing or easily catching hold of tree branches [9, 10]. In contrast with other primates, their thumbs are opposable. The smallest species of New World monkeys present the cerebral cortex with few grooves and incisions.

Due to the complexity of the tool use that is observed in primates, the executive functions are the cognitive abilities are those that are probably related to this behavior. The executive functions are defined as a series of processes whose objective is to facilitate adaptation to new situations and to modulate the most basic motor and cognitive abilities [12]. It has been proposed that they have the capacity to filter information that interferes with the task, involving themselves with behavior directed toward an objective, foreseeing the consequences of their actions and drive the concept of mental flexibility [13-17]. There is evidence that the executive functions in primates depend to a great degree on the prefrontal cortex [14-20], and on the association areas, mainly the parietal cortex [21-29]. The prefrontal cortex participates in the control, regulation, and efficient planning of behavior. To it is attributed an essential role in creativity, the development of the formal operations of thought and decision making [30-31]. On the other hand, the parietal cortex is related with the processing of somatosensory information processing, [32] and has been considered important for attention and spatial perception, as well as for polysensory integration [33-35]. Diverse studies suggest that the posterior parietal cortex also participates in intention movement and decision making [21-29].

Therefore, it is possible to suppose that the comparison of the psychophysiological processes related with the tool use among humans and the variety of families, genera, and species of existing non-human primates would allow for the determination of some cognitive, behavioral, and neurophysiological elements that underlie the tool use in the primate order. Thus, the objective of the present work was to perform a systematic review of the scientific contributions concerning the understanding of the psychophysiological mechanisms related with the tool use in non-human primates.

2. Method

The databases PubMed, Google Scholar, Redalyc, and Dialnet were utilized for the bibliographic search of the following themes: *tool use in non-human primates*; *neurological basis of the tool use in primates*, and *psychophysiology of the prefrontal-parietal circuit*. The keywords belonging to each theme were searched for independently and also were combined among themselves for the search for themes. As an inclusion criterion, it was taken into consideration that the works would permit to integrate each of the themes with scientific information, without the year of publication being a concern. Similarly, works were included on the tool use of all of the species of non-human primates and all the neurophysiological and behavioral works referring to the theme.

2.1 Tool use in non-human primates

In the international literature, there is evidence that non-human primates possess the capacity to manipulate an object (tool) with the hand to act upon other [36-39]. In orangutans [40-43] and gorillas [44-46], tool use is related mainly with obtaining food. Similarly, there is evidence that gorillas can use branches to explore the depth of a river [47]. In the chimpanzee, the tool use is also found to be related with obtaining food [42, 48, 49]; however, this has been observed mainly in females. It has even been reported that these primates are capable of using tools to hunt down vertebrates [42, 50]. With regard to Old World monkeys, in macaques, it has also been observed that females, in comparison with males, utilized tools with greater frequency (stones) to obtain food [51]. With respect to the New World monkeys, there is evidence that the capuchin monkey is one of the most studied species and even its capacity to elaborate its own tools [52, 53]. In capuchin monkeys, it has been observed that males, use tools with greater frequency [54-55]. In this species, the capacity to create, reuse, and transport tools to obtain food has also been observed [56, 57]. In a longitudinal study conducted in the species *Cebus* spp., the spontaneous use was observed of stones to dig and obtain food [58]. Likewise, the spider monkey, is capable of employing tools in the wild to scratch itself [59]. With respect to the oldest primates, tool use has been studied under laboratory conditions in two species of lemur [60-62], observing, in all cases, the use of tools to obtain food.

In non-human primates, the sequential tool use has been documented. Only a limited number of primate species are capable of utilizing tools sequentially, where a tool to obtain another tool is utilized, which later will serve to obtain an out-of-reach objective. The paradigm that is commonly employed to evaluate sequential tool use consists of presenting to the subjects a reward that is out of their reach and an easy-access tool that is which is not sufficiently long to reach the reward, but that is sufficient for reaching another tool, which can be utilized for obtaining the reward. [63].

The study of chimpanzees has been the model to evaluate the primitive traits that characterize the sequential tool use in hominids [64-66]. However, the spontaneous sequential tool use has also been reported in gorillas and orangutans [44], as well, and in capuchin monkeys [67]. In chimpanzees, there is evidence of the use of five tools sequentially to obtain food [42-44]. Likewise, the orangutan and the bonobo possess the capacity to use up to five tools to obtain food [42]. It has been reported that after some training sessions, macaques [68] and titis [61] can also use tools sequentially to obtain food, as well as primates of the species *Sapajusspp*, [69]. There is evidence that capuchin monkeys and the great apes exhibit these behaviors in the wild. Figure 1 presents a summary of the scientific works that refer the tool use in non-human primates.

Table 1: Studies on the use of tools in non-human primates

Family	Species	Author	Type of tool	Objective of th use of the tool	
Great apes	Orangután:				
	(<i>Pongo pygmaeus</i>)	Fox et al., 2004	Branches	Obtain food	
	(<i>Pongo abeli</i>)	Schaik and Knott, 2001.	Branches	Obtain food	
	(<i>Orongoabeli</i>)	Martín-Ordas et al., 2012.	Sequential use of 3-5 sticks	Obtain food	
	(<i>Pongo pygmaeus</i>)	Call and Tomasello, 1994.	Sticks	Obtain food	
	Gorilla:				
	Gorilla (<i>Gorillagorilla</i>)	Mulchay and Call, 2005.	Sequential use of two sticks	Obtain food	
	Gorilla (<i>Gorillagorillagorilla</i>)	Pouydbat, 2010.	Branches, substrate	Obtain food	
	Gorilla (<i>Gorillagorillagorilla</i>)	Pouydebat, 2005.	Branches	Obtain food	
	Gorilla (<i>Gorillagorilla</i>)	Breuer, 2005.	sticks	Explore depth of a river to cross it	
	Chimpanzee:				
	<i>Pan troglodytes</i>	Mulchay and Call, 2005.	Sequential use of two sticks	Obtain food	
	<i>Pan troglodytes</i>	Martín-Ordas et al., 2012.	Sequential use of 3-5 sticks	Obtain food	
	<i>Pan troglodytes Verus</i>	Pruetz et al., 2015.	Branches	Hunt vertebrates	
	<i>Pan paniscus</i>	Boose et al., 2013.	Branches	Obtain food	
<i>Pan paniscus</i>	Martín-Ordas et al., 2012.	Sequential use of 3-5 sticks	Hunt vertebrates		
Old Worldmonkeys	Macaque:				
	<i>Macaca Fascicularis aurea</i>	Gumert et al., 2001.	Stones	Open foods without skin (oysters, crabs, nuts, etc.)	
	<i>Macaca fuscata</i>	Hihara et al., 2003.	Sequential use of two canes secuen	Obtainfood	
New Worldmonkeys	Capuchin:				
	<i>Cebusapella</i>	Westergaard and Suomi, 1994.	Branches	Obtain food	
		Westergaard and Suomi, 1996.	Stones	Obtain food	
	<i>Cebuslibidinosus</i>	Spagnoletti et al., 2011.	Stones	Obtain food	
		Spagnoletti et al., 2012.	Stones	Obtain food	
		Elisabetta et al., 2013.	hammer stone	Obtain food	
		Mannu and Ottoni, 2009.	Branches and stones	Obtain food, dig	
		<i>Cebusspp.</i>	Moura and Lee, 2004.	Branches and stones	Obtain food
		<i>Sapajusspp.</i>	Sabbatini et al., 2014.	Sequential use of two sticks	Obtain food
		Spider monkey			
	(<i>Atelesgeoffroyi</i>)	Lindshield and Rodrigues, 2009	Branches	Scratch himself	
	Cotton-top tamari (<i>Saguinusoedipus</i>)	Santos et al., 2005a.	Canes	Obtain food	
Strepsirrhins (Prosimios)	Lemur:				
	<i>EulemurFulvus</i>	Santos et al., 2005b.	Canes	Obtain food	
	<i>Lemurcatta</i>	Laurie et al., 2005.	Canes	Obtain food	
	Aye-Aye (<i>Daubentoniamadagascariensis</i>)	Sterling and Povinelli, 1999.	Vines	Obtain food	

2.2 Neurobiological bases of tool use in non-human primates

In the international literature, there is evidence that in macaques and in humans, cerebral activity related with tool use has been studied through neuroimaging techniques. In these studies, it has been found that the observation of subjection actions carried out with simple tools activate the prefrontal-parietal circuit, which is also activated during the observation and the execution of the subjection movements of a tool [70-72]. In both species, observation of tool use activates the occipital, temporal, intraparietal, and ventral premotor cortex, in bilateral fashion. In humans, the

observation of the tool use is related with the specific additional activation of a rostral sector of the left inferior region in the parietal lobe. In these works, the activation of this region is suggested for being considered as a characteristic of the human brain, because it was not observed in the monkey studied, even after the latter received training [70-73]. These studies suggest that the observation of a hand that use a tool activates similar regions in humans and macaques, and that there exists a specific additional sector of the left inferior region of the parietal lobe, which appears to be specialized from the tools use in the *Homo sapiens*. It is noteworthy that the neural basis of the

sequential tool use has not been documented in any species of the non-human primates.

2.3 Psychophysiology of the Prefrontal-Parietal Circuit

As its name indicates, this circuit is constituted of the prefrontal and parietal cortexes, and of the reciprocal connections that exist between these. There is evidence that this circuit initiates with the send of projections from areas 9 and 10, as well as from area 7a of Brodmann to the dorsal region of the caudal head [74]. The prefrontal cortex, on the one hand, has been associated with superior cognitive operations and the executive functions[75-90].

The prefrontal cortex functions are determined by their associative nature, integrating multimodal information. It also possesses wide connections from subcortical and limbic regions. It performs an important role in prioritizing stimuli, referencing them to internal representations, appropriately directing the attention, monitoring the time sequence of the happenings permits the understanding of abstract concepts and carrying out executive functions [91]. In particular, the posterior parietal cortex is tightly interconnected with the prefrontal cortex, and it has been demonstrated that they exhibit similar properties across a broad gamma of experimental situations. Likewise, it has been documented that the posterior prefrontal cortex of primates is activated during tasks related to spatial working memory [92,93], during decision making [94], planning [95-99], the expectation of a reward [100,101], the rules [102], sorting/classifying [103,104], cognitive associations [105], and quantifying [106-110].

At present, it is known that in primates, the dorsal convexity of the frontal and parietal lobes forms a network that is implicated in attention. This network comprises the cortex along the intraparietal sulci, the inferior parietal lobe, and the dorsal premotor cortex, including the frontal ocular field. These regions are strongly interconnected with recurring fibers that pass through the superior longitudinal fasciculus. The posterior parietal cortex in primates possesses information elaborated in the sensory cortex and of representations of behavioral goals and expectations deriving from the dorsolateral prefrontal cortex and the premotor cortex [111]. Likewise, in the international literature, there is evidence that the prefrontal-parietal circuit is sustained by the interconnections of the posterior parietal cortex, the dorsolateral cortex, and the cingulum. The interconnections of the posterior parietal cortex are more prominent with the posterior zone of the cingulum, while the dorsolateral prefrontal cortex maintain the most prominent interconnections with the anterior cingulum.

In humans, the posterior parietal cortex is a zone around the intraparietal sulci that includes its own intraparietal sulci, the lateral intraparietal area, which is in reality the lateral branch of the intraparietal sulci, the inferior parietal gyrus (approximately the zone corresponding to area 39 of Brodmann) and zones of area 7 of Brodmann, possibly zone 7a for visual attention and zone 7b somatosensory attention [112]. Likewise, the posterior parietal cortex, of right predominance, constitutes the main settlement of a posterior

attentional system that controls the selective and focalized attention.

3. Discussion

Historically, the appearance of the tool use has been considered as an important step in the evolution of primates, even for defining the genus Homo[5]. In effect, the international literature supplies evidence that the use of tools is present in a great amount of non-human primate, which suggests that all primates are capable of utilizing tools, from the most ancient species to up to the great apes, among which humans are found.

Therefore, one of the most important points in this review has to do with the question: Which psychophysiological mechanisms are shared by the primates that permit them to use tools? According to this present review, it could be said that they share the great majority of psychophysiological processes, except those related with oral language social intelligence, or remembering the personal life story present in humans. There is great anatomical, structural, and neurochemical homology in the brain of the primates, and there is evidence of the activation of common cerebral areas, above all of the prefrontal-parietal circuit, in the motor and cognitive processes implicated in the tool use as humans as well as in non-human primates [113]. Only a small difference has been reported, and that is that humans present a specific activation in the left anterior supramarginalgyrus of the inferior parietal cortex during the observation and execution of tool use, which is not observed in macaques [72,73].

However, this small difference barely refers motor specialization and does not explain the abysmal difference that exists between the tool use in humans and non-human primates. Human adults without experience are capable of understanding a priori, the causal relationship between the tool use and the results obtained [114]. Thus, humans are capable of imagining, creating, perfecting, and even intentionally transforming the tools, solving a different problem from that for which they were created [115]. This suggests that distinct areas of the prefrontal cortex and the areas of association that controls the executive functions, as well as limbic-system structures related to the regulation of emotions and creativity, could make up part of the psychophysiological mechanisms comprising the broad behavioral repertoire of tool use, principally in humans. Likewise, the tool use related with the architecture, technology, science, art, and the use of arms are importantly determined by the development of the prefrontal cortex circuits and the association areas, which evolved in a different manner from to give rise to distinct species of primates, achieving greater development in humans [115,116]. In this respect, it is interesting to observe that in the international literature, there is no evidence that non-human primates build or use tools to harm other beings of their own species, or to intentionally destroy the ecosystem. The latter appears to also be an intrinsic property of human nature: a high cost of the evolution of the CNS in the primates, a brain that evolves to adapt itself and to self-destruct.

A third aspect that is highlighted in the present review is that in non-human primates, the sequential tool use has been documented, however, only the capuchin monkeys and the great apes exhibit these behaviors in the wild. Evidence exists that the proportion of the cerebral cortex and the encephalization coefficient are associated with the tool use in the primate order [113]. It is interesting to observe that New World monkeys have a cerebral-cortex proportion similar to that observed in capuchin monkeys and macaques [117], and an encephalization quotient equivalent to that of the chimpanzee [118-119]. This suggests that the cytoarchitectonic characteristics of the prefrontal and parietal cortex, the proportion of the cerebral cortex, and the encephalization quotient, as well as the cognitive and motor capacities, can comprise factors that are related with the sequential tool use in primates.

The most part of studies conducted to explore the neural bases of tool use in primates have utilized neuroimaging techniques [73, 74], which possess great spatial resolution, but very little temporal resolution. Tool use implies process of attention, planning, spatial orientation, and motor execution, which take place within a well-organized time sequence, thus the importance of employing high-resolution techniques, as is the case of Electroencephalographic (EEG); a non-invasive technique that permits the registry of electric cerebral activity, even in freely moving non-human primates [120,121]. EEG activity can be defined as voltage oscillations originating from intra- and extra neuronal ionic currents in a large population of cells that are radially disposed to the surface, which are activated synchronically [122,123]. The registry and analysis of EEG activity has been employed for many years as one of the most sensitive tools that permit the examination of cerebral functioning in relation to the different physiological states, permit among these the executive functions. Therefore, we consider that the study of the psychophysiological mechanisms of the tool use in non-human primates by means of EEG activity, would allow study the cortical mechanisms related with tool use. Finally, it is noteworthy that, there are scarce neurophysiological works on the tool use in New World monkeys and oldest monkeys. The study of these species could increase knowledge on the behavioral strategies and cerebral mechanisms implicated in the tool use into primate order.

4. Conclusion

The tool use presents in a large number of non-human primate species, which suggests that all primates are capable of utilizing tools, some even in sequential fashion. The specific activation of the inferior left rostral region of the parietal lobe, which is only observed in humans during the use of tools, suggests that this is a recent evolutionary trait in the primate order. The cytoarchitectonic and functional characteristics of the prefrontal-parietal circuit could be factors that are related with tool use in primates. The study of the psychophysiological mechanisms of the use of tools in non-human primates utilizing analysis of the EEG activity would permit more delving deeper into the cortical mechanisms related with the use of tools in the primate order.

5. Acknowledgments

Dr. Manuel Alejandro Cruz-Aguilar is grateful to the Instituto Nacional de Psiquiatría "Ramón de la Fuente Muñiz", CONACyT and to the Universidad de Guadalajara for the facilities granted to him for the carrying out of his postdoctoral fellowship (2015-2017) that endorse the present work. The authors of this paper declare that they have no conflict of interest.

References

- [1] Marmelada, C. A. (2007). Orígenes remotos del género humano (1): Hominoideos del Mioceno Inferior. Recuperado de: https://servicios.educarm.es/templates/portal/ficheros/etapasEducativas/secundaria/10/secciones/425/contenidos/6360/orgenes_remotos_del_gnero_human1.pdf
- [2] Coolidge, F. L. and Wynn, T. (2006). The effects of the tree-to-ground sleep transition in the evolution of cognition in early Homo. *Before Farming: The Anthropology and Archaeology of Hunters-Gatherers*, 2(1),16.
- [3] Johnson-Frey, S. H. (2003). What's so special about human tool use? *Neuron*, 39(2), 201-204.
- [4] Vaesen, K. (2012). The cognitive bases of human tool use. *Behavioral and Brain Sciences*, 35(4), 203-262.
- [5] Ambrose, S. H. (2001). Paleolithic technology and human evolution. *Science*, 291(5509), 1748-1753.
- [6] Oakley, K. P. (1956). *Man the tool-maker*. London: British Museum.
- [7] Van Schaik, C. P., Deaner, R. O. and Merrill, M. Y. (1999). The conditions for tool use in primates: implications for the evolution of material culture. *Journal of Human Evolution*, 36(6), 719-741.
- [8] Cartmill, M. and Kay, R. F. (1978). Cranio-dental morphology, tarsier affinities, and primate suborders. In: D. J. Chivers and K. A. Joysey (Editors), *Recent Advances in Primatology Vol. 3* (pp. 205-214). London: Academic Press.
- [9] Kay, R. F., Ross, C. F. and Williams, B. A. (1997). Anthropoid origins. *Science*, 275(5301), 797-804.
- [10] Kay, R. F., Williams, B. A., Ross, C. F., Takai, M. and Shigehara, N. (2004). Anthropoid origins: a phylogenetic analysis. In: C. F. Ross and R. F. Kay (Editors), *Anthropoid Origins: New Visions* (pp. 91-135). New York: Kluwer/Academic.
- [11] Cartmill, M. and Smith, F. H. (2009). *The Human Lineage*. New York: Wiley-Blackwell.
- [12] Burgess, P. W. (1997). Theory and methodology in executive functions research. In: P. Rabbit (Editor), *Methodology of Frontal and Executive Function* (pp. 81-116). London: Psychology Press.
- [13] Denckla, M. B. (1996). A theory and model of executive function: a neuropsychological perspective. In: G. R. Lyon and N. A. Krasnegor (Editors), *Attention, Memory and Executive Function* (pp. 263-277). Baltimore, MD, USA: Paul H. Brooks.
- [14] Goldberg, E. (2001). *The executive brain: frontal lobes and the civilized mind*. New York: Oxford University Press.
- [15] Luria, A. R. (1969). Frontal lobe syndromes. In P. J. Vinken and G. W. Bruyn (Editors), *Handbook of*

- Clinical Neurology Vol. 2 (pp. 725-757). Amsterdam: North Holland.
- [16] Luria, A. R. (1980). Higher cortical functions in man (2nd. Ed.). New York: Basic.
- [17] Stuss, D. T. and Benson, D. F. (1986). The Frontal Lobes. New York: Raven Press.
- [18] Robbins, T. W. (1998). Dissociating executive functions of the prefrontal cortex. In: A. C. Roberts, T. W. Robbins and L. Weiskrantz(Editors), The Prefrontal Cortex (pp. 117-130). London: Oxford University Press.
- [19] Fernández-Duque, D., Baird, J. A. and Posner, M. I. (2000). Executive attention and metacognitive regulation. *Consciousness and Cognition*, 9(2), 288-307.
- [20] Flores, J. C. y Ostrosky-Solís, F. (2008). Neuropsicología de lóbulos frontales, funciones ejecutivas y conducta humana. *Revista de Neuropsicología, Neuropsiquiatría y Neurociencias*, 8(1), 47-58.
- [21] Mountcastle, V. B., Lynch, J. C., Georgopoulos, A., Sakata, H. and Acuña, C. (1975). Posterior parietal association cortex of the monkey: command functions for operations within extrapersonal space. *Journal of Neurophysiology*, 38(4), 871-908.
- [22] Andersen, R. A. (1987). The role of the inferior parietal lobule in spatial perception and visual-motor integration. In: F. Plum, V. B. Mountcastle and S. R. Geiger (Editors), *The Handbook of Physiology. Section I: The Nervous System, Volume V. Higher Functions of the Brain Part 2* (pp. 483-518). Bethesda MD, USA: American Physiological Society.
- [23] Lacquaniti, F., Guigon, E., Bianchi, L., Ferraina, S. and Caminiti, R. (1995). Representing spatial information for limb movement: role of area 5 in the monkey. *Cerebral Cortex*, 5(5), 391-409.
- [24] Andersen, R. A. and Cui, H. (2009). Intention, action planning, and decision making in parietal-frontal circuits. *Neuron*, 63(5), 568-583.
- [25] Johnson, P. B., Ferraina, S., Bianchi, L. and Caminiti, R. (1996). Cortical networks for visual reaching: physiological and anatomical organization of frontal and parietal lobe arm regions. *Cerebral Cortex*, 6(2), 102-119.
- [26] Kalaska, J. F., Scott, S. H., Cisek, P. and Sergio, L. E. (1997). Cortical control of reaching movements. *Current Opinion in Neurobiology*, 7(6), 849-859.
- [27] Rizzolatti, G., Fogassi, L. and Gallese, V. (1997). Parietal cortex: from sight to action. *Current Opinion in Neurobiology*, 7(4), 562-567.
- [28] Graziano, M. S. A. and Gross, C. G. (1998). Visual responses with and without fixation: neurons in premotor cortex encode spatial locations independently of eye position. *Experimental Brain Research*, 118(3), 373-380.
- [29] Burnod, Y., Baraduc, P., Battaglia-Mayer, A., Guigon, E., Koehlin, E., Ferraina, S. and Caminiti, R. (1999). Parieto-frontal coding of reaching: an integrated framework. *Experimental Brain Research*, 129(3), 325-346.
- [30] Ardila, A. and Surloff C. (2007). *Dysexecutive Syndromes*. San Diego, CA, USA: Medlink: Neurology.
- [31] Ardila, A. y Ostrosky-Solís, F. (2008). Desarrollo histórico de las funciones ejecutivas. *Revista Neuropsicología, Neuropsiquiatría y Neurociencias*, 8(1), 1-21.
- [32] Mountcastle, V. B. (1957). Modality and topographic properties of single neurons of cat's somatic sensory cortex. *Journal of Neurophysiology*, 20(4), 408-434.
- [33] Critchley, M. (1953). *The Parietal Lobes*. London: Arnold.
- [34] Ungerleider, L. G. and Mishkin, M. (1982). Two cortical visual systems. In: D. J. Ingle, M. A. Goodale and R. J. W. Mandsfield(Editors), *Analysis of Visual Behavior* (pp. 549-586). Cambridge, MA, USA: MIT Press.
- [35] Colby, C. L. and Goldberg, M. E. (1999). Space and attention in parietal cortex. *Annual Review of Neuroscience*, 22(1), 319-349.
- [36] Köhler, W. (1917). *Aus der Anthropoidenstation auf Teneriffa. III: Intelligenzprüfungen an Anthropoiden*. Berlin: Kgl. Akad. d. Wiss; G. Reimer in Komm.
- [37] Iriki, A., Tanaka, M. and Iwamura, Y. (1996). Coding of modified body schema during tool use by macaque postcentralneurons. *Neuroreport*, 7(14), 2325-2330.
- [38] Ishibashi, H., Hihara, S. and Iriki, A. (2000). Acquisition and development of monkey tool-use: behavioral and kinematic analyses. *Canadian Journal of Physiology and Pharmacology*, 78(11), 958-966.
- [39] Ducoing, A. M. and Thierry, B. (2003). Withholding information in semi free-ranging Tonkean macaques (*Macacatonkeana*). *Journal of Comparative Psychology*, 117(1), 67-75.
- [40] Fox, E. A., van Schaik, C. P., Sitompul, A. and Wright, D. N. (2004). Intra- and interpopulational differences in orangutan (*Pongopygmaeus*) activity and diet: implications for the invention of tool use. *American Journal of Physical Anthropology*, 125(2), 162-174.
- [41] van Schaik, V. C. and Knott, C. D. (2001). Geographic variation in tool use on Neesia fruits in orangutans. *American Journal of Physical Anthropology*, 114(4), 331-342.
- [42] Martín-Ordas, G., Schumacher, L. and Call, J. (2012). Sequential tool use in great apes. *PLOS ONE*, 7(12), 1-15.
- [43] Call, J. and Tomasello, M. (1994). The social learning of tool use by orangutans (*Pongopygmaeus*). *Human Evolution*, 9(4), 297-313.
- [44] Mulcahy, N. J., Call, J. and Dunbar, R. I. M. (2005). Gorillas (*Gorilla gorilla*) and orangutans (*Pongopygmaeus*) encode relevant problem features in a tool-using task. *Journal of Comparative Psychology*, 119(1), 23-32.
- [45] Pouydebat, E., Reghem, E., Gorce, P. and Bels, V. (2010). Influence of the task on hand preference: individual differences among gorillas (*Gorillagorilla gorilla*). *Folia Primatologica*, 81, 273-281.
- [46] Pouydebat, E., Berge, C. and Gorce, P. (2005). Use and manufacture of tools to extract food by captive *Gorilla gorillagorilla*: experimental approach. *Folia Primatologica*, 76(3), 180-183.
- [47] Breuer, T., Ndoundou-Hockemba, M. and Fishlock, V. (2005). First observation of tool use in wild gorillas. *PLOS Biology*, 3(11), 2041-2043.

- [48] Boose, K. J., White, F. J. and Meinelt, A. (2013). Sex differences in tool use acquisition in bonobos (*Pan Paniscus*). *American Journal of Primatology*, 75(9), 917-926.
- [49] Mulcahy, N. J., Call, J. and Dunbar, R. I. M. (2005). Gorillas (*Gorilla gorilla*) and orangutans (*Pongopygmaeus*) encode relevant problem features in a tool-using task. *Journal of Comparative Psychology*, 119(1), 23-32.
- [50] Pruetz, J. D., Bertolani, P., Ontl, K. B., Lindshield, S., Shelley, M. and Wessling, E. G. (2015). New evidence on the tool-assisted hunting exhibited by chimpanzees (*Pan troglodytesverus*) in a savannah habitat at Fongoli, Sénégal. *Royal Society Open Science*, 2(4), 140507.
- [51] Gumert, M. D., Hoong, L. K. and Malaivijitnond, S. (2011). Sex differences in the stone tool-use behavior of a wild population of Burmese long-tailed macaques (*Macacafascicularisaura*). *American Journal of Primatology*, 73(12), 1239-1249.
- [52] Westergaard, G. C. and Suomi, S. J. (1994). Hierarchical complexity of combinatorial manipulation in capuchin monkeys (*Cebusapella*). *American Journal of Primatology*, 32(3), 171-176.
- [53] Westergaard, G. C. and Suomi, S. J. (1996). Hand preference for stone artefact production and tool-use by monkeys: possible implication for the evolution of right-handedness in hominids. *Journal of Human Evolution*, 30(4), 291-298.
- [54] Spagnoletti, N., Visalberghi, E., Ottoni, E., Izar, P. and Fragaszy, D. (2011). Stone tool use by adult wild bearded capuchin monkeys (*Cebuslibidinosus*). Frequency, efficiency and tool selectivity. *Journal of Human Evolution*, 61(1), 97-107.
- [55] Spagnoletti, N., Visalberghi, E., Verderane, M. P., Ottoni, E., Izar, P. and Fragaszy, D. (2012). Stone tool use in wild bearded capuchin monkeys, *Cebuslibidinosus*. Is it a strategy to overcome food scarcity? *Animal Behaviour*, 83(5), 1285-1294.
- [56] Elisabetta, V., Haslam, M., Spagnoletti, N. and Fragaszy, D. (2013). Use of stone hammer tools and anvils by bearded capuchin monkeys over time and space: construction of an archeological record of tool use. *Journal of Archaeological Science*, 40(8), 3222-3232.
- [57] Mannu, M. and Ottoni, E. B. (2009). The enhanced tool-kit of two groups of wild bearded capuchin monkeys in the Caatinga: tool making, associative use, and secondary tools. *American Journal of Primatology*, 71(3), 242-251.
- [58] Moura, A. C. A. and Lee, P. C. (2004). Capuchin stone tool use in Caatinga dry forest. *Science*, 306(5703), 1909.
- [59] Lindshield, S. M. and Rodrigues, M. A. (2009). Tool use in wild spider monkeys (*Atelesgeoffroyi*). *Primates*, 50(3), 269-272.
- [60] Santos, L. R., Mahajan, N. and Barnes, J. L. (2005). How prosimian primates represent tools: experiments with two lemur species (*Eulemurfulvus* and *Lemur catta*). *American Psychological Association*, 119(4), 394-403.
- [61] Santos, L. R., Rosati, A., Sproul, C., Spaulding, B. and Hauser, M. D. (2005). Means-means-end tool-use in cotton-top tamarins (*Saguinusoeidipus*): finding the limits on primates' knowledge of tools. *Animal Cognition*, 8(4), 236-246.
- [62] Sterling, E. J. and Povinelli D. (1999). Tool use, aye-ayes, and sensorimotor intelligence. *Folia Primatologica*, 70(1), 8-16.
- [63] Taylor, A. H., Hunt, G. R., Holzhaider, J. C. and Gray, R. D. (2007). Spontaneous meta tool use by new Caledonian crows. *Current Biology*, 17(17), 1504-1507.
- [64] McGrew, W. C., Tutin, C. E. G. and Baldwin, P. J. (1979). Chimpanzees, tools, and termites: cross-cultural comparisons of Senegal, Tanzania, and Rio Muni. *Man*, 14(2), 185-214.
- [65] Tooby, J. and DeVore I. (1987). The reconstruction of hominid behavioral evolution through strategic modeling. In: W. G. Kinzey(Editor), *The Evolution of Human Behavior: Primate Models* (pp. 183-238). Albany, NY, USA: SUNY Press.
- [66] Fay, J. M. and Carroll, R. W. (1994). Chimpanzee tool use for honey and termite extraction in Central Africa. *American Journal of Primatology*, 34(4), 309-317.
- [67] Ottoni, E. B. and Izar, P. (2008). Capuchin monkey tool use: overview and implications. *Evolutionary Anthropology*, 17(4), 171-178.
- [68] Hihara, S., Obayashi, S., Tanaka, M. and Iriki, A. (2003). Rapid learning of sequential tool use by macaque monkeys. *Physiology & Behavior*, 78(3), 427-434.
- [69] Sabbatini, G., Manrique, H. M., Trapanese, C., Vizioli, A. D. B., Call, J. and Visalberghi, E. (2014). Sequential use of rigid and pliable tools in tufted capuchin monkeys (*Sapajus* spp.), *Animal Behaviour*, 87(1), 213-220.
- [70] Binkofski, F., Buccino, G., Posse, S., Seitz, R. J., Rizzolatti, G. and Freund, H.J. (1999). A frontoparietal circuit for object manipulation in man: evidence from an fMRI-study. *European Journal of Neuroscience*, 11(9), 3276-3286.
- [71] Grèzes, J., Armony, J. L., Rowe, J. and Passingham, R. E. (2003). Activations related to "mirror" and "canonical" neurones in the human brain: an fMRI study. *NeuroImage*, 18(4), 928-937.
- [72] Peeters, R., Rizzolatti, G. and Orban, G. A. (2013). Functional properties of the left parietal tool use region. *NeuroImage*, 78(1), 83-93.
- [73] Peeters, R., Simone, L., Nelissen, K., Fabbri-Destro, M., Vanduffel, W., Rizzolatti, G. and Orban, G. A. (2009). The representation of tool use in humans and monkeys: common and uniquely human features. *Journal of Neuroscience*, 29(37), 11523-11539.
- [74] Selemon, L. D. and Goldman-Rakic, P. S. (1985). Longitudinal topography and interdigitation of corticostriatal projections in the Rhesus monkey. *Journal of Neuroscience*, 5(3), 776-794.
- [75] Miller, E. K. and Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, 24(1), 167-202.
- [76] Fuster, J. M. and Alexander, G. E. (1971). Neuron activity related to short-term memory. *Science*, 173(3997), 652-654.
- [77] Funahashi, S., Bruce, C. J. and Goldman-Rakic, P. S. (1989). Mnemonic coding of visual space in the

- monkey's dorsolateral prefrontal cortex. *Journal of Neurophysiology*, 61(2), 331-349.
- [78] Kim, J. N. and Shadlen, M. N. (1999). Neural correlates of a decision in the dorsolateral prefrontal cortex of the macaque. *Nature Neuroscience*, 2(2), 176-185.
- [79] Barraclough, D. J., Conroy, M. L. and Lee, D. (2004). Prefrontal cortex and decision making in a mixed-strategy game. *Nature Neuroscience*, 7(4), 404-410.
- [80] White, I. M. and Wise, S. P. (1999). Rule-dependent neuronal activity in the prefrontal cortex. *Experimental Brain Research*, 126(3), 315-335.
- [81] Wallis, J. D., Anderson, K. C. and Miller, E. K. (2001). Single neurons in prefrontal cortex encode abstract rules. *Nature*, 411(6840), 953-956.
- [82] Leon, M. I. and Shadlen, M. N. (1999). Effect of expected reward magnitude on the response of neurons in the dorsolateral prefrontal cortex of the macaque. *Neuron*, 24(2), 415-425.
- [83] Asaad, W. F., Rainer, G. and Miller, E. K. (2000). Task-specific neural activity in the primate prefrontal cortex. *Journal of Neurophysiology*, 84(1), 451-459.
- [84] Freedman, D. J., Riesenhuber, M., Poggio, T. and Miller, E. K. (2001). Categorical representation of visual stimuli in the primate prefrontal cortex. *Science*, 291(5502), 312-316.
- [85] Shima, K., Isoda, M., Mushiake, H. and Tanji, J. (2007). Categorization of behavioural sequences in the prefrontal cortex. *Nature*, 445(1), 315-318.
- [86] Nieder, A., Freedman, D. J. and Miller, E. K. (2002). Representation of the quantity of visual items in the primate prefrontal cortex. *Science*, 297(1), 1708-1711.
- [87] Averbeck, B. B., Chafee, M. V., Crowe, D. A. and Georgopoulos, A. P. (2002). Parallel processing of serial movements in prefrontal cortex. *Proceedings of the National Academy of Sciences*, 99(20), 13172-13177.
- [88] Hoshi, E. and Tanji, J. (2004). Area-selective neuronal activity in the dorsolateral prefrontal cortex for information retrieval and action planning. *Journal of Neurophysiology*, 91(6), 2707-2722.
- [89] Inoue, M. and Mikami, A. (2006). Prefrontal activity during serial probe reproduction task: encoding, mnemonic, and retrieval processes. *Journal of Neurophysiology*, 95(2), 1008-1041.
- [90] Berdyeva, T. K. and Olson, C. R. (2010). Rank signals in four areas of macaque frontal cortex during selection of actions and objects in serial order. *Journal of Neurophysiology*, 104(1), 141-159.
- [91] Rezaei, K., Andreasen, N. C., Alliger, R., Cohen, G., Swayze II, V. and O'Leary, D. S. (1993). The neuropsychology of the prefrontal cortex. *Archives of Neurology*, 50(6), 636-642.
- [92] Rushworth, M. F. S., Ellison, A. and Walsh, V. (2001). Complementary localization and lateralization of orienting and motor attention. *Nature Neuroscience*, 4(1), 656-661.
- [93] Andersen, R. A. and Buneo, C. A. (2002). Intentional maps in posterior parietal cortex. *Annual Review of Neuroscience*, 25(1), 189-220.
- [94] Gold, J. I. and Shadlen, M. N. (2007). The neural basis of decision making. *Annual Review of Neuroscience*, 30(1), 535-574.
- [95] Desmurget, M., Reilly, K. T., Richard, N., Szathmari, A., Mottolese, C. and Sirigu, A. (2009). Movement intention after parietal cortex stimulation in humans. *Science*, 324(5928), 811-8113.
- [96] Gnadt, J. W. and Andersen, R. A. (1988). Memory related motor planning activity in posterior parietal cortex of macaque. *Experimental Brain Research*, 70(1), 216-220.
- [97] Quintana, J. and Fuster, J. M. (1992). Mnemonic and predictive functions of cortical neurons in a memory task. *Neuroreport*, 3(8), 721-724.
- [98] Constantinidis, C. and Steinmetz, M. A. (1996). Neuronal activity in posterior parietal area 7a during the delay periods of a spatial memory task. *Journal of Neurophysiology*, 76(2), 1352-1355.
- [99] Chafee, M. V. and Goldman-Rakic, P. S. (1998). Matching patterns of activity in primate prefrontal area 8a and parietal area 7ip neurons during a spatial working memory task. *Journal of Neurophysiology*, 79(6), 2919-2940.
- [100] Shadlen, M. N. and Newsome, W. T. (1996). Motion perception: seeing and deciding. *Proceedings of the National Academy of Sciences U S A*, 93(2), 628-633.
- [101] Yang, T. and Shadlen, M. N. (2007). Probabilistic reasoning by neurons. *Nature*, 447(1), 1075-1080.
- [102] Crowe, D. A., Averbeck, B. B., Chafee, M. V. and Georgopoulos, A. P. (2005). Dynamics of parietal neural activity during spatial cognitive processing. *Neuron*, 47(6), 885-891.
- [103] Platt, M. L. and Glimcher, P. W. (1999). Neural correlates of decision variables in parietal cortex. *Nature*, 400, 233-238.
- [104] Sugrue, L. P., Corrado, G. S. and Newsome, W. T. (2004). Matching behavior and the representation of value in the parietal cortex. *Science*, 304(5678), 1782-1787.
- [105] Stoet, G. and Snyder, L. H. (2004). Single neurons in posterior parietal cortex of monkeys encode cognitive set. *Neuron*, 42(6), 1003-1012.
- [106] Freedman, D. J. and Assad, J. A. (2006). Experience-dependent representation of visual categories in parietal cortex. *Nature*, 443, 85-88.
- [107] Swaminathan, S. K. and Freedman, D. J. (2012). Preferential encoding of visual categories in parietal cortex compared with prefrontal cortex. *Nature Neuroscience*, 15(1), 315-320.
- [108] Fitzgerald, J. K., Freedman, D. J. and Assad, J. A. (2011). Generalized associative representations in parietal cortex. *Nature Neuroscience*, 14(1), 1075-1079.
- [109] Nieder, A. and Miller, E. K. (2004). A parieto-frontal network for visual numerical information in the monkey. *Proceedings of the National Academy of Sciences U S A*, 101(19), 7457-7462.
- [110] Roitman, J. D., Brannon, E. M., Andrews, J. R. and Platt, M. L. (2007). Nonverbal representation of time and number in adults. *Acta Psychologica*, 124(3), 296-318.
- [111] Ptak, R. (2012). The frontoparietal attention network of the human brain: action, saliency, and a priority map of the environment. *Neuroscientist*, 18(5), 502-515.

- [112] Pardo, J. V., Fox, P. T. and Raichle, M. E. (1991). Localization of a human system for sustained attention by positron emission tomography. *Nature*, 349(6304), 61-64.
- [113] Panger, M. A. (2007). Tool use and cognition in primates. In: C. J. Campbell, A. Fuentes, K. MacKinnon, M. Panger and S. K. Bearder (Editors.), *Primates in Perspective* (pp. 665-667). Oxford, U.K.: Oxford University Press.
- [114] Povinelli, D. J. (2000). *Folk Physics for Apes: the Chimpanzee's Theory of How the World Works*. Oxford, U.K.: Oxford University Press.
- [115] Jerison, H. J. (1973). *Evolution of the brain and intelligence*. New York: Academic Press.
- [116] Kudo, H. and Dunbar, R. I. M. (2001). Neocortex size and social network size in primates. *Animal Behaviour*, 62(4), 711-722.
- [117] Stephan, H., Baron, G. and Frahm, H. D. (1988). Comparative size of brains and brain components. In: H. D. Steklis and J. Erwin (Editors), *Comparative Primate Biology. Vol. 4. Neurosciences* (pp. 1-38). New York: Alan R. Liss.
- [118] Barrett, L., Henzi, P. and Dunbar, R. (2003). Primate cognition: from 'what now?' to 'what if?' *Trends in Cognitive Sciences*, 7(11), 94-497.
- [119] Deaner, R. O., van Schaik, C. P. and Johnson, V. (2006). Do some taxa have better domain-general cognition than others? A meta-analysis of non-human primate studies. *Evolutionary Psychology*, 4(1), 149-196.
- [120] Cruz-Aguilar, M. A., Ramírez-Salado, I., Arenas-Rosas, R. V., Santillán-Doherty, A. M. and Muñoz-Delgado, J. I. (2009). Sleep characterization of a one-month-old freely moving stump-tail macaque (*Macaca arctoides*): a pilot study. *Journal of Medical Primatology*, 38(5), 371-376.
- [121] Cruz-Aguilar, M. A., Ayala-Guerrero, F., Jiménez-Anguiano, A., Santillán-Doherty, A. M., García-Orduña, F. and Velázquez-Moctezuma, J. (2015). A sleep in the spider monkey (*Ateles geoffroyi*): a semi-restrictive, non-invasive, polysomnographic study. *American Journal of Primatology*, 77(2), 200-210.
- [122] Thatcher, R. W., Krause, P. J. and Hrybyk, M. (1986). Cortico-cortical associations and EEG coherence: a two compartmental model. *Electroencephalography and Clinical Neurophysiology*, 64(2), 123-143.
- [123] Mesulam, M. M. (1990). Large-scale neurocognitive networks and distributed processing for attention, language, and memory. *Annals of Neurology*, 28(5), 597-613.
- FuenteMuñiz, CDMX, Mexico. Manuel Cruz is primatologist and specialist in sleep neuroscience. Develops research related to executive functions in New World Monkeys. Likewise, develops research related phylogeny, neurophysiology, pharmacology and psychophysiology of sleep.



Miguel Angel Guevara, PhD in Physiological Sciences by the Center of Neurobiology of the National Autonomous University of Mexico. Dr. Guevara is responsible for the Laboratory of Electroencephalographic Correlation and Behaviour of the Institute of Neurosciences at the University of Guadalajara, Mexico. Dr. Guevara develops specialized methods and techniques for EEG analysis. It also studies the participation of the prefrontal cortex in cognitive and motivated processes. He has published both national and international articles and chapters in various research books, as well as several computer programs designed for the capture and analysis of electroencephalographic signals and computerized application of tasks that evaluate cognitive processes.



Marisela Hernández-González, PhD in Physiological Sciences by the Neurobiology Center of the National Autonomous University of México. Postdoctoral fellowship at the Peripheral Unit of the Biomedical Research Institute, National Autonomous University of México, and at the Faculty of Psychology of the University of Tromsø, Norway. Marisela Hernández-González is responsible of Neurophysiology of Reproductive Behavior Laboratory at the Institute of Neurosciences, University of Guadalajara, México. Her line of research focuses on the neural basis of execution and motivation both sexual and maternal. Using the electroencephalographic technique as the main tool, she has performed multiple works in both humans and rats that have been published internationally.



Ignacio Ramirez Salado, Bachelor's Degree, University by Universidad Nacional Autónoma de México, Faculty Psychology. B.Sc. in Psychology. Master in Sciences by University Pablo de Olavide and the College of America, Center for Advanced Studies for Latin America and the Caribbean, Master in Sciences in Physiology and Sleep Medicine. Doctorate, Universidad Autónoma Metropolitana, Ph.D. Appointment, Tenured Researcher in Medical Sciences, Head of the Chronobiology and Sleep Laboratory, Neuroscience Division, National Institute of Psychiatry Ramón de la Fuente Muñiz, CDMX, Mexico. Research Interests: Sleep Medicine, Sleep disorders, Parasomnia, Dementia, Alzheimer's disease, Epilepsy, Metabolic syndrome and sleep, Sleep and Cognition.



Francisco García-Orduña, Biologist and Master in Neuroethology at the Universidad Veracruzana, México. He is currently director of the Institute of Neuroethology at this university. Master Gracia-Orduña conducts studies on endocrinology and health, dietary behavior, cognition, genetics and conservation in non-human primates.

Author Profile



Manuel Alejandro Cruz-Aguilar (corresponding author) Psychologist by Universidad Autónoma del estado de México. Doctorate in Biológicas Sciences by Universidad Autónoma Metropolitana, Unidad Iztapalapa. Postdoctoral fellowship from CONACYT / Instituto de Neurociencias, Universidad de Guadalajara. Appointment, Tenured Researcher in Medical Sciences into the Chronobiology and Sleep Laboratory, Neuroscience Division, National Institute of Psychiatry Ramón de la