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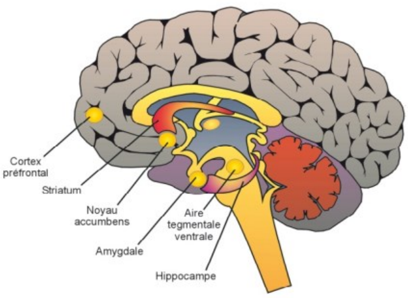
PARLIAMENTARY OFFICE FOR SCIENTIFIC AND TECHNOLOGICAL ASSESSMENT

Briefing 20 — November 2019

Neuroscience and Juvenile Responsibility



Source: INSERM. Addictive behaviour in adolescents. Practices, prevention and support. "Expertise collective" series, INSERM, 2014

Summary

- *Over the past thirty years, the field of neuroscience has added real scientific content[1] to the notion of immaturity of minors, which justifies their autonomous status under criminal law.*
- *During adolescence, a major structural and functional reorganization of the human brain takes place, simultaneously accompanied by profound cognitive, psychological and behavioural transformations. Only at the end of this process will young individuals possess the capacity for discernment and control of their actions that enables them to be considered fully responsible from a criminal law perspective.*
- *Despite this contribution to the thinking on juvenile justice, neuroscience stops short of enabling us to scientifically define an age of criminal responsibility. Moreover, to date, brain imaging techniques alone are not a reliable tool for forensic expertise.*

Mr Michel Amiel, Senator

Specialised justice for juveniles seeking to build on scientific foundations

The word "juvenile" is used here in reference to the Order of 2 February 1945, which relates to juvenile delinquency. This founding text defines childhood, from a criminal law perspective, as the period of life that ends with the minority[2] and during which the law excludes the application of general criminal law in favour of specific treatment in criminal matters. In France, this treatment conforms to two rules, which the Constitutional Council has defined and enshrined as constitutional principle:[3]

- the first is that the criminal responsibility of children should be mitigated due to their age. This is referred to as the "*excuse de minorité*" (mitigating circumstance of minority);[4]

- the second dictates that the penalties imposed in response to the offences committed by minors should be handed down by specialised courts, or according to adapted procedures,[5] and that such measures should, as far as possible, be focused on their educational and moral rehabilitation.[6]

Although long-established, the institution by law of a specialised justice system for juveniles has long dispensed with scientific justification and been primarily based on common sense, i.e. on the collective belief – supported by observations that can be made by any adult – that the capacities for discernment and self-control required in order to answer for one's actions before a court of law can only be fully acquired with age. Indeed, it is the immaturity of children – the fact that they are developing people – that is the doctrinal justification for assessing and adjusting criminal responsibility according to their degree of maturity.

This briefing therefore aims firstly to establish whether the progress made in neuroscience over the last thirty years has changed our understanding of this notion of immaturity, and secondly, to consider what this implies for the organisation and functioning of the juvenile justice system.

A structural and functional reorganization of the brain occurs during adolescence

Advances in non-invasive brain observation techniques[7] have confirmed that the adolescent brain is not a "miniature" adult brain, and has marked anatomical and functional specificities.[8] From puberty and until the third decade of life, under the complex and as yet poorly understood effects of endogenous biological mechanisms and interactions with the social environment, the following phenomena occur:

- a massive destruction of synapses within the different cerebral areas, leading to a significant reduction in the volume of grey matter.[9] This synaptic pruning[10] does not occur synchronously in the different parts of the brain. The prefrontal cortex region,[11] which is closely related to the performance of executive cognitive functions,[12] matures more slowly than the limbic system,[13] which is involved in emotional states such as fear, aggression, stress, pleasure and desire;

- a significant increase in white matter, and therefore of structural connectivity between areas of the brain. Diffusion tensor imaging,[14] which allows for the visualisation of the structure of myelinated axon bundles, reveals the profound transformation of this

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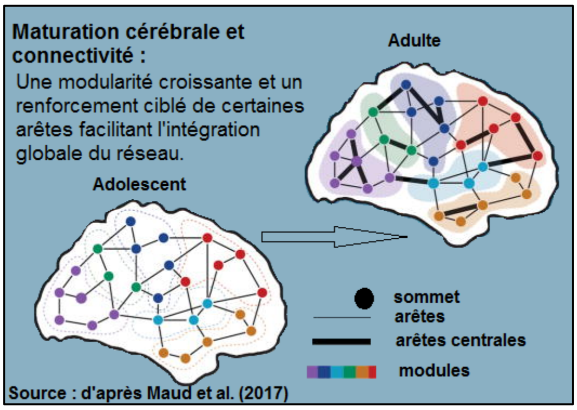
structure during adolescence, particularly due to the development of fibres connecting the cortex to the thalamus, the lenticular nucleus and the caudate nucleus. Analysis of functional neuroimaging data using graph theory confirms that this process results in a significant improvements in the synergistic functioning of brain areas. In adults, the activation correlation between distant parts of the brain is significantly higher than in adolescents, particularly when performing executive tasks: adults therefore simultaneously mobilise relatively dispersed areas of the brain, whereas adolescents mobilise much more localised brain circuits.



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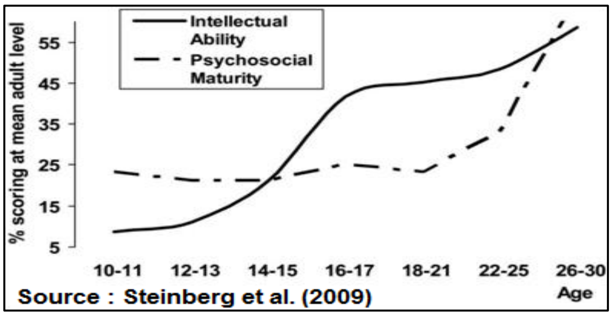
Brain maturation is accompanied by strong cognitive and psychosocial development

Concomitantly with the neurobiological maturation of the brain, profound cognitive, psychological, relational and behavioural changes also occur during adolescence. In particular, it can be observed that:[16]

- the cognitive abilities involved in logical reasoning develop strongly from the age of 11, on average, and reach similar levels to those observed in adults by 15-16 years of age. At this age, most individuals are capable of abstract reasoning, of evaluating the meaning and consequences of actions, and ultimately, of making decisions in the same way as adults, at least in the absence of emotional stress and peer pressure;

- the capacities that define psychosocial maturity improve significantly from the age of 14-15 onwards and continue to develop after adolescence and into the thirties. The evaluation of this psychosocial maturity by psychological testing takes account of attitudes towards risk,[17] the tendency to seek thrills, impulsiveness, resistance to peer pressure and the ability to integrate long-term considerations into decision-making. It is found that, in these different domains, young subjects do not attain the median performance level of adults until they are around 22-23 years of age. Therefore, significant differences in the ability to exercise self-control are observed between adolescents and young adults, and more mature adults.[18]



Brain maturation and adolescent behaviour: links that need to be better understood

Brain maturation and the psycho-cognitive and behavioural changes that occur from puberty onwards are, in all likelihood, closely related. Understanding their interactions has currently become one of the major focuses of research in cognitive neuroscience, which uses functional brain imaging techniques to observe the changes that occur in the brain when people are performing a given task. This makes it possible to establish ever-more precise and systematic correlations between what happens *inside* the brain (particularly in terms of the activation of brain areas) and emotional states, cognitive processes and behaviours.[19]

The hypothesis favoured by neuroscientists to explain the specificities of adolescent actions – including increased sensitivity to immediate rewards and peer pressure, greater involvement in risky activities, and less ability to control impulses and emotions – is that "the *immaturity of the cortical structures involved in high-level decision-making processes, located primarily within the prefrontal cortex, causes them to be excessively influenced by the limbic system, and by the reward*[20] *and punishment systems.*[21] This time lag between the maturation of the emotional centres and that of the higher control systems, is likened to "*starting the engine without a skilled worker*".[22]

Although it is not yet possible to describe the mechanisms in operation in a precise and exhaustive manner, cognitive neuroscience tends to confirm this hypothesis of a link between cerebral maturation and the particularities of adolescent behaviour:

- in adolescents, the brain areas involved in emotional responses to emotionally charged experiences are relatively more highly activated than in adults. This over-activation is particularly apparent in the amygdala, which is known to be involved in fear, anger and stress reactions. This finding is consistent with the behavioural tendency of adolescents – proven by psychological tests – to act more impulsively than adults; it is also consistent with observations pointing towards the relative precocity of synaptic pruning in the limbic system;[23]

- with regard to the reward system and the underlying dopaminergic circuits, neuroimaging studies show hyper-reactivity of the striatum during adolescence during the performance of tasks related to the evaluation of the benefit/cost/risk ratios of actions. In addition, it is now known that levels of dopamine availability, as well as dopamine receptor density, are higher in the brain during adolescence. This observation is consistent with behavioural data proving that adolescents show relatively more interest than adults in short-term prospects of reward and thrill-seeking experiences;

- finally, structural imaging studies show that the connections between the prefrontal cortex and the emotional brain, especially the striatum, are the last ones to be established. Their integration between the subcortical nuclei, where emotional reactions are initiated, and the prefrontal centres involved in inhibition and control processes thus remains incomplete until early adulthood. This is consistent with the fact that adolescents are less successful than adults in performing executive tasks in emotionally charged situations. This is also consistent with functional neuroimaging observations which show that the connections between distant parts of the brain function more synergistically in adults than in children.

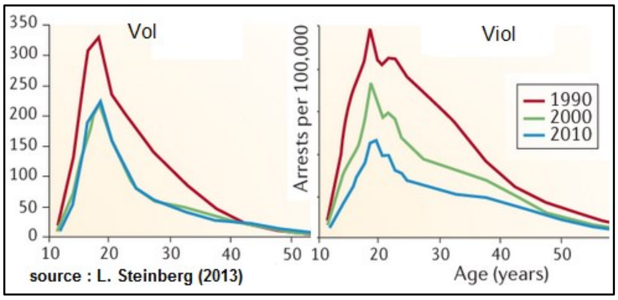
The founding principles of juvenile justice are supported by neuroscience

Improvements in the knowledge of the adolescent brain over the past 30 years have helped shed light on several aspects of the public debate on juvenile justice, without, at this stage, changing the terms of this debate.[24] Firstly, neuroscience confirms that discernment and control of actions, which are two prerequisites for criminal responsibility,[25] are clearly linked to faculties that are only acquired after a long process of neurobiological maturation and psycho-cognitive development. Presuming that a child or an adolescent possesses these faculties in the same way as an adult contradicts the findings revealed by developmental neuroscience,[26] which, therefore, endorses the principle of the criminal law system for minors being separate from general criminal law system.

Neuroscience also sheds light on the legal notions of discernment and control of actions. On the neurobiological and cognitive levels, these two notions refer to different aptitudes, which are based on distinct neuronal circuits and develop at specific rates. When not acting in the "heat of the moment", an adolescent may be able to discern the consequences of his or her actions, but this same adolescent may be unable to adopt an appropriate attitude in a real-life situation in which he or she is influenced by peers or strong emotions. This confirms the value of maintaining two pivotal ages in juvenile justice: the age of criminal responsibility, which corresponds to the age of access to discernment, and a later age corresponding to the maturity of the control functions, which marks the end of the period during which the mitigating circumstance of minority can be invoked.

A third important point concerns the assessment of danger and the risk of recidivism. Neuroscience dictates that the "normal" development process[27] for human beings during adolescence leads to a rapid increase in impulsive or transgressive behaviours, which, in the most unfavourable situations, can lead to delinquent behaviour during this period of life.[28] By the same token, the end of the period of adolescent upheavals also favours a return to behavioural patterns that are more rational from the adult point of view. These observations suggest that juvenile delinquency has a strong transitory component and that the dangerousness of juvenile offenders can be analysed, in many cases, not as an intrinsic characteristic of the individuals concerned, but as a momentary and reversible disruption of their behaviour.

This is consistent with statistical observations which show that the frequency of criminal misconduct and risky behaviour follows an inverted U-shaped curve, known as the "crime curve", which increases rapidly during adolescence, peaks around 18-20 years of ages, and then declines rapidly and sharply in adulthood. Thanks to neuroscience, we now have a better understanding of the reasons for this peak in criminal behaviour: it coincides exactly with the period of life in which executive control capacities are being established.



The transitional component of juvenile delinquency helps to legitimise the pre-eminence of measures for the education and protection of minors.[29] Indeed, while justice must punish and take steps to protect society, it must also prepare for the future by avoiding the tendency to define juvenile offenders in fixed terms that do not correspond to the reality of an ongoing maturation process and a relatively low risk of recidivism. Protecting and educating juvenile offenders is fully justified since the immaturity of their personality may explain their guilty behaviour and augurs well for their future development as they mature.[30]

These protective and educational measures are all the more necessary as neuroscientists have re-evaluated the importance of adolescence in brain and psycho-cognitive development. It is now known that not everything is determined at the foetal stage and in early childhood. Adolescence is another key period in the construction of the intellect and personality. Therefore, the judicial response to juvenile delinquency cannot ignore the implications of this extreme plasticity of the adolescent brain and psyche. Creating a supportive emotional, social and cultural environment is particularly important during this crucial phase of life when the future adult is still in the making.[31] Consequently, placing juvenile offenders in a closed prison environment, where their personal development will be shaped exclusively by contact with other offenders, creates conditions that are likely to make them more hardened offenders. Likewise, failing to remove juveniles from the influence of deleterious emotional, family or social environments that push them towards delinquency is tantamount to consigning them to a delinquent fate. Arguments founded on neuroscientific evidence can now be used to defend these ideas.

A final contribution of neuroscience to the thinking on juvenile justice concerns the status of young adults under criminal law. Insofar as the neurobiological maturation of the circuits involved in executive functions continues to develop well beyond the age of majority, the application of certain juvenile justice provisions[32] to young adults may be appropriate, in order to avoid an overly abrupt transition to the adult criminal justice system at the age of 18. Young adult offenders whose brain maturation and psychological development are incomplete may indeed need a little more time to complete their personal development under more favourable conditions.

"Neurolaw" remains a pipe dream given the current state of scientific knowledge

Beyond confirming these general principles, neuroscience does not enable the formulation of precise recommendations on a central issue for juvenile justice, i.e. the definition of threshold ages. At what age should the acquisition of discernment be presumed, and at what age should the age of criminal responsibility be set? Up to what age should it be presumed that there is a diminished capacity for control that could justify invoking the mitigating circumstance of minority? At present, neuroscience cannot be relied upon to answer these questions. The high interindividual variability[33] of brain, cognitive and psychological maturation processes, reflecting both the native specificities of each individual but also – and just as crucially – the differences in the affective, cultural and social contexts in which people interact and develop, mean that it is impossible to describe a single pathway or period of maturation, and therefore to define universally applicable threshold ages.[34] This does not mean that setting a legal age of criminal responsibility is unjustified, simply that it is a matter of political responsibility rather than science.

Finally, the limitations, and even the risks, of using neuroscience as a tool for judicial expertise, whether to establish a person's responsibility or to assess his or her dangerousness,[35] must be stressed. Neuroscience can indeed describe the functioning of the human brain, but only after the statistical processing of numerous individual observations.[36] Although useful in the context of medical and scientific research, these results are probabilistic and therefore not relevant for helping the justice system to judge or anticipate individual behaviours.[37] Particular attention should be drawn to the lack of a neuroscientific basis for a reliable assessment of dangerousness that could justifiably be used to "screen" high-risk individuals before they commit an offence. The use of neuroscience for this purpose would constitute a misuse that would pose serious threats to individual freedoms and the rule of law.[38]

The Office's websites:

http://www.assemblee-nationale.fr/commissions/opecst-index.asp

http://www.senat.fr/opecst/

References

[1] Neuroscience has potentially beneficial applications in numerous aspects of everyday life – including education. However, this briefing focuses solely on the implications of neuroscientific advances in the field of criminal law, and more specifically, in criminal law applicable to juveniles. Certainly, other important issues could be addressed in a similar briefing by the Parliamentary Office for Scientific and Technological Assessment, including the question of the links between neuroscience and education.

[2] According to Article 388 of the French Civil Code, "A minor is an individual of either sex who has not yet reached the full age of eighteen years."

[3] Principle laid down by the Constitutional Council in its ruling no. 2002-461 DC of 29 August 2002. The Council ruled that, from the Act of 12 April 1906 on the age of criminal responsibility to the 1945 Order on juvenile delinquency and the Act of 22 July 1912 on juvenile courts, the laws of the French Republic have consistently recognised these two rules, which justifies their enshrinement as a constitutional principle.

[4] The *excuse de minorité* (mitigating circumstance of minority) allows for the reduction of penalties imposed on minors who are found criminally responsible but at the same time remain too immature to merit the severe penalties applicable to adults. In France, the *excuse de minorité* can halve the penalties that would be incurred by adults. It may be waived on an exceptional basis and with sufficient justification for minors who have turned 16 years of age. The idea that criminal responsibility should be assessed and adjusted according to age is found in most European legal systems. This is also a very old idea, since even under Roman law, age was a normal or natural cause of irresponsibility, which decreased with age according to three categories:
- *infance*, up to 7 years of age;
- *infanciae proximus*, a state close to childhood but far from puberty;
- *puberti proximus*, ending at 14 years for boys and 12 for girls.

The system of irresponsibility differed according to the category to which the young offender belonged. This shows that even in ancient times, there was a desire to interpret responsibility according to people's age and degree of maturity.

[5] The judge sitting in juvenile courts (*juge des enfants*) is one of the specific institutions responsible for juvenile justice in France. These judges are the cornerstone of the system, as they have jurisdiction in both civil and criminal matters and have the power to initiate proceedings, to investigate and try cases, and to monitor the application of their rulings, which is a unique situation in French law.

[6] The juvenile justice system thus establishes the pre-eminence of education over repression and introduces specific educational monitoring – supervised education (*éducation surveillée*) – which has become the judicial protection system for young people.

[7] Among these observation techniques, it is relevant to distinguish between structural and functional imaging techniques:
- structural (or anatomical) brain imaging techniques include X-ray absorption tomography, which uses several X-ray images taken from different angles to create an image of the brain, and magnetic resonance imaging (MRI), which creates images by exploiting the "echo" produced by the hydrogen atoms in the body when they return to their initial state after being "excited" by a strong magnetic field. MRI, introduced in the late 1970s, provides a much finer spatial resolution than X-ray absorption tomography but both of these techniques enable the detection of lesions, including tumours;
- functional brain imaging techniques are used to assess brain activity. Of course, they do not enable the observation of thoughts themselves, simply certain physiological changes that occur during brain activity. The oldest of these techniques is electroencephalography (EEG), which records the electrical activity of the brain (with a very high degree of temporal accuracy but low spatial definition). Positron emission tomography (PET) detects the changes in cerebral blood flow that occur when a group of neurons is activated. This is accompanied by a dilatation of cerebral blood capillaries in order to provide more blood, and therefore more oxygen, which facilitates neuronal activity. Changes in blood flow can be measured by detecting the positrons emitted by radioactive water or glucose previously injected into the subject under observation. Finally, functional magnetic resonance imaging (fMRI) is based on the same physiological phenomenon as positron emission tomography (dilatation of blood vessels in active brain regions) but it does so by exploiting another signal – in this case local variations in the concentration of deoxy-haemoglobin (oxygen-depleted haemoglobin). High concentrations of deoxy-haemoglobin (detected by disturbances in the magnetic field generated by this molecule) indicate that a significant intake of blood oxygen has taken place, which is an indirect indicator of a local increase in brain activity.

While advances in brain imaging have played a major role in the development of neuroscience over the past 30 years, it should nevertheless be noted that neuroscience also relies on invasive biological techniques and the study of laboratory animals or cultured cells. For example, axonal guidance – the process that allows a neuron to extend its reach to another, distant area of the brain – is studied in cultured neurons.

[8] For this reason, adolescence can no longer be considered as a purely sociological construction, nor can it be reduced to a series of pubertal somatic transformations. There is indeed a neurobiological dimension to adolescent phenomena. It should also be emphasised that in recent years, the field of neuroscience, taking account of the fact that the brain undergoes

highly differentiated phases of development, has tended to become increasingly specialised according to age. The adolescent brain or the juvenile brain have thus become separate fields of research with their own experts and specialised literature.

[9] In the nervous system, a distinction is made between grey matter and white matter. The former is composed of neuronal cell bodies, dendrites and non-myelinated axons. The latter is primarily composed of myelinated axons – myelin is a kind of sheath surrounding the axons and accelerating the transmission of nerve impulses. Within the central nervous system, grey matter is mainly located in the central nervous system, the cortex and the central grey nuclei. White matter occupies the rest of the brain space: it connects the different areas and nuclei that make up the grey matter and ensures the flows of information between the brain centres.

[10] The detailed functioning of the mechanisms that control synaptic pruning is not yet fully understood, but we do know that this is not a random process. It has a selective and adaptive dimension: the most frequently used synaptic connections are retained, while those that are seldom or never used are eliminated. This pruning leads to a localised simplification of the synaptic organizational structure, with gains in the efficiency of brain function. It should be stressed that dysfunctions in the synaptic pruning process are now suspected of playing a major role in the appearance of certain neurodevelopmental problems, such as autism or epilepsy (deficient pruning), and schizophrenia (excessive pruning).

[11] The cerebral cortex consists of convolutions (or gyri) separated by deep grooves (or fissures) and superficial grooves (or furrows). In each hemisphere, certain deeper grooves divide the cortical surface into lobes: the frontal lobe at the front, the parietal lobe above and slightly behind, the occipital lobe at the back, the temporal lobe at the sides and the insular lobe partially overlapped by the temporal, parietal and frontal lobes. The prefrontal cortex is part of the frontal cortex. This is a vast region that includes the dorsolateral prefrontal cortex, the ventrolateral prefrontal cortex and the orbitofrontal prefrontal cortex. It plays a central role in all complex cognitive functions, and especially in executive functions. Through its links with the limbic brain and the reward circuit, it intervenes in the conscious control of emotional reactions and behaviours related to pleasure and desire.

[12] The cognitive functions that psychologists describe as “executive” are those that help define appropriate behaviour in situations in which routine responses are inappropriate. They are therefore essential for regulating behaviour in complex or new contexts. The main executive functionalities identified by psychologists are mental flexibility (switching), i.e. the ability to change tasks or move from one cognitive operation to another, planning or the ability to organise a sequence of actions over time, and finally, the control and regulation of action, which includes both an updating capacity, i.e. the ability to integrate new information in order to update the short-term memory, and an inhibition capacity, which includes mechanisms for eliminating spontaneous cognitions and reactions, as well as the ability to resist interference caused by irrelevant information.

[13] The limbic system incorporates several cortical and sub-cortical structures including parts of the hypothalamus, thalamus, hippocampus and amygdala. It intervenes in the dynamics and control of emotional behaviour (pleasure, fear, aggression). Some of its structures (amygdala, hippocampus and insular cortex) also participate in the pleasure circuit (see note 20 below). It is often referred to as the emotional brain, even though we now know that emotions, like thoughts, are not confined to a precise location in the brain. It also plays a major role in learning and memory.

[14] This technique uses magnetic resonance imaging (MRI), which enables the direction of the diffusion of water molecules to be observed. Since this diffusion is constrained by the surrounding tissue, the images obtained show the position and orientation of fibrous structures, particularly the bundles of white matter in the brain. Diffusion tensor imaging therefore provides an accurate map of the axon networks in the brain and reveals how these networks are reconfigured during brain development in adolescence.

[15] A glossary of concepts used to describe structural and functional brain connectivity is provided by Van den Heuvel and Sporns (2013) – see bibliography below. A module is a group of vertices in the network that are densely interconnected and possess a relatively small number of connections to vertices outside their module.

[16] This is not neuroscience in the strict sense of the term, but rather experimental psychology describing the cognitive, psychological and behavioural transformations that occur during adolescence. It should be noted that these transformations can also be described, along with other concepts, by performing psychoanalysis on adolescents, which underlines that adolescent behaviour is characterised by the primacy of the sexual drive and the quest for identification with peers, which is reflected in behavioural traits such as the need to resolve dilemmas immediately, gregarious tendencies, impulsivity, the desire to act, greater risk-taking than in adults, and emotional control that is more frequently marked either by excessive inhibition or, on the contrary, by insufficient inhibition leading to violence.

[17] Risk assessment and risk awareness are two concepts that must be clearly distinguished. Adolescents relate to risks differently than adults not because they are unaware of the risks associated with a particular action, but because they assess them differently. Numerous experiments with 15 to 16-year-old adolescents have indeed shown that young people’s “intellectual” awareness of risks is similar to that observed in adults. They are equally aware of the probable consequences

of their choices. However, this does not prevent them from frequently making decisions that are aberrant from the perspective of adult rationality. Indeed, two phenomena alter their relationship to risk. Firstly, it is observed that the presence or perceptions of peers causes adolescents to increase their risk-taking very substantially. In their minds, the consequences in terms of self-image and reputation according to their peers are indeed considered much more important than among adults. For example, while teenagers or young adults are just as aware as older adults that getting into a vehicle driven by a drunk person is dangerous, they are more likely to get into such a vehicle than adults because the risk of having an accident is offset, in their minds, by the risk of damage to their image. Another determinant of adolescent attitudes towards risk is their stronger preference for the present. Although they are aware of medium or long-term risks, they consider them less important that the benefits expected in the here and now.

[18] To a large extent, the behavioural sciences confirm that commonly held conceptions of adolescent behaviour are not completely devoid of empirical bases.

[19] Cognitive neuroscience is a rapidly growing scientific discipline that bridges the gap between neuroscience as it is traditionally defined and the behavioural sciences. For many years, the brain and cognition have remained relatively distinct fields of study: at its essence, neuroscience – a discipline derived from medicine and biology – initially focused on the anatomy and functioning of the brain, but had little contact with the disciplines responsible for studying behaviour and representations, such as psychology or psychoanalysis, and vice versa. This can be explained by the lack of adequate observation tools to establish links between these two approaches. Of course, long before the advent of modern means of observing brain activity, clinical observations had proved the existence of links between the anatomical structure and the electro-biochemical functioning of the nervous system and ways of thinking, feeling and acting. For example, it has long been known that certain types of brain damage or the use of certain medication can affect mood, disinhibit impulses and lead to the adoption of aberrant, criminal or delinquent behaviour. One example is the famous case of Phineas Cage who, in 1848, developed frontal lobe syndrome following an accident in which his left temporal lobe was perforated by a crowbar. In addition, animal studies have long been used to explore the links between the brain and behaviour, although the generalised extension of experiments performed on animals to human beings cannot be envisaged, of course. The seminal research of Olds and Milner who, in 1954, discovered the reward circuit following experiments on rats in which electrodes had been implanted, is worthy of mention. However, starting in the 1990s, it was actually the spectacular development of non-invasive brain-observation techniques – especially functional neuroimaging – that ushered in the systematic study of the links between thoughts and actions and their neurobiological foundations, and the extension of this study from pathological to non-pathological situations. However, despite rapid scientific progress, the links between the brain and cognition are still poorly understood and there is no way to determine what people are thinking from their brain function. In particular, the psychological and cognitive maturation of adolescent subjects cannot be considered to be purely a consequence of the anatomical and functional maturation of their brains. The processes involved are already understood in sufficient detail to confirm that the transformations of the brain and psyche during adolescence are certainly dependent on biological variables, but also, and just as crucially, on the emotional, cultural and social environment and the interactions that take place within it. From the outset, this complex dialectic between biological and the social factors in the construction of the psyche totally undermines the scientific relevance of biological reductionism.

[20] The reward circuit is structured around the medial forebrain bundle (often shortened to MFB). This bundle of axons connects the ventral tegmental area (VTA), housing the cell bodies that generate these axons, to the nucleus accumbens (which together with the ventromedial parts of the caudate nucleus and the putamen forms the ventral striatum), and also to other cerebral structures such as the amygdala, septum or prefrontal cortex (see diagram on the first page of this briefing). This is a dopaminergic circuit, i.e. in which dopamine is used as a neurotransmitter. When activated, dopamine is released into these various structures, including the nucleus accumbens via the mesolimbic pathway and the prefrontal cortex via the mesocortical pathway.
The punishment circuit (periventricular system or PVS) is activated in response to unpleasant stimuli or the prospect of unpleasant situations. It involves the hypothalamus, thalamus and the central grey matter surrounding the Sylvius aqueduct, with secondary centres in the amygdala, the hippocampus, and the habenula. One of the neurotransmitters that enables it to function is acetylcholine. Its activation ultimately results in the stimulation of the adrenal gland which releases adrenaline to prepare for flight or fight reactions. Stimulation of the punishment circuit may inhibit the reward circuit.

[21] Jacques DAYAN, Bérengère GUILLERY-GIRARD, "C*onduites adolescentes et développement cérébral: psychanalyse et neurosciences*"; Adolescence, 2011, p. 480.

[22] "*Starting the engine without a skilled worker*". Cf. R. Dahl, "*Affect regulation, brain development and behavioral/emotional health in adolescence*", CNS Stectrum, 6, 2001.

[23] As can be seen, there is no direct demonstration in the form of a complete description of the mechanisms linking brain function and behaviour. It is the overall consistency of multiple observations, made on different levels, that reinforces the presumption of a link between early neurobiological maturation of the limbic system and the greater emotional reactivity of adolescents.

[24] As Laurence Steinberg, an American psychologist who specialises in adolescence, points out, the strength of neuroscience-based arguments stems less from the fact that they revolutionise our representations of adolescence than from the fact that their conclusions concur with the common knowledge and findings previously established by the behavioural sciences (cf. L. Steinberg, "The influence of neuroscience on US Supreme Court decisions about adolescents' criminal culpability", Nature Reviews/Neurosciences, vol.14, July, 2013).

[25] Pursuant to Article 122-1 of the French Criminal Code, the responsibility of "a person who, at the time he acted, was suffering from a psychological or neuropsychological disorder which reduced his discernment or impeded his ability to control his actions" should generally be excluded or mitigated. Article 122-8, which more specifically addresses the criminal responsibility of minors, only refers to the concept of discernment: "Minors capable of discernment are criminally responsible for the felonies, misdemeanours or petty offences of which they have been found guilty".

[26] Presuming means considering something to be probable. Statistically, the cerebral and psycho-cognitive immaturity of children and adolescents is now an established fact. However, this statistical truth does not prevent the existence of very strong interindividual differences in the development rates of the capacities for discernment and control. Some young people develop capacities for discernment and control approaching those of the average adult much sooner than others. Certain factors that help to explain this variability are starting to be clarified. It is now known that there is a lag in brain maturation between girls and boys during the peripubertal period, which has psychological and behavioural implications. Similarly, hormonal influences and the effects of addictive substances are major factors in the interindividual variability of brain maturation during adolescence.
In addition, a history of child abuse, which epidemiology has shown to be more common in adolescent and adult offenders than in the general population, has been linked to statistical differences on the anatomical and functional level extending as far as cell histology and transduction pathways in adults.

[27] The characteristics of adolescent action that can be interpreted negatively (extreme impulsivity, excessive exposure to risk, insufficient resistance to peer pressure, etc.) are often presented by neuroscientists as characteristics that are favourable for the species in the long term. They undoubtedly correspond to an adaptive requirement that has been selected by the evolutionary process. Indeed, it is impossible to become an adult without developing autonomy and therefore without discovering, experimenting, and engaging in trial and error, without also developing social relationships outside one's original circles. At the individual level, the changes occurring in adolescence increase the risks and hazards to which each individual is exposed, but at the level of the species, these changes promote greater adaptability and resilience. "*From an evolutionary perspective, these changes enable not only the transition to adulthood, but also a precise adaptation to the social changes that take place within the span of generations*." (DAYAN, GUILLERY-GIRARD, op.cit., p. 480).

[28] The neurobiological and psycho-cognitive transformations of adolescence clearly do not lead all individuals to adopt risky, let alone delinquent, behaviours. The reasons for following delinquent pathways are multifactorial. Social, cultural and educational processes are also (and probably especially) involved. The typical neurobiological and psycho-cognitive changes that occur during adolescence are nonetheless a factor in increasing the frequency of risky and delinquent behaviour, even if this is just one of many factors. While not all adolescents are delinquents, conversely, not all juvenile delinquency is related to neurobiological and psycho-cognitive changes during adolescence.

[29] According to the explanatory statement for the 1945 Order on *juvenile* delinquency, "*the French Republic intends to provide effective protection for minors, particularly juvenile delinquents*". The philosophy underlying this text is that delinquent children need to be protected as well as punished. This philosophy is supported by the progress made in neuroscience: if a minor's lack of maturity helps to explain his or her misbehaviour, this will indeed justify the efforts made to help him or her to gain maturity in order to emerge from delinquency. This is in the interest of the young offender, but also of society.

[30] One of the key issues in juvenile justice is to assess the factors determining the dangerousness of adolescent offenders as accurately as possible. During his hearing, Professor Jean-Luc Martinot made an interesting distinction between "hot-blooded aggression", referring to behavioural disorders linked to the difficulties that some individuals might experience in controlling their emotions, especially during adolescence due to the immaturity of their executive functions, and "cold-blooded aggression", perpetrated by people who act in a rational and planned manner. While brain maturation and the development of control capacities may gradually reduce the dangerousness of people in the first case, the same cannot be said for those in the second. Prognoses for the evolution of dangerousness must obviously be made on a case-by-case basis, based on a precise analysis of delinquent behaviour and logic.

[31] The notion of neuroplasticity and the empirical evidence that supports it definitively refutes the relevance of the biology-based or reductionist conceptions which claim that it is possible to determine people's thoughts from their biology and their mental state by studying their brain. Neuroplasticity places the brain at the crossroads of the biological and the environmental – i.e. the natural and the cultural – dimensions, which are in a state of permanent interaction.

[32] This is already the case in several European countries. In Italy, Germany, the Netherlands and Spain, the judge may apply juvenile law to young people between the ages of 18 and 21.

[33] Interindividual differences are differences that can be observed from one individual to another. Intraindividual differences are differences that can be observed in the same individual at different times or under different circumstances.

[34] The U.S. Supreme Court has certainly relied on neuroscience to justify its recent rulings on the unconstitutionality of the death penalty and life imprisonment without parole for persons under 18 years of age (rulings: "Roper v. Simmons", 2005; "Graham v. Florida", 2010; "Miller v. Alabama", 2012). These rulings are, of course, to be welcomed from a human rights perspective, but there is nothing in neuroscience today to justify whether or not such thresholds should or should not be established and, if they are, whether they should be set at 18 rather than at a different age. Similarly, there is no neuroscientific evidence to justify a minor being automatically declared irresponsible under a certain age. Unlike the situation in most other European countries, the French criminal law system for minors has so far chosen not to set a legal age of criminal responsibility, and settles for stating that "*Minors capable of discernment are criminally responsible for the felonies, misdemeanours or petty offences of which they have been found guilty*" (Article 122-8 of the Criminal Code). This choice is not unfounded in light of current neuroscientific knowledge.

[35] In many countries, neuroscience is increasingly used for judicial expertise, although there are significant differences, which no doubt relate to national specificities concerning the organisation and functioning of judicial institutions. Neuroscience can be called upon to serve justice in a wide variety of cases, which may involve: (a) proving the criminal irresponsibility of a defendant or mitigating his or her responsibility; (b) establishing proof of the damage caused to the victim as a material element of the offence committed; (c) proving the impairment of discernment under civil law; (d) establishing an individual's unfitness to participate in proceedings on grounds of the right to a fair trial and respect for the right of defence; (e) assessing and preventing the risk of recidivism.

[36] Structural brain imaging is of greater relevance. Identifying the presence of a tumour in brain areas that are involved in impulse inhibition processes or empathy phenomena can help to explain certain types of criminal behaviour, for example.

[36] If it is employed by experts as an assessment tool, functional brain imaging comes up against two limitations: 1) the recordings of brain activity provided are obtained in experimental situations rather than in real-life situations, which makes it impossible to understand the often decisive impact of the context – especially emotional; 2) recordings of functional brain data are characterised by strong intraindividual variations, which prevent the justice system from considering such specific recordings as reliable evidence in a court of law.

[37] The obsession with prevention, prediction and personalisation – stemming from medicine based on the famous "3 Ps" (preventive, predictive, personalized), which has made recognised contributions to the research on vulnerability factors, prognosis and better-adapted treatments – should not lead to the pigeonholing of individuals from a very young age, which was an important recommendation made by the INSERM report: "Troubles des conduites chez l'enfant et l'adolescent" (Behavioural disorders in children and adolescents) (2005). In the prevailing climate of insecurity, under the pretext of screening high-risk individuals before they commit any offence, there is a risk of shifting the emphasis from guilt to dangerousness, which would diminish the importance of responsibility and free will in favour of a certain scientific determinism, albeit in a much more sophisticated form than that developed in the nineteenth century by Franz Joseph Gall, who claimed to be able to associate people's personality traits with their skull contours, or by Cesare Lombroso, who, in his famous work, "Criminal Man" (1887), established a statistical correlation between people's facial features and their morals. Although these theories may now raise a smile, they are based on the same logic as more contemporary theories, concerning the supernumerary Y chromosome (known as the "crime chromosome") or the "locationist" theories which attribute violent behaviour to dysfunctions in the limbic system, and excessive aggression to a shortage of certain neurotransmitters. We are increasingly witnessing recourse to scientific expertise by the judiciary, including psychiatric and even functional MRI in the USA as a preventive and predictive measure, with the risk of transferring normative power to scientists, whereas this should remain the preserve of the law. In this manner, on the basis of the precautionary principle, it could be tempting for our society, which no can longer tolerate risk and uncertainty, to cling to a form of hygienism, and change from a society of discipline to a society of control.

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