Cognitive enhancement : toward the integration of theory and practice

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Conclusion

Cognitive enhancement (i.e., any means aimed at enhancing cognitive performance) has gained great attention over the past years, as the economic problems of the welfare system have boosted interest in procedures and activities that make welfare more affordable for society. Especially with regard to the aging population, there is the need to enhance vitality and healthy aging in order to keep people autonomous. In addition, societies seem to become more individualistic and emphasize the idea that an individual is the director of his or her own life. As such, interest in procedures and activities that help express individual needs as well as to minimize weaknesses and further support strengths has increased rapidly. The present dissertation aimed to not only demonstrate which methods are promising ways to enhance cognition, but also to get a better understanding of the underlying mechanisms of how enhancement methods (e.g., brain stimulation, the intake of food supplements, or playing videogames) can affect cognition and behavior in healthy humans. That is, in order to reach interesting levels of enhancement and in order to be able to eventually possibly apply this to the general public, clear ideas about the mechanisms underlying the cognitive functions one aims to improve are required. Cognitive enhancement is generally aimed at improving executive functions including attentional control, inhibitory control, working memory, and cognitive flexibility, but can be aimed at improving social cognition as well. That is, social cognition and social behavior stem from numerous cognitive processes (e.g. attention), and can therefore be targeted by cognitive enhancement. In this thesis, enhancing effects on both cognitive and social functioning, and the respective underlying mechanisms were therefore discussed.

Brain stimulation techniques allow researchers to infer causal relations between the stimulated neurotransmitter or brain area and the behavioral outcome. An example is transcutaneous vagus nerve stimulation (tVNS), which stimulates the GABA-ergic and noradrenergic systems as well as increases activation in the thalamus, prefrontal cortex and insula. tVNS

provides a relatively safe, healthy, and easy tool to investigate and possibly enhance the functioning of these systems, which are assumed to play a crucial role in action cascading and vicarious ostracism. Although active tVNS led to enhanced action cascading performance (Chapter 1), suggesting a possible causal role for GABA and norepinephrine in action cascading, it did not affect prosocial helping behavior in the Cyberball game (Chapter 2). One major problem with brain stimulation techniques is that, given the sometimes promising findings, the brain-training industry is bringing these techniques to the commercial market. However, the underlying mechanisms are often not well understood, and applying these techniques commercially can actually have detrimental effects on cognition (e.g. working memory, Chapter 3). It is therefore important that the scientific community becomes more active in warning consumers for the possible dangers of using such techniques, and evaluating the far-reaching claims made by the brain training industry. Another very important issue that warrants further research is the question whether, and under what circumstances, brain stimulation techniques like tDCS are actually able to modulate cognitive function in the first place. With regard to tDCS specifically, there is ongoing discussion about whether tDCS can target specific brain areas and affect behavior associated to that area (such as the dorsolateral prefrontal cortex and working memory, Horvath, Forte, & Carter, 2015a, 2015b, but see Antal et al., 2015). That is, it is well known that there are various factors affecting the effectivity of tDCS. To mention a few examples, it has been shown that electrode montage and drift (e.g. Woods, Bryant, Sacchetti, Gervits, & Hamilton, 2015), genetic differences (Nieratschker, Kiefer, Giel, Krüger, & Plewnia, 2015), anatomical differences (e.g. Datta, Truong, Minhos, Parra, & Bikson, 2012) , and even hair thickness (Horvath, Forte, & Carter, 2015b) can affect tDCS effectivity, which in itself may also interfere with a wide range of cognitive functions (for extensive reviews see Tremblay et al., 2014, Horvath, Forte, & Carter, 2015a, 2015b, Antal et al., 2015; Sellaro, Nitsche, & Colzato, in press). For now, given the wide range of variability in experimental protocols (e.g. with regard to stimulation parameters, the implemented task, individual differences, etc.), it is difficult to converge on the idea that tDCS unequivocally modulates cognitive performance.

Besides applying actual devices or techniques, certain 'lifestyles' that in itself train certain cognitive processes can enhance cognitive performance as well. For example, first person shooter video game playing is associated with enhanced performance with regard to the prioritizing and cascading of actions (Chapter 4). Playing these games most likely allows for cognitive-control improvements as these games are not just about pressing a button at the right moment, but require the players to develop different action control strategies to rapidly react to fast moving visual and auditory stimuli, and to flexibly adapt their behavior to an ever-changing context. Interestingly, this resembles complex daily life situations, such as multitasking conditions, in which we are required to inhibit a planned, ongoing response and to rapidly adapt our behavior (e.g., to execute a different response). Even though this has promising potential, further studies are needed to investigate how much experience with such videogames is needed to obtain enhancing effects, and to investigate for how long these effects last. More acute beneficial effects on cognitive performance and social behavior in healthy humans are observed after the intake of food supplements such as GABA, tyrosine and tryptophan. GABA enhances action cascading performance both when an action has to be stopped and changed towards an alternative one simultaneously, and when one is given more time to stop the first action (Chapter 5). This is especially important with regard to our ever-changing and demanding environment, in which we have to efficiently cascade and prioritize actions. In addition, tyrosine improves cognitive flexibility in terms of pro-active task switching (Chapter 6), again very important with regard to our everyday lives. Looking at social cognition, tryptophan supplementation was found to stimulate charitable donating (Chapter 7). A review of the available studies on tryptophan supplementation (Chapter 8) suggests that tryptophan re-biases attention away from negative stimuli and towards more positive ones. These studies support the idea that the food we eat modulates the synthesis of certain neurotransmitters, which affects the way we perceive and act upon the world. This idea is further supported by the existence of the "gut-brain axis", where communication involves interactions with the intestinal microbiota, which for example release immune activating molecules. Supporting the intestinal microbiota by taking probiotic food

supplements may be used to modify the stress response and consequent symptoms of anxiety and depression, which can reduce cognitive reactivity to sad mood and make people less vulnerable to develop depression (Chapter 9).

In sum, the present dissertation provides further evidence for the idea that brain stimulation, video gaming, and food supplements provide promising tools in enhancing cognitive performance and social behavior. Moreover, this dissertation attempted to gain further insight into the underlying mechanisms that can explain the observed effects. These findings have important societal and economic implications and go hand-in-hand with the ideological individualistic trend in society. More research is needed in order to gain better insights into the underlying mechanisms and the role of individual differences (in for example genetic predispositions, gender, age, etc.) in modulating the observed effects. But the discussed techniques do have promising potential not only in possibly delaying cognitive decline in elderly, but also enhancing social functioning and mental well-being in healthy humans. Similarly, the risk of behavioral problems and pathology in children might be reduced by training (i.e., enhancing) them – which likewise implies considerable savings for our welfare systems.

On a final note, the studies discussed in this thesis do not only have important implications for society in terms of the aging population and costs of welfare, but also at a more personal level. For example, students nowadays tend to apply sometimes dangerous methods to work more efficiently and to be better able to focus and study (e.g. by taking drugs such as methylphenidate or stimulating their brains using commercially available devices). Although these methods have beneficial effects for some individuals, they can be detrimental for and do serious harm to others. What is concerning about this is that people, sometimes even scientists, apply these methods without having any knowledge about the underlying mechanisms. In this thesis, based on the mechanisms involved in these cognitive processes, more healthy and safe ways to enhance cognitive performance are provided. Again, although future studies are needed to gain more insight into the underlying mechanisms, (some of) the methods discussed in this dissertation may eventually be applied to the general

public. Nevertheless, keeping in mind the competitive nature of today's society and combining this with the natural human tendency to always grow, develop, and learn more, and always demand more from ourselves, we should exert caution not to be overenthusiastic, and ask ourselves where to draw the line. In the end, the use of cognitive enhancers could increase the pressure of always being the best and in control, to work harder, longer, and more intensively and so it could, in fact, end up actually worsening the very problem it was intended to solve.