Research Article **Open Access**

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Neuroscience: A Traditional and Innovative Approach to Education with Focus on Stress with Learning

DOI 10.1515/sigtem-2016-0012

Abstract: Learning must be brain-based. This topic would include contents like perception, attention and memory. But here the focus is on 'stress' in the context of the role of emotions on learning. Cognition and emotions are not separated in the brain, but they work together. Stress is a survival programme, but has some negative effects on learning. A specific part of the brain, the hippocampus, is very vulnerable. The consequences are that anxiety and stress must be reduced, and we must learn to cope with stress. For coping, a combination of instrumental, mental and regenerative management of stress is recommended. An intensive focus should be given to physical exercise: it has positive impacts not only on health, but also on cognitive learning as well. The neuroscientific approach confirms old pedagogic principles.

Keywords: Stress, emotions, coping, neuroscience, learning.

Introduction

In the last twenty years, insight into the brain has dramatically improved by new techniques, which enable us to look into the living brain, even after the death of a person. All these new methods focus also on the connection between brain research and learning. It is very simple. Teaching and learning are based on the brain, because learning is done by the brain. Learning must be brain-based.

There are some important topics, which we would have to deal with:

- How does information come into the brain?
- How will information be stored in the 'hard disk or library' of the brain?
- The important role of attention and emotions, with a special focus on stress.

Aim of the Study

The article shows how important are emotions for learning. In particular, the neurobiology of stress is explained and necessary consequences are described.

Materials and Methods

The neuroscientific literature is analysed using practical experience as the background.

In this paper, we **focus on stress.** Nevertheless, there are very short remarks to neuroscience – mind, thinking, memory and feelings made by our nerve cells. The power of human brain and also of thinking and

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learning can only be explained by the gigantic number of nerve cells. We have up to 86 billion neurons and the same number of glia cells (Herculano-Houzel, 2012).

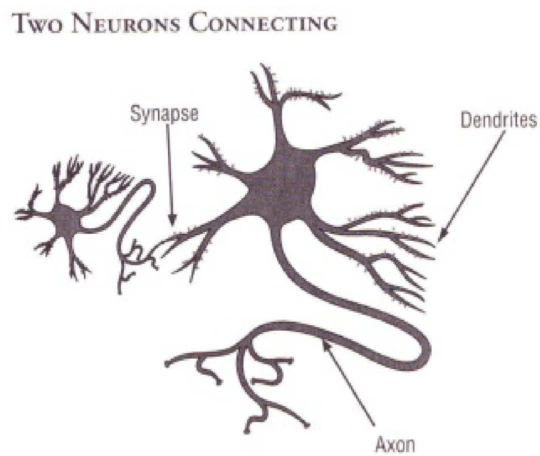

Figure 1. Two connected nerve cells (Jensen, 2008, 17)

And all work according nearly the same principle. Information comes into the cells via a lot of nerve fibres/cables (dendrites). The cell body processes this information and gives the result via one fibre (the axon) to other nerve cells or to muscles (see Figure 1). The contact point is called synapse. The number of synapses is mind-blowing: 20,000 (30,000?) synapses per neuron in the cortex, which is 86 billion × 10,000 (on average) = 860 000 000 000 000 (860 billion in the whole brain). In addition, there is also communication between neurons and glia cells.

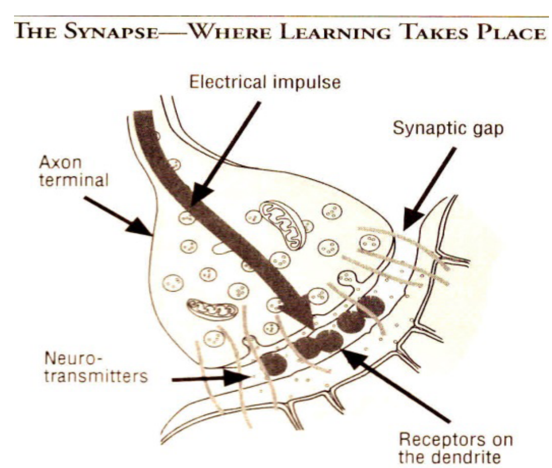

Figure 2. Transfer of impulses at the synapse (Jensen, 2008, 17)

What happens inside the nerve cells? The message (electrical impulse) of the first cell releases transmitters with the help of calcium into the synaptic gap. These transmitters are taken up by the receptors of the second cell (see Figure 2). This leads to streaming of sodium into the second cell. With learning, the synapse is changed and stabilised. Storing is done by chemical processes, with contribution of genetical processes (with genes like CREB, RbAp48, discovered by Kandel).

Learning makes the network stronger, thicker, faster and more stable. This includes sprouting of dendrites, increasing the number of synapses, and strengthening and stabilising the synapses. And very surprising and fascinating is that neurogenesis, which means new neurons are built, also takes place (see Figure 3) (Berninger, Gotz, 2009, 58-63; Shors, 2009, 41-48; Ma et al., 2009, 1074-1077).

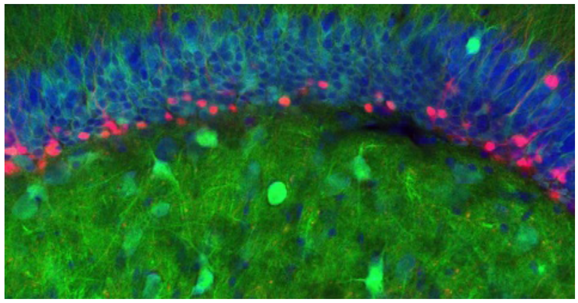

Figure 3. Neurogenesis, the red dots are new cells (Danielson, 2016)

Some basic guiding principles

Revise, **repeat:** The learning matter leads to repeated electrochemical processes in the nerve circuits and strengthens them.

Take breaks: It is necessary to give these processes time to work. The best consolidation is done during sleep. Sleeping has two functions: during sleep the synaptic connectivity will be reduced, in order to conserve space and energy in the brain, but at the same time synapses in specific circuits will be strengthened to reinforce and consolidate newly encoded memories (Miller, 2009, 22).

Feedback is very important. Some teachers neglect the principle that to modify wrongly learned matter is always more difficult than to learn it right from the beginning. Therefore, feedback must be given as soon as possible in order to make right chemical memory traces. Feedback with reward is very important, because the strength of synapses will be improved by dopamine neurons in the midbrain, in the limbic system.

It is very interesting to note that the prognosis of reward also causes positive effects (Stuber et al., 2008).

Dopamine increases also with distance and size (and value) of rewards. "Such prolonged dopamine signalling could provide sustained motivational drive … and follows closely the principles of reinforcement learning theory" (Howe et al., 2013, 575).

Linking ideas and topics to structures is the way of our brain. Memory consolidation can be fostered very strongly if an 'associative scheme' is provided, into which new information can be incorporated. So, teachers must underpin these processes by establishing schemas, patterns, framework and structure.

And all these methods and principles are dominated by an 'overall principle': Teachers must take care that pupils are motivated because they are convinced of the sense of learning. Pupils must understand the contents. And the contents must be part of associative networks.

Figure 4. Separation of mind and emotion? (Schachl, 2012, 19)

Now we move on to the topic of 'stress', which is part of the larger topic 'emotions and feelings with learning'. The cartoon in Figure 4 points at the long and often discussed separation of rationality and emotionality. But this separation does not exist in the brain. Therefore, it is very important for teaching and learning too. Feelings and emotions have a strong influence on learning (Roth, 2011, 180). Mental activities are done in the context of their emotional background.

Essential for teaching and learning

The amygdala (almond) is an emotional marker of the contents on their way to long-term memory and it has essential functions with anxiety, fear and joy (see Figure 5). It plays a role in recognising emotional signals in mimic expressions (Roth, 2011, 44, 324). The mesolimbic system (nucleus accumbens, ventral tegmental area in the pons, substantia nigra) is the central rewarding system and rewarding memory and also relevant for motivation, interest, etc. (Roth, 2011, 444; Stuber et al., 2011). Therefore, this system is very important for learning.

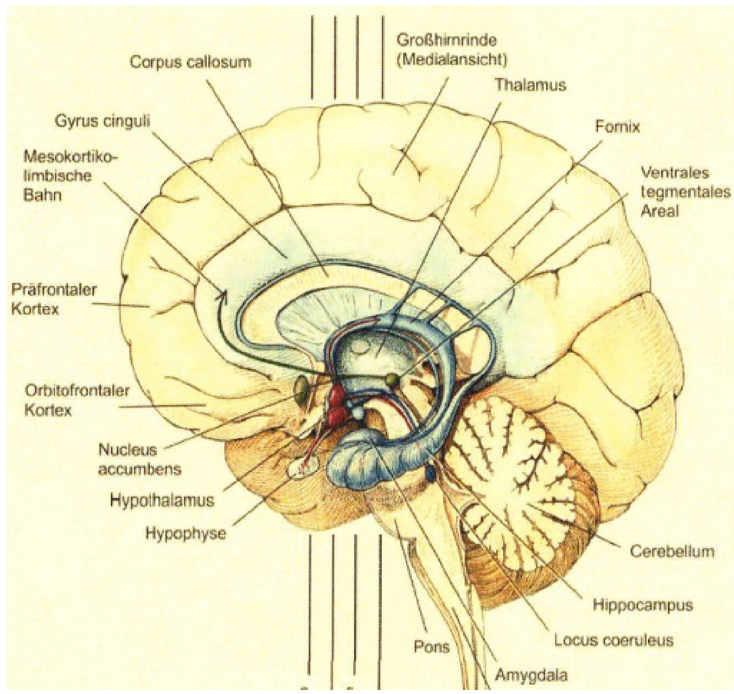

Figure 5. Anatomy of cognition and emotion (Förstl, Hautzinger, Roth, 2006, 5)

The working chemicals are called endogen opioids (endorphins) and dopamine (Rossato et al., 2009). Nucleus accumbens and ventral tegmental area play an important role also in addiction (Kasanetz et al., 2010; Lüscher, 2009) and in stress-induced depression (Lemos et al., 2012). Dopaminergic neurons fire with expected and unexpected rewards. But, if expected rewards do not occur, the relevant chemical reaction also does not occur (Cohen, et al. 2012, 88). The orbitofrontal cortex is responsible for controlling moral and ethical behaviour (Roth, 2011, 45). The prefrontal cortex (PFC) is an important part of 'working memory' (Wang, 2011) and also of intelligence. This interpretation of PFC as 'location' is partly criticised and the PFC is seen as a kind of attentional filter in the process of working memory (Wolf, 2009, 56-61). The PFC is essential for introspection und metacognition too (Fleming et al., 2010). The prefrontal cortex is called the highest leader in the brain or the highest initiator (Kandel, 2012, 425), responsible for creativity, planning (dorsolateral part), making decisions and proper social behaviour (ventromedial part). Of utmost importance is the hippocampus. This part is responsible for storing information into long-term memory, and also for retrieving (together with prefrontal cortex), but it's not the long-term memory itself. It´s like a working memory (Roth, 2011, 109; Miller, 2008b; Gelbard-Sagiv, 2008). And on the other hand, the PFC is not only responsible for retrieving, but also for consolidating information (about 2–6 weeks after learning). A very clear message is that if the hippocampus is damaged or doesn't work anymore, you can learn nothing new. It's the case for instance with Alzheimer's disease (AD). People with AD ask you the same question ten times in half an hour because they cannot store the answers. They have a 'moment to moment' consciousness. But the hippocampus has a double function: it is also important for emotions (Roth, 2011, 110). That means emotions have influence on storing and vice versa memory influences perception and retrieving of emotions. Entorhinal cortex and hippocampus interact for storing and retrieving of information. For that job, electrical power with frequencies of 20–40 Hz (theta- and gamma-waves) were used as a proof (Igarashi, 2014). Additional tasks of hippocampus include the following: The hippocampus (especially the right posterior hippocampus) plays an important role with spatial navigation. This part increases with experience (experiment with taxi drivers in London). There is an impairment after the so-called transient global amnesia (Bartsch et al., 2010).

Results

Cognition and emotion are not separated, but they work together even in an anatomical structure and via chemical processes. That means, for teaching and learning, you must take care of good emotions. In this context now, the focus is on the special topic of 'stress'. As we all know, stressful events are very common in private and professional life, and above all, in schools. Some teachers think pupils would not be motivated to learn, if there are not under pressure. Obviously these teachers are not well informed. Because we know a lot about stress-related disorders, and we also know that stress with learning can impair cognitive functions and thereby lead to worse achievements in exams. What is the current state of knowledge about stress and learning? What is stress? (see Figure 6).

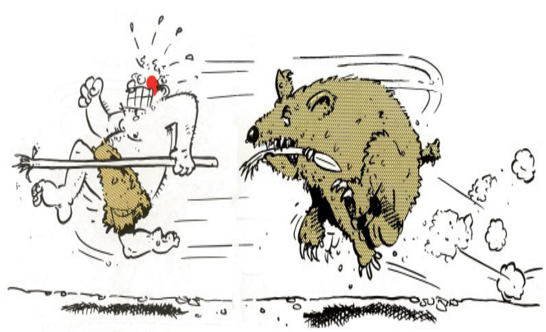

Figure 6. Fight or flight (Schachl, 1991, 13/14)

We developed stress in the course of evolution as an important survival programme. For that, we need activation of brain, heart (blood, oxygen), breathing, sweating, muscles, blood pressure, energy and also of pain and immune tolerance as well as blood coagulation. And we have a reduction of digestion, saliva production in the mouth and libido.

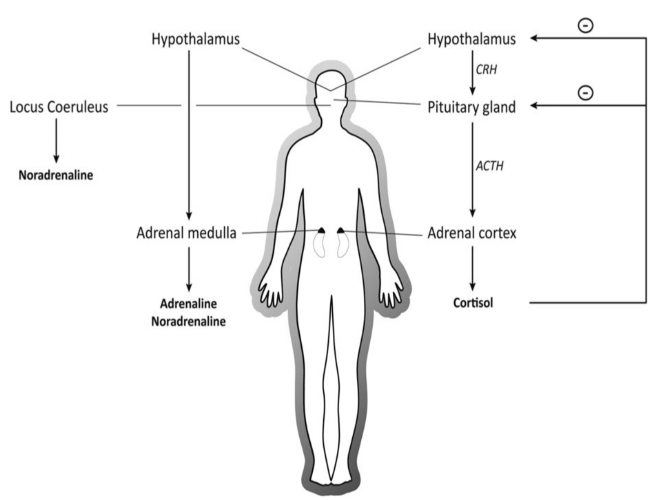

Figure 7. Two major stress systems (Vogel, Schwabe, 2016)

Although the stress response is very complex, we can focus on two major stress systems (see Figure 7).

First, the rapid autonomous nervous system is activated within seconds to release catecholamines from the adrenal medulla and the locus coeruleus in the brain stem. Catecholamines (adrenalin and noradrenalin) are implicated in the 'fight-or-flight' response (activation of circulation and breathing, but they also have profound effects on attention, working memory and long-term memory). If after this first action there is no danger, the stress response will stop. If not, the second action starts: Somewhat slower, the hypothalamus–pituitary–adrenal axis is activated, releasing corticotropin-releasing hormone (CRH) from the hypothalamus, which stimulates the anterior pituitary to secrete the adrenocorticotropic hormone (ACTH). ACTH, in turn, causes the adrenal cortex to produce cortisol and release it into the blood stream. Cortisol reaches peak level concentrations ~20–30 min after stress onset and readily enters the brain to affect cognition and behaviour. Cortisol binds to two different receptors: the glucocorticoid receptor (GR), which is expressed ubiquitously throughout the brain, whereas the mineralcorticoid receptor (MR) is mainly expressed in brain regions related to memory and emotion (hippocampus, amygdala and prefrontal cortex). On binding to these receptors, cortisol operates via two different modes of action: a non-genomic, often MR-mediated mode, develops rapidly and enhances neural excitability in the amygdala and hippocampus, presumably supporting memory formation. This rapid mode is followed by a slower, often GR-dependent mode, which is assumed to develop about 60–90 min after stressor onset and to involve longer-lasting changes to DNA translation and transcription (Vogel, Schwabe, 2016).

Cortisol feedback to the pituitary, hypothalamus and other brain areas (e.g. the hippocampus) prevents the system from overshooting. Cortisol is released not only with stress, but in shifts during 'normal life', with a peak after awakening (Roth, Strüber, 2015, 135).

The bodily consequences of stress are well known: diseases of heart and circulation, of stomach and gut, problems with sexuality, weakening of immune system, psychiatric disorders and so on.

What are the effects of stress on learning and memory?

They are different, depending on the temporal proximity of the stressful event and the memory process (Vogel, Schwabe, 2016) (see Figure 8).

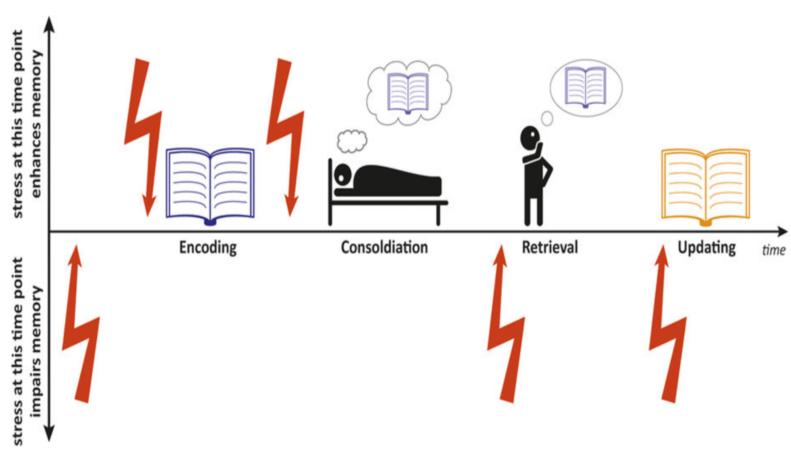

Figure 8. Effects of stress on memory

Stress impairments: Stress, long before encoding, impairs memory processes, because of a decrease of neural excitability in the hippocampus. Stress just before a retrieval process (with high level of noradrenalin and adrenalin, but not elevated cortisol) impairs the recall of information (e.g. stress before exams). Also earlier (20 min and more), before a retrieval process (noradrenalin and adrenalin are on a baseline again; cortisol is now working) is negative for recall. The recall deficit was found already in children in the age of 8–10 years (Vogel, Schwabe, 2016). The integration of new information into existing knowledge is fundamental for learning and for the whole life too. Updating former stable memories are shortly unstabilised and then reconsolidated again, which is done by hippocampus and prefrontal cortex. But stress impairs this memory-updating, the reconsolidation process. Relevant for this process is the cortisol activity in the amygdala.

Stress just before encoding, after presentation of new information, and consolidation enhances memory building, probably because of enhancing attentional processes by noradrenalin and adrenalin, especially for emotionally arousing material. There is a dependence on emotion and on context too: In sum, being moderately stressed can enhance memory formation for emotional material and information, which is related to the stressful context, whereas stress may impair the encoding of stressor-unrelated material. The different effects of stress on memory depend on interactions between noradrenalin and cortisol in the amygdala and are thus often stronger for emotional learning materials (Vogel, Schwabe, 2016).

Vulnerability of Hippocampus

The hippocampus is very vulnerable (maybe because of a bigger number of cortisol receptors (Suzuki, Fitzpatrick, 2016, 239) to severe and prolonged stress (Rahman, et al, 2016). Reduction of hippocampal volume was found, because of loss of dendritic spines and less neurogenesis (Egeland, Zunszain, Pariante, 2015; Ewen, 2016), and also because of reduced glial volume and numbers. Brain-derived neurotrophic factor (BDNF), very important for neuronal growth and plasticity, is also reduced with chronic stress. Stress affects important proteins like CREB negatively (Sardari et al., 2015).

This is also important because a high level of corticotropin-releasing factor (CRF), a main regulator of stress response, impairs motivation, decision processing (Bryce, Floresco, 2016) and working memory in the prefrontal cortex (Hupalo, Berridge, 2016). This impairment leads to poorer performance in learning tasks and, for instance, to deficits in spatial memory. Oxytocin can work as an antidote (Jurek, 2015), because of its benefit on CRF. That means, positive social relations (associated with oxytocin) are helpful for coping with stress.

Furthermore, it was shown that 'stress induces a qualitative shift in the systems guiding learning (and, most likely, retrieval), from a cognitive, hippocampus-dependent memory system towards a habit-like memory system based on striatum' (Vogel, Schwabe, 2016)! 'Prolonged or chronic activation of the hypothalamus-pituitary-adrenal-axis has been consistently associated with neuronal loss, decreased neurogenesis and altered neural connectivity and ... stress exposure has also been strongly linked to alterations in epigenetic markers that may ultimately lead to changes in gene expression. ... And these epigenetic mechanisms could play a role in the pathogenesis of neurodegenerative disorders including Alzheimer disease' (Cordner, Tamashiro, 2016).

Repeated, chronic stress has negative impacts on nerve cells. Dendrites shrink, and the spine (docking station for other nerve cells) density in hippocampus and prefrontal cortex is reduced. These processes are reversible to some extent, especially in young animals and humans; physical exercise has a positive influence (Ewen, 2016).

New research (Morena et al., 2016; Di et al., 2016) has shown that the endocannabinoid system plays an important role in stress, because it affects the hypothalamus-pituitary-adrenal-axis: it can be attenuating, but also anxiety enhancing. Chronic stress can modify this system. In this context, the use of cannabis must be discussed for both its positive and negative effects (Haney, Evins, 2016; Ramaekers et al., 2016; Fedota et al., 2016; Sutherland et al., 2016).

Figure 9. Anxiety before exams (Schachl, 2012, 95)

Stress with learning

Stress is a big problem in education. So nearly 70% of primary school children (Valizadeh et al. in Vogel, Schwabe, 2016) report symptoms such as worries, anxiety or sadness, and many teachers complain about too much stress (see Figure 9).

Stress with learning (and also teaching) has very important consequences. On the one hand, emotions and light stress (challenges, unexpected and new information) have positive effects on memory formation.

But, on the other hand, stress, especially anxiety, leads to stronger storing of negative events (bad exams, interpersonal conflicts with parents, teachers, peers) with enduring frustration and negative attitudes towards school and learning (no motivation for life-long learning). And finally, stress may lead to rigid memories and the retrieval of habits rather than creative and complex solutions (Vogel, Schwabe, 2016).

Especially this last consequence, but all the others too, are also a problem for teachers. Stress impairs the quality of teaching, and in a 'devil's circle' rigid behaviour leads to further stress. Also dangerous is a possible weakening of the trust in self with the consequence of 'learned helplessness' (Seligman, 1979). In animal studies, it could be shown that helplessness leads to lower activation in many brain areas, like prefrontal cortex, reward-processing regions, amygdala and hippocampus (Kim, et al., 2016). Therefore, it is clear that helplessness is combined with lower learning and memory achievement. Often the learner's abilities are underestimated, because their full achievement cannot be reached. Stress before exams impairs recalling the knowledge.

The effects of stress follow an 'inverted U-shape' curve (Ewen, 2016), which means higher levels of stress and prolonged stress are impairing. This is in accordance with the old Yerkes-Dodson law (1908). This law shows an empirical relationship between arousal and performance, which was developed by Yerkes and Dodson in animal studies. It means that performance increases with arousal, but after a medial level, there is a decrease (see Figure 10).

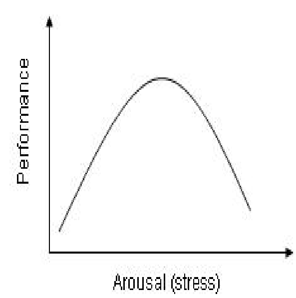

Figure 10. Yerkes-Dodson-law (http://changingminds.org/explanations/motivation/yerkes-dodson.htm)

Further research and practical observation found that in humans there are individual differences and dependences on tasks too. For simple tasks, more arousal is needed, and for difficult and complex tasks, less arousal (more relaxation) is needed (see Figure 11).

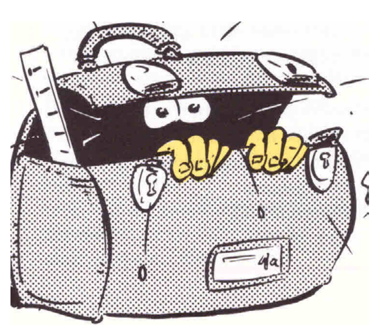

Figure 11. Against anxiety (Schachl, 1991, 27)

What must be done against anxiety and stress in schools and also in an adult‘s life? First of all, anxiety and stress must be reduced. For that, teachers, parents and students must be informed and be aware of the effects of stress on learning and life. And we must learn to cope with stress.

Reduction of anxiety and stress

The guiding principle is to learn (and also teach and live) with joy.

Teachers must give interesting lessons, which are understandable, and they have to underpin the learning process. And above all, teaching must make students curious. The teachers must be enthusiastic themselves.

Our life, on the whole – learning, professional performance and private satisfaction – is mainly dominated by the areas of emotions, the limbic system. Most of the processes are driven by subconscious memory. To influence these processes, we must focus on good relationship, empathy, trust and positive reinforcement. And we must avoid aggressive, anxiety-causing behaviour. The most important duty of teachers is 'don‘t forget the human being'. The good guiding principle is that make humans strong and clarify the facts. But besides the best teachers, best lessons, anxiety and stress remain. Therefore coping is necessary. What causes stress depends on the personal appraisal. The individual appraisal of possible stressful events and stressors and also available methods of coping determine whether the biological reactions occur and impair.

Because of its subjectivity (genetics, prior experiences), we have different reactions on stress and we need different coping strategies.

A combination of some of the following possibilities is recommended (see Figure 12).

Figure 12. Stress with learning (Leitner, 1972)

Coping with stress

'Instrumental' management of stress: We need competencies in the subjects we have to learn (that means, we must learn to learn); social competencies (mutual supporting etc.); self-management competencies (planning, organising, preparation for exams in time, establishing a good working place, ...). Very important, but the most difficult one is mental management of stress : accepting the reality, self-control (accepting the own limits, for instance to ask, whether the steps are too high?) critical analysis of own appraisals (am I really a loser? comparison of all achievements), change of thinking (exams as challenges, not as threats), self-affirmations' (I will succeed, I am well prepared, ...).

Important for teachers: Teaching should be more focused on strengths rather than on weaknesses.
'Regenerative' management of stress: Recovery, enjoying, relaxing, breaks.

Special techniques: Yoga, meditation, autogen training, Jacobson's progressive muscle relaxation.

The Jacobson technique of progressive muscle relaxation is very easy and works well to come down from high-level stress. Focusing on good breathing also makes sense. 'Attention to breath meditation' has positive impacts on regulating aversive emotions, by down-regulating activation of amygdala (Doll et al., 2016).

Meditation has also positive effects (Ricard et al., 2015), depending on the kind of meditation. Concentration meditation activates frontal brain areas, carefulness meditation areas in the parietal and temporal lobes and empathy meditation has impacts on regions between parietal and temporal lobes, and medial prefrontal cortex and insula.

During meditation, ‘neuronal oscillations’ occur, which means, synchronous electrical impulses are generated. In particular, gamma-waves (frequency 40 Hz) are interesting, because they are related to higher cognitive functions and consciousness. A research on Tibetan monks, who meditated for a long time very intensively, revealed the most intensive gamma-waves, which were never observed with humans (Suzuki, Fitzpatrick, 2016, 348).

Other studies (with MRI) showed a surprising result (Suzuki, Fitzpatrick, 2016, 354.). During meditation, there is less activity in frontal areas. It is surprising but nevertheless logical because of a better control of attention less work was necessary. It fits with the theory of transient hypofrontality (Dietrich; Schneider in Landrichinger, 2015, 34).

Another finding is that with meditation, inflammation markers are decreased and the activity of telomerase (important with aging) increased.

Now we move on to a very special and important topic, the positive effects of physical exercise. From evolutionary and also ontogenetic history, physical exercise is a natural basic need. And it is very important for cognitive learning too. Physical exercise is important for health of the whole body: muscles, circulation, breathing, immune system and so on. And it is also important for brain, therefore for mental health and for learning too. It helps in multisensoric integration, increasing of attention and has a positive impact on synapses and on neurogenesis, reduction of cortisol, and therefore reduction of stress.

There is also a positive impact on chemistry of soul: Stimulation of dopamine, endorphines and endocannabinoids.

Other studies in this field

Study at the University of Miami by Hollar (Beck, 2014, 18) showed that short interruptions (10–15 min) of lessons, filled with some physical exercises, led to better performances in mathematics and language courses. A long-term study at the Universities Glasgow und Dundee on 5000 pupils (Beck, 2014, 18) showed that regular physical exercises from the age of 11 until 16 improved the marks in English, mathematics and sciences. The California Department of Education found that higher cognitive processes (steered by hippocampus and prefrontal cortex) were improved by physical fitness (Hannaford in Landrichinger, 2015, 29). Running, riding bicycles, swimming etc. increased creativity (shown by a study of Stanford University, Suzuki, Fitzpatrick, 2016, 330f.). Physical exercise increased the brain derived neurotrophic factor (BDNF), important for growing of synapses, which were also found in several studies (Cotman in Beck, 2014, 4; Schmidt-Kassow in Beck, 2014, 41; Suzuki, Fitzpatrick, 2016, 159). BDNF is also important for neurogenesis.

In animal studies, it could be shown that neurogenesis increased very much (in hippocampus) after physical exercises (Praag in Ratey, Hagerman, 2013, 66). Aerobic training is especially helpful (Perini, et al. 2016). This kind of training (with enough oxygen) increases the level of serotonin, dopamine, noradrenalin and endorphin. Therefore, it improves mood and cognitive learning too (Suzuki, Fitzpatrick, 2016, 136, 207).

For learning, very important is also the effect of exercise on attention in the classroom. If the attention is higher, if the lessons are interrupted by breaks with exercise, but on the highest level, if teaching itself is done with moving elements (Dordel, Breithecker in Leitner, Kainberger, 2015, 22; Möller et al., 2016), the results must lead to a change of thinking about the traditional ‘frontal teaching’.

But how is it in reality? There is too less physical exercise (see Figure 13). And the consequences are diseases, too much weight, problems with concentration, behaviours like aggression with less effective learning. In Austria, more and more schools are engaged in a specific very positive programme, called ‘moved school’ (www.bewegteschule.at).

Figure 13. Enough physical exercise in schools? (Schachl, 1991, 13)

Coping should be a combination of regenerative elements (exercise) and mental methods.

For older people, movement and physical exercise are important for anti-ageing It has positive influences on the chemistry of hippocampus (Jacobson, 2013) and on the telomerase (Entringer, 2014). Shrinking of dendrites, reduction of spine density and weaker neurogenesis because of chronic stress are reversible to some extent by physical exercise in older people too (Ewen, 2016).

At the end, is a neuroscientific approach traditional or innovative? When we are looking for some guiding principles, like repeat, take breaks, give positive feedback, foster physical exercise, avoid anxiety, learn coping with stress and others, they are not new (see Figure 14).

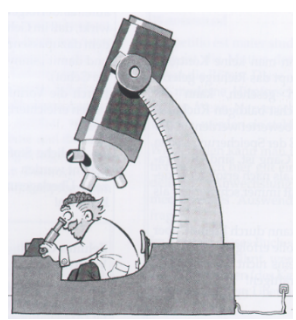

Figure 14. The brain explores itself (Schachl, 2012, 100)

Contribution of Brain Research

Some principles are 'old wine', but confirmed well by neuroscience. Together with the fruit from the tree of knowledge, we were given the desire to 'know ourselves' and we must explore our brain processes in order to better learn, better understand and give a better world to our children.

Conclusions

Stress has enormous consequences on our ability to learn, perform and to think. Especially in schools we have to do intensive work for reducing unnecessary and sometimes really silly stressful events. And we must teach our pupils to cope with anxiety and stress. This is helpful for our future careers, satisfying business and private life, and above all, for physical and mental health. Let's take care of our children and youngsters.

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