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Review

Tackling cognitive decline in late adulthood: Cognitive interventions

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Abstract

Affordable and easy-to-administer interventions such as cognitive training, cognitively stimulating everyday leisure activities, and non-invasive brain stimulation techniques, are promising avenues to counteract age-related cognitive decline and support people in maintaining cognitive health into late adulthood. However, the same pattern of findings emerges across all three fields of cognitive intervention research: whereas improvements within the intervention context are large and often reliable, generalisation to other cognitive abilities and contexts are severely limited. These findings suggest that while cognitive interventions can enhance the efficiency with which people use their existing cognitive capacity, these interventions are unlikely to expand existing capacity limits. Therefore, future research investigating generalisation of enhanced efficiency constitutes a promising avenue for developing reliably effective cognitive interventions.

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Cognitive aging, Cognitive training, Lifestyle engagement, Non-invasive brain stimulation.

Introduction

With advancing age, cognitive performance typically declines, especially in fluid abilities such as attention, processing speed, and reasoning [1]. These changes observed during healthy ageing are often accompanied by profound changes in brain architecture [2,3] and can affect everyday functioning and life satisfaction [4,5]. Therefore, intensive research efforts have been invested into developing interventions with the potential to mitigate these age-related cognitive changes to support people maintaining their cognitive health into late adulthood. The most popular and widely researched interventions include process-specific cognitive training, promoting cognitively stimulating everyday leisure activities, and administering non-invasive brain stimulation (NIBS).

Cognitive benefits of these interventions are evaluated using pre-test/post-test study designs, in which participants are randomly assigned to an experimental group receiving the intervention or to a control group. Control groups can be passive or active. Whereas participants in passive control groups go on about their life as normal in-between assessments, active control groups complete an alternative intervention that is designed to be minimally demanding for the targeted cognitive function. Both types of control groups allow for disentangling learning effects arising from completing the same assessment multiple times from intervention-specific effects. Active control groups additionally control for non-specific intervention effects such as expectation and placebo effects [6,7]. Experimental and control groups are then compared before and after the intervention, and sometimes at a follow-up (typically between 1 month to a year).

A hallmark of successful cognitive interventions is to establish generalised cognitive benefits beyond the cognitive processes and skills targeted by the intervention. The degree of generalisation of intervention effects can range from near transfer, that is, benefits on tasks and in contexts highly similar to the intervention, to far transfer, that is, improvements in abilities and contexts different to the intervention. In this article, we review recent evidence for the effectiveness of cognitive training, cognitively stimulating leisure activities, and NIBS to yield such broad cognitive benefits.

Cognitive training

Over the past 20 years, process-based cognitive training has been a particularly popular intervention approach. Cognitive training involves repetitively practising cognitive tasks that are assumed to measure specific cognitive processes and functions. A prime target for cognitive training is working memory, the cognitive ability that provides temporary access to representations that are needed for complex cognition in the present moment. Working memory capacity is severely limited, typically to 3 to 5 representations at a time. Individual differences in working memory capacity are highly predictive of other cognitive abilities and everyday competencies [8], giving rise to the hypothesis that expanding working memory capacity improves cognition more broadly. However, despite initially promising findings [9,10], it soon became clear that the typically observed large improvements in trained working memory tasks often show only little or inconsistent benefits on untrained, structurally different working memory tasks, and rarely generalise to other cognitive abilities [11]. Similar patterns of results have been found for cognitive training of other fluid cognitive abilities, including attention, multitasking, and episodic memory training (for a recent review, see [12]), perhaps with the exception of interventions targeting processing speed [13]. Ongoing research is investigating why processing speed training may be a relatively more successful approach in generating broad benefits including to everyday cognitive functioning [14].

A possible explanation for the presence of large training effects in the absence of transfer effects may be that individual differences in baseline cognitive ability and other characteristics such as personality, motivation, and training adherence affect the effectiveness of working memory training [15]. However, the evidence for such a substantial role of individual differences in the effectiveness of working memory training is mixed [16,17], and the adequate analysis methodologically challenging [18,19]. Another, not mutually exclusive, explanation is that training solely fosters the acquisition of paradigm-specific strategies and routines [20] and stimuli-specific expertise [21], thereby enabling people to use their existing cognitive capacity more efficiently without expanding its limits [12]. Enhanced efficiency will boost performance in the trained task but may rarely generalise to other contexts for which it is unclear how or why these newly acquired strategies and expertise can be applied.

More recent approaches have, therefore, explored the potential of metacognitive training. Metacognition is the ability to monitor and understand one's own thought processes. Improved metacognition can be beneficial for cognitive performance for several reasons. For example, for people who would otherwise underestimate their performance (e.g., due to stereotypes of cognitive aging), more accurate monitoring and estimating of self-performance may increase confidence, self-efficacy, and motivation to tackle challenging tasks, and in people who would otherwise overestimate their performance, better metacognition may enable them to exert more effort on learning. Metacognitive training can involve psychoeducation about cognitive abilities and how they are affected by ageing [22] or metacognitive instruction of how to use newly acquired strategies and skills in other contexts [23]. Other interventions explored targeting metacognitive processing directly (e.g., improving the accuracy of judgments of learning [24]) or combined these approaches with cognitive training (e.g., with working memory training [27]). First encouraging meta-analytic findings suggest these approaches may be a promising avenue [25]; however, only few studies with randomised and actively controlled study designs are yet available and, thus, a more robust body of evidence is needed.

Cognitively stimulating leisure activities

An alternative to training specific cognitive processes through repetitive practice is to promote increased engagement in leisure activities that are thought to contribute to a healthy and cognitively stimulating lifestyle. Empirical and meta-analytical evidence suggests enrichment through physical, cognitive, and social activities can have lifelong effects on cognitive functioning [26], attenuate cognitive decline, and even delay the onset of dementia [27]. Therefore, interventions directly targeting cognitively stimulating leisure activities may yield generalised cognitive benefits.

Likely, leisure activities involving greater cognitive challenge have more potential to induce cognitive improvements. The Synapse Project tested this proposition by comparing activities with high challenge (digital photography and quilting) to activities that are relatively less challenging (socialising and completing tasks with low cognitive demands) [28]. Although the groups' cognitive performance was similar after the intervention, engagement in more cognitively demanding activities led to increased neural efficiency in brain regions associated with attentional and semantic processing. Similarly, highly complex qigong practice involving slow, coordinated physical movements, breathing techniques and meditation, has been shown to produce a range of structural and functional neural changes including in the prefrontal cortex and hippocampus that are associated with better cognitive functioning [29]. These changes on the neural level suggest that these activities may facilitate positive cognitive change, but the typical interventions may not be intensive enough to translate into reliably improved cognitive performance.

Another potential target of intervention studies is playing music, a highly complex activity requiring a range of cognitive, sensory, and motor functions. Cross-sectional studies have shown that playing a musical instrument during life relates to better performance in measures of global cognition, working memory, executive functions, language and visuospatial abilities, as well as greater grey-matter volume in somatosensory brain areas [30,31]. However, randomised-controlled intervention studies in late adulthood are scarce. One exception is a recent 12-months intervention study, in which healthy older adults were randomly allocated to either an experimental group who learned to play the piano, or an active control group receiving music culture lessons with instructions in analytical music listening and music theory [32]. Although both groups showed increased grey matter volume after the intervention, unique associations between tonal working memory improvements and cerebellar grey-matter volume changes and piano training intensity suggest possible indirect effects of musical training on cognitive and brain health.

Finally, playing board and videogames have become popular intervention targets. Cross-sectional work suggests that playing board games is related to everyday cognitive performance in healthy older adults [33], and cognitive improvements have been observed following interventions involving playing traditional boardgames, such as chess, Go, or mahjong, at least in older adults at risk or with cognitive impairment [34]. However, the small number of existing boardgame intervention studies, which also often include only small samples and suffer from high attrition rates, limits these otherwise promising effects. In addition, board games typically require playing with others and, thus, traditional boardgames may not be ideal activities for targeted interventions.

In contrast, videogames, which often involve complex, fast, and dynamic play, can be played either alone or with others over the internet. Thus, training with videogames may constitute a viable alternative to boardgame interventions. Furthermore, observational, cross-sectional research suggests playing videogames to be more strongly related to cognitive performance than playing boardgames, at least in younger adults [35]. Videogame training studies with older adults and active control groups are still scarce. Based on the limited number of studies, tentative meta-analytic evidence suggests videogame training to be similarly effective in younger and in older adults, with an overall small to moderate effect size ($g = 0.25$) [36]. The potential effectiveness of different types of videogames in improving cognition may, however, vary with age. For example, a recent observational, cross-sectional study reported that superior working memory capacity and distraction resistance was associated with strategy videogames in younger adults but with puzzle videogames in older adults [37]. The relationship between cognitive performance and in-game performance (e.g., aim accuracy, stealth-oriented behaviour) has also been shown to vary with age, possibly suggesting that older adults differ from younger adults in how they interact with game mechanics [38]. A better understanding of age differences in utilising game mechanics is important given that the effectiveness of videogame training seems to depend on specific game features, with, for example, larger cognitive benefits after videogame training with first-person perspective than with videogames involving a third-person perspective [36]. Hence, to unlock the full potential of videogames as interventions, more research is needed to identify the specific features and games associated with cognitive benefits across the lifespan.

Non-invasive brain stimulation

Different to behavioural interventions, NIBS methods aim at enhancing cognition by inducing changes in neural plasticity and neural networks. The most common forms include transcranial direct current stimulation (tDCS), transcranial magnetic stimulation (TMS), and transcranial alternating current stimulation (tACS) [39]. The simplest and most accessible technique is tDCS. It modulates the cortical excitability by changing the electric field of the targeted brain regions and networks through a weak, direct electric current (typically 1−2 mA) that is constantly induced from anodal to cathodal electrodes. Safe and effective tDCS protocols for older adults typically administer 1 to 10 sessions of 15−30 min duration each [40,41]. A recent systematic review of 44 studies reported positive, typically medium-sized effects of tDCS benefits, in particular for anodal tDCS targeting the left dorsolateral prefrontal cortex (DLPFC) benefitting working memory and episodic memory [42].

Relative to tDCS, TMS is more expensive and demands a higher level of technical skills. When performing TMS, a transient magnetic field (typically up to 2 Tesla within 1 ms) is focally applied over the target region to generate an electric current in a perpendicular direction. When applied repetitively, TMS modulates cortical excitability differently depending on its frequency: low-frequency TMS ($\leq$1 Hz) decreases cortical excitability, whereas high-frequency TMS ($\geq$5 Hz) increases cortical excitability, resulting in inhibitory and excitatory effects, respectively [39]. TMS, especially repetitive TMS over the DLPFC, can yield medium cognitive benefits (gs ≥ 0.71) that were still observable 3 months later in people with mild cognitive impairment (MCI) and Alzheimer's Disease (AD) [40,43].

Finally, tACS also alters cortical oscillations depending on the frequency with which it is administered. For example, a recent study found that tACS enhanced working memory and long-term memory performance in healthy older adults by entraining low-frequency (theta) rhythms in the parietal cortex and high-frequency (gamma) rhythms in the prefrontal cortex, respectively

[44]. These medium to large effects (ds $\geq$ 0.75) were still observable one month after the intervention. Similar promising effects were found for people with MCI and AD for tACS using a gamma frequency range [45].

To boost the intervention-induced benefits, NIBS techniques have also been coupled with other interventions, such as cognitive training. A recent meta-analysis of 18 studies with samples of both younger and older adults found that, although small (g = 0.14), synergistic effects of working memory training and tDCS were significant and still observable at follow-up testing typically 1 month later [46]. Yet, these effects are rather elusive and difficult to replicate. For example, one randomised-controlled trial with 5 sessions of working memory training combined with tDCS over the DLPFC found that stimulation augmented transfer effects to short-term memory and reasoning in older adults [47]. However, another study found that benefits of 9 sessions of working memory and decision-making training combined with tDCS over the DLPFC emerged only for one near transfer working memory task but not the trained or any other transfer tasks [48].

The cognitive benefits of NIBS techniques are also difficult to replicate when studied in isolation. For example, an analysis of 30 randomly selected, published articles reporting cognitive benefits of tDCS in healthy adults yielded no evidential value, likely due to these previous studies being substantially underpowered [49]. Consistent with these findings, empirical studies also failed to replicate tDCS-induced benefits when testing bigger sample sizes [50]. Taken together, NIBS is a promising technique for counteracting cognitive declines both in healthy aging and in MCI and AD. However, identifying consistent and reproducible NIBS-induced effects is pivotal for building a foundation prior to its wide application.

Conclusion

Cognitive training, cognitively stimulating leisure activities, and NIBS have the potential to mitigate age-related cognitive decline. However, across all three fields of research, despite reliable large improvements in tasks and contexts highly similar to the intervention activities, the evidence for generalised cognitive benefits is limited. Taken together, the pattern of evidence suggests that these interventions are highly unlikely to expand cognitive capacity limits. Yet, in contrast, these interventions have great potential to enhance the efficiency with which people can use their existing capacity [12]. Hence, a promising future research direction will be to develop interventions that capitalise on mechanisms of cognitive efficiency and target their generalisation. To enhance engagement with these interventions and better tailor them to individual needs, methodologically rigorous and well-powered studies are needed to determine how intervention-specific features and people's individual differences and characteristics contribute to the effectiveness of interventions [15].

Credit author statement

Claudia C. von Bastian: Conceptualization, Writing – Original Draft, Writing – Review & Editing, Supervision, Funding Acquisition. **Eleanor R. A. Hyde**: Conceptualization, Writing – Original Draft, Writing – Review & Editing. **Shuangke Jiang**: Conceptualization, Writing – Original Draft, Writing – Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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