The Future of Cognitive Training

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This chapter concludes the broad overview of cognitive training activities that this book aims to provide. Where will these activities lead us? What are the upcoming challenges? It is these future-directed questions that we would like to address in this final chapter. We will do so by mixing informed guesses about to-be-expected trends, problems, and challenges in the near future, with our wish list of developments that we would like to see without being able to judge how realistic our wishes are at this point. Among other things, we explain why more specific, mechanistic theories will be necessary to guide the development of successful cognitive training programs, how cognitive training might benefit from combining them with other cognitive-enhancement techniques, and how virtual reality and gamification could be used to support the efficiency of cognitive training. We also emphasize the importance of considering individual differences and discuss the societal and ethical implications of enhancement programs.

Need for Theory

There are only few areas where Kurt Lewin's claim that "nothing is as practical as a good theory" does not apply but hardly any to which it applies more than to the area of cognitive training (see also Taatgen this volume). That people get better when they repeat doing the same thing over and over again is an insight that has been with academic psychology for more than 150 years. And yet, we still see many approaches to cognitive training that do not seem to go much beyond this general insight. The

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typical punishment for such theoretically parsimonious approaches is the lack of any interesting transfer from the actually trained cognitive ability to any other cognitive task or skill, which should not be surprising. To reach interesting levels of transfer requires rather good ideas about the mechanisms underlying the cognitive functions one aims to improve. But we still do not see too many of them.

For instance, theorizing about cognitive control—a particularly important cognitive function worth enhancing in many subpopulations—still does not go beyond distinguishing some general, vaguely described factors (like updating, shifting, and inhibition: Miyake et al. 2000) and related brain areas, while specific models about what these factors and areas are really doing and exactly how they operate are lacking. Consider task switching, which plays an important role in many training programs. How exactly do people switch from one task to another? What do we really know about this process and the cognitive codes it operates on, after it has been addressed in hundreds and hundreds of studies? What exactly is a task set? How is it generated from instructions? Can they become stored and retrieved? As long as we have no interesting, mechanistically detailed answers to questions of that sort, it is difficult to see how training programs can generate far transfer in systematic, generalizable ways. Generating more interesting answers is likely to require more collaboration between researchers with more theoretical and researchers with more practical skills and interests. Creating such collaborations will require flexible funding schemes and substantial resources.

Enhancing Cognitive Training

From a more practical perspective, it would seem promising to combine methods suitable for cognitive enhancement. Indeed, there is preliminary evidence that cognitive training programs can be successfully enhanced by boosting performance outcomes in various ways.

First, there is increasing evidence that cognitive training may benefit from the combination with pharmacological interventions. In particular, interventions acting on the dopaminergic system seem ideal to enhance learning in cognitive training given the role of dopamine in associative learning (Schultz et al. 1997) and executive functioning (Colzato et al. 2010, 2014). Indeed, the combined administration of L-Dopa and D-amphetamine has been found to boost language learning in healthy humans (Breitenstein et al. 2004; Knecht et al. 2004). More recently, Gilleen and colleagues (2014) sought to enhance performance on cognitive tasks (working memory [WM], verbal learning, and learning a new language) in healthy participants by combining cognitive training with the cognitive-enhancing drug modafinil. While memory and verbal learning was unaffected, new-language learning was significantly enhanced through the combination, which is at least encouraging.

Second, there is some evidence that cognitive training benefits from the combination with brain stimulation by means of *transcranial direct current stimulation* (tDCS). tDCS is a noninvasive brain stimulation technique that involves passing a constant direct electrical current through the cerebral cortex (via electrodes placed upon the scalp) flowing from the positively charged anode to the negatively charged cathode (Nitsche and Paulus 2011). This technique has developed into a promising tool to boost human cognition (Kuo and Nitsche 2012). Very recently, Richmond and colleagues (2014) suggested that tDCS might support WM training. Participants engaged in an adaptive WM training regime for 10 sessions, concurrent with either active or sham stimulation of dorsolateral prefrontal cortex. Before and after training, a battery of tests tapping domains known to relate to WM abilities was administered. tDCS was shown to enhance learning in the verbal part of the cognitive training and to enhance near transfer to other untrained WM tasks. We emphasize that this study did not include a follow-up session and needs to be replicated and generalized to other cognitive domains. And yet, it does provide preliminary evidence that tDCS might enhance cognitive training and support far transfer.

Third, a number of findings suggest that cognitive training may benefit from a combination with neurofeedback. Neurofeedback is a technique that teaches participants to control their own brain activity by providing systematic feedback about internal states (Sherlin et al. 2011), such as neural oscillations and slow cortical potentials assessed by means of electroencephalography (EEG; Birbaumer et al. 2009). The modulation of neural oscillations through EEG neurofeedback has been shown to enhance different cognitive functions as a function of the frequencies of neural activity (see Gruzelier 2014 for a recent review). For instance, upregulating the upper alpha band improves mental rotation (e.g., Hanslmayr et al. 2005; Zoefel et al. 2011), upregulating gamma-band activity enhances episodic retrieval (Keizer et al. 2010), and upregulating the mu-rhythm supports declarative learning (Hoedlmoser et al. 2008). Very recently, Enriquez-Geppert and colleagues (2014) have investigated the modulation of frontal-midline theta oscillations by neurofeedback and its putative role for executive functioning. Before beginning and after completing an individualized, eight-session gap-spaced intervention, tasks tapping executive functions were administered while measuring the EEG. Compared to a pseudo-neurofeedback group, the group receiving active neurofeedback training showed better performance in WM updating and cognitive flexibility. The idea that learning to increase frontal-midline theta amplitudes facilitates executive functions is captivating and opens the possibility to use neurofeedback to boost the efficiency of cognitive training.

Fourth, research on human-machine interfaces increasingly points to an interesting role of haptic feedback, as provided by means of somatosensory information (vibration) delivered through a user interface. Training with haptic feedback has AU2 been found to reliably support the acquisition of knowledge in chemistry (Bivall et al. 2011) and physics (Han and Black 2011), as well as object manipulation (Stepp et al. 2012). Even though it is not yet clear whether such learning improvements transfer to other tasks, the incorporation of haptic feedback in cognitive training programs represents an interesting avenue for the future.

These are just a few examples for how cognitive training techniques can be enhanced by techniques that have been shown to support learning, but progress in technology is likely to generate more and more options in the near future. While many of them are interesting indeed, their novelty brings a number of risks with it. For instance, new developments have made it possible to produce tDCS-based tools for the use in daily life. While that provides interesting opportunities for research (e.g., in freeing participants from daily visits in the lab), official tests and guidelines for the safe personal use of such devices are lacking. As pointed out by Jwa (2015), given that tDCS is currently not covered by the existing regulatory framework, there are potential risks of misusing this device, in particular as its long-term effects on the brain have not been fully investigated and understood. A recent initiative supported by several research institutes and scientists calls for a more critical and active role of the scientific community in evaluating the sometimes far-reaching, sweeping claims from the brain training industry with regard to the impact of their products on cognitive performance (Max Planck Institute on Human Development, Stanford Center on Longevity 2014).

Recently, colleagues and us (Steenbergen et al. 2015) have taken this recommendation to heart and tested whether and to what degree the commercial tDCS headset *foc.us* improves cognitive performance, as advertised in the media. We used a single-blind, sham-controlled, within-subject design to investigate the effect of online and off-line *foc.us* tDCS—applied over the prefrontal cortex in healthy young volunteers—on WM updating. In contrast to the previous positive findings with CE-certified laboratory tDCS, active stimulation with foc.us led to a significant *decrease* in WM updating. This observation reinforces the view that the scientific community can, and presumably should, play a crucial role in helping to create regulations and official guidelines for the future incorporation of cognitive and neuro-technologies in cognitive training.

Virtual and Augmented Reality

The use of virtual and augmented reality (VAR) has become popular in several areas of cognitive and clinical psychology, where it, for instance, is used to treat phobia (Juan et al. 2005). These kinds of uses could also be seen as enhancing techniques, similar to those discussed in the previous section. Indeed, VAR techniques can serve to visualize instructions and provide more realistic feedback about the achievements of trainees. However, we think that VAR techniques are particularly well suited to address an aspect of cognitive training that has remained underdeveloped so far: the possibility of embodied cognition. The embodied-cognition approach is not particularly homogeneous and theoretically straightforward (for a discussion, see Wilson 2002), but the general idea is that cognition emerges from concrete sensorimotor interactions with one's environment, which assigns an important role to one's body. This fits with older ideomotor considerations about the emergence of cognition through action (Hommel 2015), which, for instance, have motivated the development of the theory of event coding (Hommel et al. 2001). It remains to be seen whether, and in which sense, the idea of embodiment increases our insight into basic cognitive functions and control processes, but if it does, we will need more realistic experimental designs and training conditions. For these purposes, VAR seems ideal.

For instance, cognitive aging is not unlikely to be associated, if not facilitated, by motivational decline that is produced by changes in self-perception. As elaborated elsewhere (~~Hommel~~ 2016), the retired elderly is likely to perceive herself as someone who is no longer productive. Given that most jobs allow people to exert impact on the real world, this impression is based on a real fact—retirement does mean losing this impact. To the degree that the outcome of self-perception affects motivation, this would be likely to undermine the motivation of the retired individual. This in turn would make it difficult both to maintain one's cognitive abilities and to compensate for age-related cognitive decline by means of training. VAR could help to prevent and counteract vicious cycles of this sort by turning the self-perception into a more active one.

Gamification

The widespread popularity of smartphones has led to a real explosion of "apps" to enhance cognitive functioning, ranging from simple alerts reminding the elderly to take ~~his~~ pill to theoretically guided programs to systematically improve specific cognitive functions, such as spatial imagination. Industry and funding agencies have taken notice of the many opportunities these techniques can open, and the current European research agenda (Horizon 2020) has various calls to promote gamification. Obviously, this is likely to strengthen this trend further in the near future, but we think that the full potential of gamification is not always appreciated. Turning psychological experiments and training procedures into apps is certainly handy for both researchers and users, especially as it allows to integrate training programs better with real-life circumstances. Even more importantly, however, gamification will make cognitive training programs more acceptable and increase the motivation to get through with them. Laboratory work on the impact of cognitive training is typically based on data collected from paid or otherwise compensated participants, which reduces the risk of dropout even with extensive training and not-so-exciting tasks. To make it to real-life circumstances, however, the format of cognitive training will need to change dramatically, so to convince individuals to participate. Like physical exercise, it can take a while before cognitive training produces benefits that are recognizable for the trainee. Continuous, fine-graded feedback helps to overcome that problem but only if improvements are visible enough to keep the trainee motivated. Especially training with more preventive aims, for which immediate benefits may not be visible at all, motivation remains an issue. Gamification can help to tackle that issue by making the process more fun and providing additional, benefit-independent reward.

Individual Tailoring

Most cognitive training programs have a one-size-fits-all design and assume that everyone benefits from the intervention more or less the same way and to more or less the same degree (see also Katz et al. this volume). There are several reasons suggesting that this is unlikely to be true. In fact, we suggest that the efficiency of cognitive training and the successful transfer to untrained tasks will often be modulated by interindividual differences, including pre-existing neurodevelopmental factors and differences with a genetic basis. Accordingly, only training programs that are tailored to individual abilities, skills, and needs are likely to succeed.

In particular, we believe that substantial parts of the current controversy about the benefit of the regular use of cognitive training are due to the failure to consider individual differences. For instance, while Schmiedek and colleagues (2010) found positive transfer of cognitive training both in young and older adults, Owen and colleagues (2010) famously reported about a failure to find transfer in 11,430 participants trained online over a period of six weeks. The participants of Owen et al. were trained on cognitive tasks developed to improve reasoning, memory, planning, visuospatial skills, and attention. Participants improved in every single task, as one would expect, but the benefit did not generalize to any untrained tasks. The authors conclude that this provides "no evidence to support the widely held belief that the regular use of computerized brain trainers improves general cognitive functioning in healthy participants beyond those tasks that are actually being trained" (Owen et al. 2010, p. 777).

While we do not question the importance of such large-scale studies, we consider arguments based on mean findings in not further differentiated populations problematic, especially if individual improvements are not taken into account as well. The reason why this is important is that the functions relating psychological functions (and/or their neural underpinnings) to performance are often not linear. For instance, brainstorming-like creativity is assumed to rely on mood and on (presumably striatal) dopamine, but there is evidence that a medium (i.e., not the highest) dopamine level produces the best performance (Akbari Chermahini and Hommel 2010). Given the evidence that inducing positive mood increases the dopamine level, this suggests that individuals with a low dopamine level get better, while those with a medium dopamine level do not or even get worse—which is indeed what has been observed (Akbari Chermahini and Hommel 2012).

Along the same lines, we also considered that successful transfer of game-based cognitive improvements to untrained tasks might be modulated by the genetic variability related to the catechol-O-methyltransferase (COMT)—an enzyme responsible for the degradation of dopamine (Colzato et al. 2014). Participants were genotyped for the COMT Val^{158}Met polymorphism and trained on playing "Half-Life 2," a first-person shooter game that has been shown to improve cognitive flexibility. Pre-training (baseline) and post-training measures of cognitive flexibility were acquired by means of a task-switching paradigm. As predicted, Val/Val homozygous individuals (i.e., individuals with a beneficial genetic predisposition for cognitive flexibility) showed larger beneficial transfer effects than Met/-carriers, supporting the possibility that genetic predisposition modulates transfer effects and that cognitive training promotes cognitive flexibility in individuals with a suitable genetic predisposition. Even if this study needs to be replicated with a larger sample size, we view it as proof-of-principle that highlights the importance of considering individual differences. Considering these differences and assessing how they interact with different training regimes will allow for the development of personalized, individually tailored training programs. Not only will these programs be more effective but they also will be much more motivating for participants (as unnecessary failures due to person-method mismatches can be avoided) and more cost-efficient. This in turn will make the implementation of such programs more likely even in times of sparse budgets. In view of the rapid aging of European societies, the number of potential beneficiaries of such an individualized approach is dramatically increasing, and the societal need for maximizing the human cognitive potential in the elderly will grow further as the economic situation will require extensions of the working lifetime.

Societal Context

Research on, and the application of, cognitive training depends on the societal context, which affects the respective funding budgets and acceptability. Accordingly, it is important to consider which direction societal developments related to these issues are taking. Economically, the interest in cognitive training is mainly driven by the increasing costs of the welfare system, especially with regard to the increasing age of citizens in Western societies. Cognitive training can help, so one version of the idea, to delay cognitive decline in the elderly, which would extend the time people can live autonomously and, thus, reduce the welfare costs for the time thereafter. Along the same lines, training children could speed up the education of healthy individuals and reduce the risk of behavioral deviance and pathology, again with considerable savings for welfare and education systems. But there is also a more ideological reason for the increased interest in cognitive training. Both Eastern and Western societies are continuously driven toward more individualism, which emphasizes the existence and often also the importance of individual differences over commonalities and collectivistic values. These tendencies go hand in hand with ideological developments in public opinion and within political parties, which in many countries have gravitated toward more neoliberal, individualism-heavy positions over the last 15 years or so. Among other things, this has involved a rather systematic deconstruction of the welfare system and established the view of the individual as an architect of his or her own life.

Research on cognitive training has benefited from both aspects of this trend. The economic problems of the welfare system have boosted the interest in procedures and activities that make welfare societally more affordable, and the ideological turn toward individualism provides a natural breeding ground for the public interest in procedures and activities that help to express and to further develop individual needs and interests. We do not expect that the economic problems will disappear soon, but it is possible that the ideological development leads to a swing back. To the degree that it will, the opposition and ethical objections to cognitive training programs may increase substantially.

Ethical Challenges

Like any psychological intervention, cognitive training raises all sorts of ethical issues (Bostrom and Sandberg 2009). In the following, we would like to emphasize two of them, as we suspect that they are likely to dominate future discussions. The first issue has to do with the "naturalness" of the intervention. Encouraging people to take considerable active efforts to change their mind and brain, as we would hope for effective training, must be considered unnatural, in the sense that it is likely to create a situation that without these efforts would not exist. While this is the very point of any sort of training, some people take issue with that. For instance, it has been considered that methods of cognitive enhancement may disrespect dignity and human nature, augment inauthenticity and cheating behavior, and may encourage an uncontrolled striving for excellence and perfection (Habermas 2003; Kass 2002). Such considerations are not far-fetched, as witnessed by the increasing use of cognitive-enhancing drugs, such as modafinil and Ritalin, by students to boost their academic performance. Soon, universities may opt to prohibit drug use altogether or to tolerate it in some situations (exams). The same reasoning is also applicable to commercial brain stimulation devices, which are available on the Internet without any restrictions.

The second, somewhat related issue is that the availability of cognitive training techniques ~~create~~, or at least ~~increase~~, a tension between two widely shared ethical principles: individual freedom and equality. While effective cognitive training programs can be taken to support the expression of the former (assuming that the "unnaturalness" objection can be overcome), it may conflict with the latter. Societies and upward mobility in particular rely increasingly on competition, which emphasizes individual performance and abilities. Cognitive training is likely to create "positional benefits" by improving one's social and economic status as compared to others. While this may be considered an acceptable individual choice, it may have repercussions for general public expectations and criteria. Once a number of individuals have demonstrated that it is possible to improve one's cognitive abilities, public pressure on other individuals could arise to improve their abilities as well. The existence of effective cognitive training programs could thus create or increase the pressure of always being "at the top," to work harder, longer, and more intensively, which in the end may exacerbate the problems one was intending to solve. In other words, the mere possibility to enhance one's cognitive abilities could increase social competition. Worse, as the probability to benefit from cognitive training may differ between individuals, the availability of training programs may contribute to the emergence and increase the size of societal gaps (cf. Bostrom and Sandberg 2009).

Counterarguments exist for both of these ethical issues. For one, any kind of psychological intervention and any kind of training must be considered equally unnatural as cognitive training. Accordingly, if one finds psychologically guided education and physical exercises of athletes acceptable, it is difficult to see in which sense cognitive training falls into an ethically different category. For instance, while objections to cognitive enhancement by means of particular diets or food supplements (Colzato et al. 2013) have not been put forward so far, the impact of cognitive-enhancing drugs and neuro-technologies, such as tDCS and neurofeedback, ~~rest~~ basically on the same cognitive and neural mechanisms. Obviously, this raises the question why social acceptance might be more widespread for the former than for the latter.

For another, cognitive training could well be used as a way of reducing, rather than increasing, societal/social inequalities by allowing all, and not just the economically privileged individuals, to fully explore and exploit their cognitive potential. This would not eliminate competition but create more equal terms (Savulescu 2009). Moreover, it is important to consider that the widespread use of cognitive training and the associated cognitive benefits might have rather dramatic social benefits. Indeed, some studies estimate that augmenting the average IQ of the world population by no more than 3 % would reduce poverty rates by 25 % (Schwartz 1994) and result in an annual economic gain of US$ 165–195 billion and 1.2–1.5 % GDP (Salkever 1995).

Conclusion

Taken altogether, the future of cognitive training will heavily depend on theoretical, technological, and societal developments. For some of these developments, cognitive researchers are solely responsible, while they can only contribute to others. As we have tried to emphasize, cognitive training is not just one more psychological intervention, but it touches important societal and ethical issues. Accordingly, it would be wise if researchers actively engaged in public discussion of these issues to bring in the necessary expertise, so as to make sure that both risks and promises of cognitive training are realistically assessed.

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