The Vulnerability and Strength of the Adolescent Brain

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The Vulnerability and Strength of the Adolescent Brain

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Abstract

Around 20% of adolescent suffer from a mental illness, and suicide is the third leading cause of death among this age group. An interesting but disturbing fact is mental illness onset surge in adolescents. This article dives into the neuroscience of why and how the adolescent brain is more vulnerable to mental health challenges. The article discusses the two major sensitive periods of brain development: infancy and adolescence, of which the latter will be discussed in the context of sex hormones, neurotransmitters, anatomical maturation, and error signals generated by the brain. The major take-away is that the adolescent brain is in a period of construction that makes it more challenging to make the right decisions in the right situations. It is emphasized how the adolescent brain does not choose to act irrationally or succumb to peer pressure. Rather, the adolescent brain is in a transition phase that requires time and support to mature. This article is the first in a two-part series on adolescent brain development and function. This article was first published in Subkiton April 05, 2022 (https://www.subkit.com/pernillebuelow/posts/the-vulnerability-and-strength-of-the-adolescent-brain).

Have you come across one of the news-articles stating that anxiety and depression levels have never been higher among adolescents? (see for example this one and this one).

These articles often attribute current mental health challenges in the youth to climate change, political upheaval, lack of community, and social media. The rise of mental health disorders in the youth is a serious problem that necessitates serious actions. However, it is also easy to feel helpless. A parent or a teenager cannot change climate change, politicians, or the social media culture on their own. It is also impossible to "just" create a community. In other words, while these news-articles are important (and attention-grabbing!) they are not always constructive sources of information on the whys and hows of mental health in our youth.

This will be the first of a series of articles that explore ***why adolescents are at greater risk of developing mental health disorders,*** *and* ***how we can prevent the onset of mental health disorders and instead nurture mental health wellness.***

Adolescence is a critical period of brain maturation, which is reflected in the slow but steady development of their executive functions, such as their emotional self-regulation, patience, and ability to make plans (and follow through with them!). The adolescent brain is particularly sensitive to the environment. Experiencing safety, love, boundaries, and community are corner stones for developing a physically healthy brain and psychological mindset. The lack of these environmental factors not only creates acute distress but impacts the brain's development in such a way that it becomes more likely to develop and maintain mental health disorders later in life. **Sadly, around 20% of adolescents suffer from a severe mental health challenge and suicide is the third leading cause of death in this age-group.**

An interesting, but disturbing, phenomenon is the surge of mental health challenges that arise specifically during adolescence: older teens are more than twice as likely to suffer from mood disorders compared to younger teens. On the flip-side, adolescents are more than twice as likely to experience substance use and mental health disorders compared to adults. **In short, something happens during adolescence that renders them more likely to develop mental health problems.** Let's dive into the biology.

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Infancy is the first time where the brain undergoes major changes after birth. An infant brain has a sudden increase in the number of synaptic connections between neurons in the brain. This period is called synaptogenesis and is thought to reflect an enhanced opportunity to create strong "brain connections" that can support newly learned behaviors. During enhanced synaptogenesis, you can typically acquire new skills faster and with more ease. Synaptogenesis is one of the reasons it is easier to learn new languages if you are exposed to them from a very young age. In response to the synaptogenesis, the brain goes into a period of "pruning": a deliberate removal of synaptic connections that are not being used. You may have heard the saying "use it or lose it" for new skills you have learned. This saying is also true for the brain, and especially so during periods of enhanced synaptogenesis. Synaptogenesis and pruning happen in different areas of the brain at different developmental time points (See Figure 1). That means that it is easier for you to learn different skills at different periods of your life. However, for the most part, this enhanced learning ability starts tapering off for all skills around age 3-4.

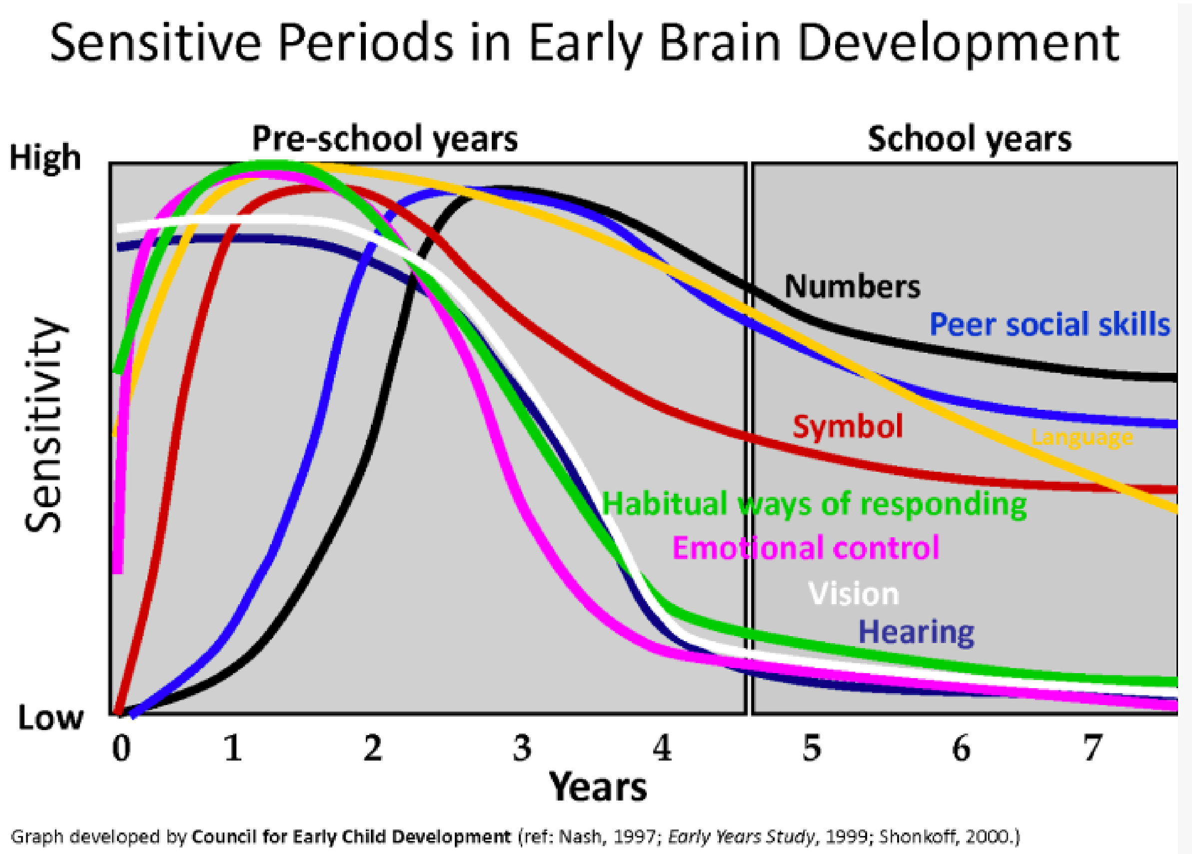


Figure 1: *Sensitive periods in early life - periods of brain development where we are particularly good at acquiring new skills due to enhanced neural plasticity*

But infancy is not the only time our brains go through a surge of synaptogenesis and subsequent pruning. As we enter puberty our brains once again send signals to enhance synaptogenesis and yet again, we become fast learners (Arain et al., 2013) (See Figure 2). As synaptic connections are either strengthened or removed our brains become refined and sculpted to optimize our behaviors (and not waste space on connections that mediate unused behaviors). In adolescence, this period is also paired with a significant increase in myelination. Myelination is what makes up the "white matter" of the brain: axons are covered in a "white sheath" to increase their speed of information processing and signaling. Again, only the synaptic connections that are used regularly become myelinated. In short, when synaptic connections are specific and axons are highly myelinated, we are typically really good at something, whether that be playing football, solving math problems, or playing the clarinet.

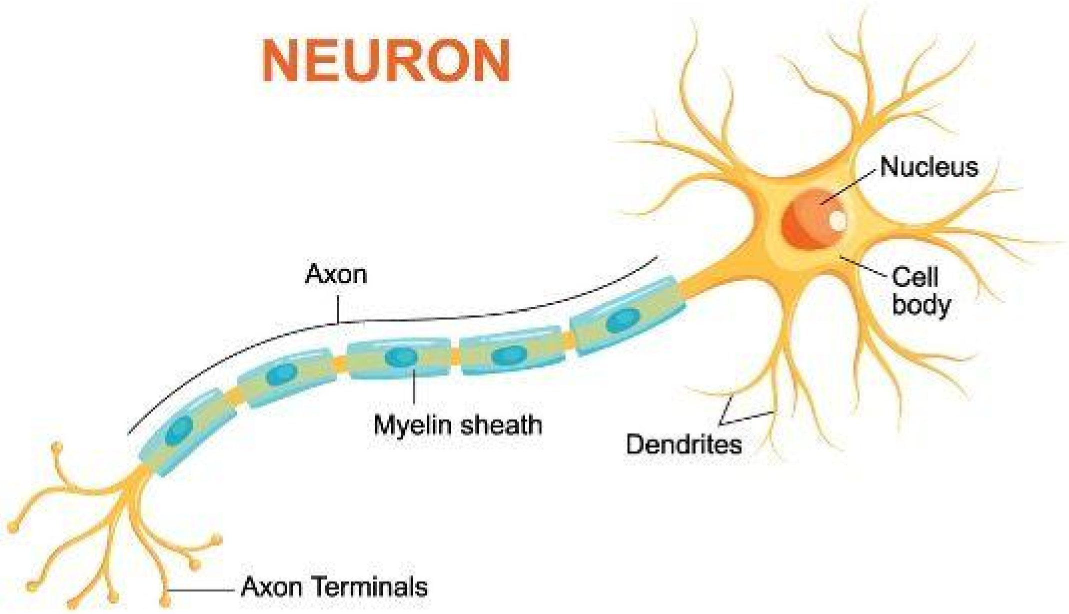


Figure 2: *Neuronal anatomy* **Image source:** https://www.sciencenewsforstudents.org/article/explainer-what-is-a-neuron

Because synaptic pruning and myelination is heightened during adolescence, the adolescent brain has enormous potential to learn and develop new skills. If the adolescent grows up in the right circumstances, they will become masters at self-regulation, problem-solving and multi-tasking in both social and non-social contexts.

If the adolescent brain is full of this potential, why do so many of them develop mental health challenges, some of which last long into adulthood?

There are 2 major reasons:

- While the adolescent brain has the potential to change, there are other biological mechanisms that counteract what we may think are "healthy" behaviors and choices. In many adolescents, these counteracting forces trump their ability to problem solve and self-regulate.
- Environmental factors, such as chronic stress, drug abuse, sedentary life-styles, and neurotoxic insults, can interfere with the adolescent brain by compromising its ability to learn or enhance the power of the counteracting forces (see #1)

In this first blog post, we will cover reason #1 which will also serve to set us up for understanding the power of external forces comprising reason #2, which will be covered next time.

In addition to synaptogenesis/pruning, which I will refer to as *neuronal plasticity*, the adolescent brain also undergoes three other major changes:

- ***A surge of hormonal changes associated with puberty***
- ***Changes in levels of the neurotransmitter dopamine***
- ***Incomplete/delayed maturation and function of the prefrontal cortex***

In the following, I will describe each of these points, paying special emphasis on how these differences alter behavior and well-being in adolescents compared to children and adults.

Sex hormones alter behavior and emotional regulation during adolescence

Sex hormones, such as estrogen and testosterone, increase at the onset of puberty. This increase in hormone levels is believed to be one of the major triggers of enhanced neuronal plasticity in the adolescent brain (Arain et al., 2013). Sex hormones affect myelination, neurotransmitter receptor activity, and cell death, and therefore have a large potential to ***change the way the brain functions***. The intensity and timing of the effects of sex hormones depends on the brain area.

During adolescents, two brain areas are particularly important:

- **The amygdala** – a cluster of cells sitting at the mid-base of the brain, responsible for regulating emotional, particularly fearful, behavior. Sometimes, the amygdala is referred to as the “fear-center” and it is a part of a number of brain regions making up the “limbic system” of the brain.
- **The prefrontal cortex** – a brain region that is especially important for regulating your motivation, attention, and decision-making processes. This region is often referred to as the “rational” center of the brain because it endows us with the ability to reassess our emotions, and act according to reason rather than feeling.

One study found that as testosterone levels increase over puberty (testosterone is present in both males and females and its levels increases in both during puberty), it correlated with better control of one’s emotions. In other words, as testosterone levels increase over puberty it enabled a person to engage their prefrontal cortex to control their emotional reactions (Tyborowska et al, 2016). An important take away from this study is that adolescents with the same age had remarkably different testosterone levels and this correlated with how well they could control their emotions and behaviors. This result emphasizes how individual differences in hormone levels can shape our brain function and behavior.

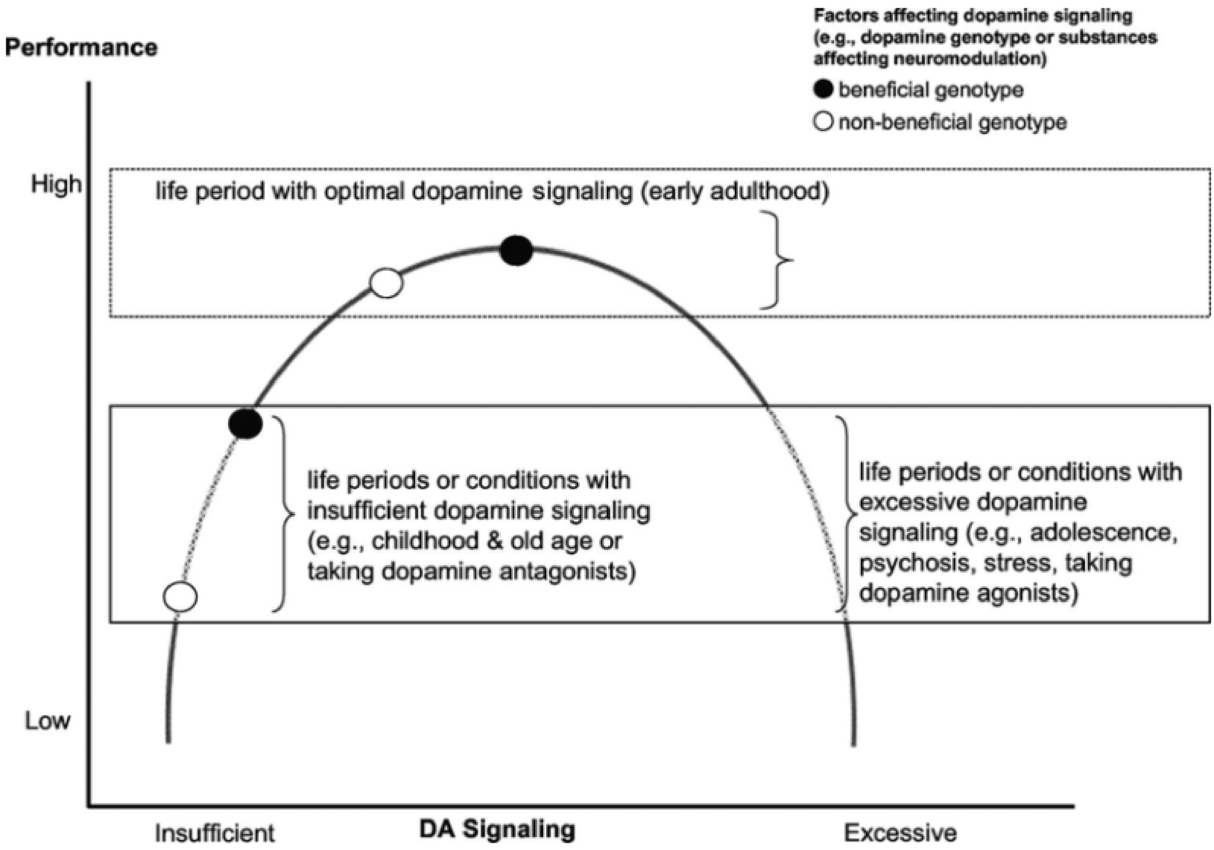
Interestingly, this relationship between testosterone and emotional self-control shifts later in adulthood: adult men with high testosterone levels were significantly **worse** at regulating their emotional reactions in social situations (Kaldewaij et al., 2019). These types of findings underscore the transient, yet important, role certain hormones can play in shaping the maturation of the brain, and how one hormone’s function can change over the course of brain maturation.

Motivation versus Motivation – Brain region specific differences in dopamine levels drive different types of motivation in adolescence

Have you ever come across a stubborn teenager who refuses to do their homework, clean their dishes, or do any other activity you could possibly suggest? Yet, in parallel, that same teenager is extremely, maybe even admiringly, motivated to spend time with their friends, play sports, or other activities that are intrinsically interesting to them?

Dopamine is one of the neurotransmitters in the brain that are particularly important for regulating our motivation and ability to stay attentive for a longer period of time (for example, paying attention to the professor during a lecture). At the same time, dopamine is also one of the major neurotransmitters that enhance our sensation-seeking and risk-taking behavior (for example, choosing to drive faster than the speed-limit). How can the same neurotransmitter play two so different and seemingly oppositional, roles? Just like with the sex hormones, dopamine's effects will depend on the brain region it is circulating in. **When dopamine acts in the prefrontal cortex, it will drive motivation to stay attentive,** but when **dopamine is circulating in the amygdala and other limbic regions it will drive sensation-seeking.** During adolescence dopamine levels increase all over the brain (Wahlstrom et al., 2010). Dopamine levels may even increase to greater than adult levels during this period. What does this increase mean for adolescent brain function and their behavior?

It is easy to think that more dopamine makes for a more motivated brain. Unfortunately, it does not always work like that, at least not in the prefrontal cortex. Scientists report an inverted U relationship between dopamine and performance (for example, when solving a math problem). If a person has too little (childhood) or too much (adolescence) dopamine it negatively affects cognitive performance. We do not fully understand the roots of this delicate relationship, but research supports the idea that enhanced dopamine signaling onto a subset of prefrontal neurons may decrease their ability to be active at the right times (Wahlstrom et al., 2010). In sum, excessive dopamine signaling may lead to "unproductive" communication in brain circuits during adolescence. The fact that the prefrontal cortex is also immature during adolescence likely also contributes to and aggravates the negative effects of increased dopamine levels.



Source:
https://www.researchgate.net/figure/The-inverted-U-function-relating-dopamine-signaling-and-performance-implies-that-the_fig2_224869525

In contrast to the prefrontal cortex, the amygdala is fully developed in the adolescent brain and so are the other brain regions comprising the limbic system (aka your emotional brain). Increased levels of dopamine during adolescence are also associated with enhanced motivation for exploration and novelty-seeking. In other words, testing new drugs, driving fast, and other "irrational" behaviors, often correlate with heightened dopamine signaling in the limbic regions. In combination with reduced prefrontal cortex-driven "rational" behavior, **teens experience a greater drive towards novelty- and sensation-seeking behaviors** than what full-fledged adults might. While dopamine levels naturally increase during adolescence, experiences can change that. An adolescent's drive to try a new drug (motivated by enhanced dopamine activity), may lead to continued drug usage. Repeated drug use can trigger a reduction in the natural production of dopamine (and other pleasure-related neurotransmitters). This reduction leads to enhanced "craving" for using the drug again and can give rise to drug-dependence. Given the immaturity of the prefrontal cortex, enhanced dopamine signaling can render the adolescent brain more vulnerable to addiction and dependencies on other pleasure-seeking activities. It is important to note that an adolescent's vulnerability will depend on their unique make-up, such as their genetic profile, maturation stage, and their support system. An adolescent with a support system is significantly less likely to develop substance use and mental health disorders (Güroglü 2020). For an adolescent with a genetic profile that renders them more susceptible to addictive behaviors, a support system can buffer and minimize the extent to which these behaviors are enacted.

The Failure of Prefrontal Cortex Engagement in Social Situations

I have referred a few times to the delayed maturation or immaturity of the prefrontal cortex in adolescence. Indeed, the prefrontal cortex does not reach full maturity until mid-twenties and this delay is hypothesized to contribute to the lack of sound decision-making processes in teens (Blakemore and Robbins, 2012).

Intriguingly, despite this "physical" delay, adolescents (age 15 and older) and adults perform equally when assessing whether hypothetical situations and courses of actions would lead to positive or negative outcomes (Arain et al., 2013; Andrews et al., 2021). In other words, when adults and teens evaluate whether an action is a good choice or a bad one, they perform equally well. This result suggests that teens are as good as adults at understanding if a situation is risky or carries potential for harm. **However, in the real world, these teens still made choices that led them to risky behaviors.** While adolescents may be completely able to understand the danger of a certain choice when you are discussing it with them around the dining table, they may not be as good at following through with the appropriate behavior.

Why is that?

One of the reasons is that teens are more easily influenced by their own emotions, and they are more likely to read others' emotions incorrectly (Arain et al., 2013). This is demonstrated in neuro-imaging studies where researchers can take images of the activity levels of the brain based on the blood flow through specific brain regions. During interpersonal interactions and decision-making, adolescents had less activity in the "rational" prefrontal cortex area compared to adults. In parallel, when trying to read a peer's emotions, adolescents have higher activity in emotional brain regions, such as the amygdala, compared to adults. Overall, reduced prefrontal and increased amygdala activity will bias decision-making towards behaviors that *are impulsive and motivated by their own feelings*. **Somehow, interacting with other people in the real world makes it much more difficult for teens to make the**

rational choices they can do around the dinner table. Researchers think that one of the reasons for this “disconnect” is due to an ongoing maturation of “neuronal fiber tracts” that connect the rational and emotional brain regions to one another.

Regret and Error Signals

Another issue embedded in this incomplete communication between the “rational” and “emotional“ brain is that regret and error signals (e.g. when doing something you know is wrong) do not activate a motivation to change (i.e. to not perform that behavior again) (Blakemore and Robbins, 2012). Adults with lesions in a part of the brain called the ventromedial prefrontal cortex (also referred to as the “vmPFC”) lack signs of regret (Clark et al., 2008). In general, these individuals are more easily motivated by the possibility of a reward than a person without any vmPFC lesion. It is hypothesized that one of the reasons for this “emotional” behavior is due to the loss of effective error signals – a signal that tells you when you did something wrong and motivates you not to do it again. Interestingly, adolescents have similar behavioral patterns, and this is reflected in the brain as well (Geier et al., 2010, Cohen et al., 2010, Sturman et al., 2012). Normally, risky decisions are associated with activity in the prefrontal cortex which serves to “constrain” your motivation to make high-stake choices (for example, gambling or taking drugs). However, in adolescents, because the prefrontal cortex is not fully engaged and developed yet (see section above), the “emotional” areas dominate and drive risky behavior. The missing error signals reduce the feeling of regret rendering the adolescent less consciously aware of the negative implications of a decision. To say it differently, **reduced feelings of regret in adolescents open the door for more risky choices.** When an adolescent does not learn from a mistake, chances are high that their “error-signal” was not activated to the extent that it would in an adult.

Finishing remarks

As you can tell, the adolescent brain (and body!) undergoes several significant changes that influence their decision-making processes, social life, and ultimately mental health. We can categorize some of the major changes into:

- Hormonal changes that activate or reduce neuronal activity
- Changes in neurotransmitter levels such as dopamine that drive motivation

- Brain structure changes that regulate their behavior in social contexts and their ability to learn from prior mistakes

We still have a lot to learn about the adolescent brain. We still do not fully understand how rising hormone levels change the structure or function of the brain, nor what exactly accounts for how influenced adolescents often are by their friends (but not their parents……….).

The most important take-away is to appreciate that **the adolescent brain is in a period of construction that makes it more challenging to make the right decisions in the right situations.** Importantly, **the adolescent *does not* choose** to act irrationally, nor do they choose to care so much about what their friends are up to. *They are simply in a transition phase*. Adolescents may not have access to the words they need to describe their frustrations, sadness, and confusions. You may feel that your teen does not need you, but really what is happening is that ***they are relying on other adolescents to provide a mirror*** for their own feelings, experiences, and thoughts. Just like toddlers (and, to be honest, adults), adolescents need support, love, boundaries, and safety.

The next blog post will focus on how the environment can interfere with the adolescent brain and make them more likely to develop mental health disorders.

About the Author

Pernille Bülow is a science writer, research consultant, and mentor. Originally from Denmark, she moved to the U.S. to finish her B.S. in psychology at UC Berkeley, followed by a PhD at Emory University and a subsequent Post-doctoral fellowship at Harvard Medical School/Massachusetts General Hospital (MGH). Pernille is an expert on brain development and mental health research, topics on which she consults and writes. She currently lives in Boston with her two cats and guinea pig. Pernille has a monthly newsletter on neuroscience research and mental health (https://www.subkit.com/pernillebuelow), and offers scientific writing, mentoring and research consultation. Contact Pernille via her website: www.pernillebuelow.com.