EFFECTS OF EXPECTATIONS ON COGNITIVE ENHANCEMENT INTERVENTIONS IN YOUNG AND OLDER ADULTS

Sheida Rabipour

A thesis submitted in partial fulfillment of the requirements for the Doctorate in Philosophy degree in Psychology

Faculty of Social Sciences

University of Ottawa

Preface

Abstract

With increasing life expectancy and global population of older adults, preserving cognitive function throughout life represents a growing priority. Numerous approaches to cognitive enhancement exist, but few have scientific merit. Among the most prevalent – and commercialized – approaches are cognitive training ("brain training") and non-invasive brain stimulation through electric currents applied at the surface of the scalp. The present dissertation describes a collection of work contextualizing the appeal of these cognitive enhancement methods and addressing some of the most pervasive limitations of research in this field thus far.

One largely ignored issue in cognitive intervention research pertains to people's expectations of programs and their relationship with intervention outcomes. In a series of initial studies, we developed and validated the Expectation Assessment Scale (EAS), a tool created to measure as well as prime expectations of outcomes in the context of cognitive enhancement interventions. In our first two studies, we probed expectations of cognitive training or non-invasive brain stimulation in over 1,000 young, middle-aged, and older adults. Ratings on the EAS suggested that older adults may have particularly high expectations of cognitive training, but that expectations can be primed to increase or decrease – at least in hypothetical scenarios. We used these data to assess the psychometric properties of the EAS with item-response theory, and confirmed its internal consistency.

Next, we incorporated the EAS into two cognitive enhancement trials, one investigating a computerized cognitive training intervention in nearly 100 older adults and another examining non-invasive brain stimulation in nearly 100 young adults. Both trials had a double-blind balanced-placebo design in which participants were assigned to the intervention or control condition, and then subdivided to receive either high or low expectation priming (i.e., primed to have high or low expectations of the program's effectiveness). Although expectation ratings replicated our previous findings, results from these trials suggest little, if any, effect of either expectations or the intervention on performance outcomes. We nevertheless found that participants enjoyed their assigned program and that those who received high expectation priming tended to report a more positive experience. Our findings put into question the effectiveness of such interventions and support the need for more rigorous trials of cognitive enhancement.

Ethics and Collaboration

The work described in this thesis was approved by the University of Ottawa Research Ethics Board as well as the Research Ethics Board at the Elizabeth Bruyère Research Institute. The studies were conducted by Sheida Rabipour and Dr. Patrick Davidson, with collaboration from Dr. Walter Boot at Florida State University (data collection for the EAS; separate ethics approval obtained from the local Institutional Review Board), and Drs. Elizabeth Kristjansson (psychometric analysis of the EAS), François Tremblay, and Anthony Remaud (non-invasive brain stimulation trial) at the University of Ottawa (see Contributions of Authors). Although not included within the main body of this dissertation, part of the research conducted for the present thesis was inspired by a collaboration with Drs. Marco Iacoboni and Allan Wu at the University of California, Los Angeles (see Appendix C).

Acknowledgements

I owe the successful completion of my doctoral studies to my adviser, Dr. Patrick Davidson. Thank you for your unwavering patience and flexibility, your motivation and encouragement, and your wholehearted support of my ideas and (sometimes overly) ambitious pursuits. Thank you for always being approachable, available, and – not least of all – for your unassuming direction, without which I may have been writing this dissertation with greyer hair and wrinklier skin. I will forever be grateful for all that I learned under your guidance, and for the opportunities you encouraged me to pursue.

To my committee members, collaborators, and co-authors, thank you for your constructive insights and continual support. To Drs. Andra Smith, Vanessa Taler, and Charles Collin, my committee members in Vanier Hall, thank you for challenging me to improve the quality of my work and strengthening my competency as a scientist. Your eagerness to help and trust in my ability increased my confidence and encouraged me throughout my degree. To Dr. Ken Campbell, my informal adviser down the hall, my experience at uOttawa and doctoral research would not have been the same without your endless knowledge and generosity. I also thank Dr. Bruce Wexler at Yale University for his generous support and guidance in conducting our cognitive training trial. Drs. Marco Iacoboni and Allan Wu at UCLA, thank you for welcoming me into your labs with enthusiasm, sharing your time and resources with me, and motivating me to turn a cool idea into a research trajectory. Drs. François Tremblay and Anthony Remaud, thank you for supporting my work on brain stimulation, which greatly enriched my doctoral experience. Dr. Wally Boot, thank you for your collaborative support in gathering and interpreting data. Dr. Betsy Kristjansson, thank you for your guidance in exploring new avenues of analysis and psychometric research. And to Drs. Veronika Huta and Dwayne Schindler, I am extremely grateful for your guidance in statistical methods.

To my family and friends, who have always stood by me and supported me, words cannot describe the strength and motivation I derive from having you in my life. Thank you for always raising my standards and for setting the examples I look up to and admire. I am honoured to have built and maintained such a strong and empowering relationship with each of you. To Steve, thank you for grounding me, reminding me there is a world outside of academia, and giving me something to look forward to every day. And to Melanie, because I had to.

I am particularly grateful to my parents, who graciously tasked themselves with reminding me I could always work a little harder and felt unrestricted by the taboos of inquiring about my productivity on a daily basis, lest I somehow forget the looming deadline of a PhD dissertation. Of all the inspiring, humbling, and nurturing mentorship I benefited from throughout my academic career, none contributed more wisdom, drive, and work ethic than you provide for me each day.

Finally, to all members of the uOttawa Neuropsychology Lab – past and present – thank you for your time, your support, and your friendship. In particular, I thank the numerous student volunteers, research assistants, and honours students I had the pleasure of supervising. This work would not have been possible without your help!

Contributions of Authors

The ideas and studies described in the present thesis represent unique contributions of Sheida Rabipour, with guidance and mentorship from Dr. Patrick Davidson and input from collaborating researchers. Data collection, scoring, and verification procedures included the collective effort of members of the Neuropsychology Lab and collaborating teams. Below are the specific author contributions for the manuscripts included in the present dissertation.

Using Digital Technology for Cognitive Assessment and Enhancement in Older Adults

S.R. and P.S.R.D both drafted and edited this invited chapter to an edited volume of the Oxford Handbook series.

The (Dis)Enchantment of Brain Training Games

As sole author, S.R. wrote this chapter as an invited contribution to an edited volume.

Do You Believe in Brain Training? A questionnaire about expectations of computerised cognitive training

S.R. and P.S.R.D. designed the study and developed the instrument based on previous work from W.R.B. Both authors collected and analyzed the data, and wrote the manuscript.

What Do People Expect of Cognitive Enhancement?

S.R. and P.S.R.D. designed the study and developed the instrument based on previous work from W.R.B. Data collection in Ottawa and via web-based tools was performed by S.R. and P.S.R.D., while R.A. and W.R.B. collected data from Tallahassee. S.R. and P.S.R.D. analyzed the data, drafted the document, and finalized it based on edits from R.A. and W.R.B. All authors approved the final version of the manuscript for submission.

Measuring Expectations of Cognitive Enhancement: Item Response Analysis of the Expectation Assessment Scale

S.R. and P.S.R.D. developed the instrument and collected the data. S.R. and E.K. analyzed the data. S.R. and P.S.R.D. drafted the document, and finalized it based on edits from E.K. All authors approved the final version of the manuscript for submission.

Testing the Feasibility of a "Placebo" Training Program

This unpublished pilot study was conceived by Sheida Rabipour and carried out under the guidance of Dr. Patrick Davidson. Sheida Rabipour collected the data with help from members of the Neuropsychology Lab, including Marcelo Petrucelli, Cassandra Morrison, and Lara Geinoz. Sheida Rabipour and Cassandra Morrison carried out the statistical analyses.

Few Effects of a 5-week Computerized Cognitive Training Program in Healthy Older Adults

S.R. and P.S.R.D. designed the study with help from M.P. S.R., C.M., and J.C. collected the data. S.R. and P.S.R.D. analyzed the data with help from C.M., J.C., M.O.G.G., and A.P. S.R. and P.S.R.D. wrote the manuscript. All authors reviewed and approved the final version of the manuscript.

Examining the Interactions between Expectations and tDCS Effects on Motor and Cognitive Performance

S.R. and P.S.R.D. designed the study. S.R., P.S.V., A.R., and F.T. collected the data. S.R. and P.S.R.D. analyzed the data with help from P.S.V. S.R. and P.S.R.D. drafted the manuscript and edited it based on comments from P.S.V., A.R., and F.T. All authors reviewed and approved the final version of the manuscript.

List of Figures

Examining the Interactions between Expectations and tDCS Effects on Motor and Cognitive Performance

Supplemental Figures in Appendices

List of Tables

List of Appendices

Table of Contents

1 Introduction: Enhancing Cognition in Aging

1.1 The Impact of Aging on Cognitive Function and Psychological Wellbeing

In Western society, the old adage of growing "older and wiser" is often secondary to fears of declining mental capacity (Hertzog et al., 2008). This mindset may stem, at least partly, from evidence of increasing prevalence of dementia and other age-related diseases hallmarked by impairments in cognitive functions crucial for daily life, including memory, attention, visuospatial perception, and speed of information processing (Prince et al., 2015). Globally, dementia affects approximately 36 million people above 60 years of age, at a rate estimated to double every 5-6 years (Prince et al., 2015). In Canada alone, the personal and communal costs of dementia amount to an estimated $33 billion (Alzheimer Society, 2012). Perhaps more troubling is the fact that treatment options are currently scarce, limited in their effectiveness, and often trigger adverse side effects (Bentham et al., 2004; Ihl et al., 2011; Schneider et al., 2006).

Even in the absence of dementia, brain structure and function naturally change with age (Davidson and Winocur, 2017). These may include lower brain density (Drag and Bieliauskas, 2010), decreased lateralization (Cabeza et al., 2002), and greater recruitment of anterior networks (Davis et al., 2008). Cognitive decline is also present in healthy aging. An early, high-impact study in Canada revealed that 17% of adults over 65 year of age experience cognitive impairment in the absence of dementia (Graham et al., 1997). Declines in basic cognitive abilities such as speed of information processing, visual and auditory perception, memory, and attention, as well as in higher-level cognition (e.g., reasoning, decision making, planning) can occur naturally, in the absence of clinical conditions (Chadick et al., 2014; Glisky, 2007; Harada et al., 2013). Diminishing cognitive capacity may result from a common underlying factor (e.g., decline in a basic function such as processing speed), or from heterogeneous declines in multiple brain regions and networks that can trigger observable changes as early as 30 years of age (Kramer et al., 2006; Park and Gutchess, 2006).

An apparent dissociation exists between levels of brain pathology and changes in behaviour (Stern, 2002). Declines in cognitive function are not observed in all older adults; even when they are, significant individual differences exist in the cognitive abilities affected as well as the degree to which they decline (Glisky, 2007; Nyberg et al., 2012). While researchers have proposed a number of theories to account for age-related changes in cognition (Dennis, 2008), none can entirely account for age-related declines in cognitive function and the degree of inter-individual variability in these changes (Hedden and Gabrieli, 2004). Evidence suggests that age, in itself, may predict only 41% of changes in memory, and that early-life factors such as birth weight and parental education may contribute to its variability (Walhovd et al., 2016). Moreover, the relationship between brain activation patterns and cognitive performance may remain relatively stable throughout life (Walhovd et al., 2016). The nature and pathophysiology of age-related cognitive decline in clinically healthy adults therefore remains debated.

Aside from biological factors (Erdö et al., 2017), age-related cognitive changes in healthy older adults may associate with subjective perceptions of health and mood, and lifestyle habits (Salthouse, 2014). For example, subjective perceptions of memory deterioration in cognitively healthy adults may predict their future development of dementia (Wang et al., 2004). Furthermore, while emotional stability and wellbeing tend to increase later in life, older adults who live in greater social isolation are significantly more likely to experience emotional distress and cognitive decline compared to those who remain socially engaged (Charles and Carstensen, 2010). Similarly, lower social activity and self-ratings of successful aging are bi-directionally associated with geriatric depression (Depp, Vahia, & Jeste, 2010). Although no reliable predictors of healthy aging currently exist, converging evidence suggests that people who maintain a physically active, social lifestyle and engage in mentally stimulating activities may experience better physical and mental health, cognition, and report greater quality of life (QOL; Bherer, 2015; Merriam and Kee, 2014).

1.2 The Promise of Computerized Cognitive Training in Aging

Older adults represent the fastest growing proportion of the global population (Kochhar, 2014). Thus, developing preventative or rehabilitative techniques for cognitive decline is imperative. However, despite widespread concern over declining cognitive function among aging individuals, no clear guidelines exist for those actively seeking to enhance or maintain brain health (National Academies of Sciences et al., 2017).

Cognitive training is one appealing avenue through which older adults may counter the adverse effects of aging (Berry et al., 2010). Often referred to as "brain training" in popular media, cognitive training refers to mentally stimulating activities that aim to exercise cognitive function (e.g., attention, memory, response inhibition) through deliberate, repetitive practice with a cognitively challenging task or activity (Bahar-Fuchs et al., 2013; Rabipour and Raz, 2012). The enhancement of cognitive functions has been widely reported through numerous different approaches that may be considered cognitive training (Cespón et al., 2018; Rabipour and Raz, 2012; Yamaguchi et al., 2018). These include meditative practices (Gard et al., 2014; Zeidan et al., 2010), musical expertise or proficiency in more than one language (Bialystok and DePape, 2009), physical exercise (Hindin and Zelinski, 2012; Northey et al., 2018), interaction with nature (Berman et al., 2008), neurofeedback (Gruzelier, 2014b; Jiang et al., 2017), and non-invasive brain stimulation (Summers et al., 2016). Perhaps most typical of cognitive training practices are programs that involve gamified exercises combining various cognitive skills (Shah et al., 2017) or practice with specifically targeted cognitive tasks or strategies (Morrison and Chein, 2011). These methods are growing in popularity in clinics and among individual consumers aiming to pre-empt the possible undesirable effects of aging.

The widespread appeal of cognitive training, particularly with digital interfaces, has propelled a billion-dollar commercial market projected to be worth over $6 billion by 2020 (SharpBrains, 2013). Programs such as Lumosity (Lumos Labs Inc., 2017), Cognifit (CogniFit Inc., 2014), and Brain Age (Nintendo DS, 2017), which provide computerized cognitive exercises, typify commercialized cognitive training software and are increasingly prevalent: Lumosity, for example, boasted an annual growth rate of 150% in 2013 (Lumos Labs Inc., 2013), garnering millions of users world-wide. Such companies strategically target their "anti cognitive aging" advertising to middle-aged and older adults, preying – sometimes unlawfully (Federal Trade Commission, 2016) – on concerns of cognitive decline often prevalent among these populations (García-Betances et al., 2017).

Numerous forms of cognitive training exist. For example, programs may be domain specific, teaching strategies to improve performance on a particular cognitive skill (e.g., memory) in a particular context. Conversely, programs can aim to strengthen neural networks associated with cognitive functions (e.g., working memory, attention, executive function) through domain general "core" training, with the ultimate goal of transferring to behaviour and wellbeing beyond the context of the training. Among the most prevalent forms of cognitive exercise are computerized versions of behavioural tasks typically used in psychological or neuropsychiatric studies, with varying degrees of complexity. Such computerized cognitive training (CCT) has emerged as a promising method to maintain, enhance, and rehabilitate cognitive function in older adults (Kueider et al., 2012; Rabipour and Raz, 2012). In recent years, CCT has become particularly appealing in clinical research (Clare and Woods, 2004; Daviglus et al., 2010). Many experimental CCT paradigms specifically target adults experiencing cognitive decline due to conditions including mild cognitive impairment, Alzheimer's disease, and vascular dementias (Bahar-Fuchs et al., 2013).

CCT programs may be most generalizable when merging multiple types of cognitive tasks within a game-based interface (Green and Bavelier, 2008). Such CCT exercises adaptive problem solving with high cognitive demands (Morrison and Chein, 2011) through an engaging interface that may motivate players to better adhere to the program (Boot et al., 2013a; Drobics and Smith, 2014). Meta-analyses suggest that training with multimodal CCT programs, particularly those designed under the direction of independent research groups rather than commercial vendors, may improve memory, processing speed, and visuospatial skills (Lampit et al., 2014). For example, one study involving multi-tasking training with a virtual driving game found improvements in distractibility, sustained attention, WM, and enhanced patterns of neural activity related to cognitive control (Chadick et al., 2014). Moreover, older adults who report solving brainteasers such as Sudoku or Tetris exhibit higher speeds of visual processing compared to non-gamers (Wilms and Nielsen, 2014); improvements in other domains are unsubstantiated. Likewise, playing action video games is associated with faster reaction times in a variety of cognitive tasks (Dye et al., 2009): complex action games such as Medal of Honour and Space Fortress may further facilitate improvements in cognitive abilities such as processing speed and executive control in older adults (Basak et al., 2008). The magnitude of such improvements in cognitive function, moreover, appears to increase with age (Toril et al., 2014).

Aside from clinical contexts, evidence suggests that CCT may improve brain function and behaviour in typical aging. For example, studies have reported enhancement of general cognitive functioning or in particular cognitive domains, such as working memory (WM), long-term memory, attention, or speed of processing in healthy older adults (Kelly et al., 2014; Kueider et al., 2012; Reijnders et al., 2013). Specific approaches, such as computerized perceptual training, may increase the performance of healthy older adults on WM tasks and increase the efficiency of neural activation patterns, as evidenced by neural signals over posterior visual areas measured using electroencephalography (Berry et al., 2010). Improvements in cognition following cognitive training have also been correlated with the plasticity of neural networks, including increased cerebral blood flow and structural connectivity in regions associated with resting state activity and executive function, as well as increased white matter integrity (Chapman et al., 2013). The Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study (Jobe et al., 2001) – one of the first and largest randomized-controlled trials of CCT – demonstrated longitudinal evidence for the benefits of training verbal episodic memory, reasoning ability, and attention-based speed-of-processing independently of pharmacological intervention. A portion of the initially reported effects, mainly in outcomes proximal to the training conditions, remained at follow-up after two (Ball et al., 2002), five (Wolinsky et al., 2006), and 10 years (Rebok et al., 2014), particularly in the groups that trained reasoning ability and speed of processing (Williams et al., 2006). Further analyses revealed that participants largely retained their independence, as well as the ability to continue driving in old age despite decreased scores on cognitive tests (Ross et al., 2017). Similarly, the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) study – evaluating a commercial web-based CCT program focusing on auditory discrimination in 487 healthy older adults (Posit Science, 2015) – reported improvements in the trained tasks as well as enhanced performance on measures of auditory memory and attention (Smith et al., 2009). The authors reported sustained improvements in some of the trained and transfer tasks following a 3-month no-contact period (Zelinski et al., 2011). In the COGITO study, 100 hours of training with lab-designed tasks of processing speed, episodic memory, and WM correlated with post-training improvements in tests similar to the trained tasks as well as in general cognitive abilities such as WM and fluid intelligence (Schmiedek et al., 2010). More recently, the Iowa Healthy and Active Minds Study (IHAMS) reported improvements in instrumental activities of daily life as well as depressive symptoms in middle-aged and older adults following speed-of-processing training (Wolinsky et al., 2015). The benefits of CCT in older adults appear to be attainable regardless of technological prowess or prior experience with specific consoles (Kueider et al., 2012).

CCT may indirectly affect cognition in older adults by increasing psychological well-being. The general use of computers and other digital technologies may support independence and perceived quality of life (Mynatt, 2001), and can positively affect cognitive abilities (Kaufman et al., 2014; Tun and Lachman, 2010) and mood (Cotten et al., 2014). Moreover, intervention studies suggest that learning to use digital social networks or electronic tablets may be equally or more effective at improving speed of processing and episodic memory compared to engaging in stimulating activities of daily life and socializing (Chan et al., 2014; Myhre and Glisky, 2013). Beyond the general use of technology, participation in a custom-designed CCT program may improve behavioural measures of executive function and symptom severity in older adults with treatment-resistant depression following four weeks of training (Morimoto et al., 2014). The apparent generalizability of CCT to emotional and psychological composure represents one of most alluring features of this method in aging populations.

1.3 Cognitive Assessment and Enhancement with Digital Technology

As the prevalence of CCT programs grows, leveraging digital technology for both the training and assessment of cognitive function becomes increasingly relevant. In this book chapter, the authors discuss the promise of digital technology for improving cognitive assessment and support of older adults, while emphasizing important caveats that must be addressed. Invited for publication in the Oxford Handbook of Digital Technologies and Mental Health, this chapter aims to provide a practical guide for academics and clinicians to follow to promote successful integration of such technologies into research and practice.

Using Digital Technology for Cognitive Assessment and Enhancement in Older Adults

Sheida Rabipour[1], Patrick S. R. Davidson[1,2,3]

[1]School of Psychology, University of Ottawa, Ottawa, Canada
[2]Bruyère Research Institute, Bruyère Continuing Care, Ottawa, Canada
[3]Heart and Stroke Foundation of Ontario Canadian Partnership for Stroke Recovery, Ontario, Canada

Abstract

Digital technology is becoming increasingly prevalent in cognitive research and clinical applications for older adults. Innovations in web-based cognitive testing, digital tracking tools, and brain-computer interfaces show promise. Digital technology offers potentially safer, more effective, and less costly alternatives to pharmacological and behavioural methods. Computerized cognitive assessment and training show particular promise. The field is still in its infancy, however, and a number of possible limitations must be kept in mind. Here we outline how digital technology shows promise for improving cognitive assessment and support of older adults, while stressing caveats that researchers and clinicians should bear in mind. We conclude with highlights of current challenges and practical guidelines for future research.

Keywords

Aging; Brain-computer interface; Cognitive assessment; Computerized cognitive training; Cognitive intervention; Digital technology; Research methods; Web-based intervention

Introduction: Utopian versus Dystopian Visions of the Future

We live in the Age of Information. You may feel awestruck by how digital technology has improved our lives. Easier access to information and goods and services, instant communication, and simplification of many life tasks can make one feel that digital technology is nothing short of euthenic. You may feel this same sense of optimism when thinking about science and medicine. Digital innovation has led to the marriage of traditionally distinct domains, including clinical treatment and entertainment. The potential pay-offs for cognitive aging are numerous. Older adults no longer need to rely as much on their deteriorating memories, for example, and can instead use digital reminders or life management programs to organize their daily tasks. Researchers and clinicians can employ sophisticated testing software and conduct larger-scale studies, adapting entertainment software to render individual programs more user-friendly and engaging. Technology-mediated cognitive interventions can leverage computer- and web-based applications to become more convenient, efficient, cost-effective, and powerful. Increasingly complex algorithms can tailor cognitive exercises to the strengths and weaknesses of each individual, optimizing treatment. In short, you may feel that you are witnessing the coming of a Digital Utopia.

You may instead feel ambivalent or even harbour dystopian fears about digital technology: Unlimited access to information and digital multi-tasking can lead to overload, and might limit opportunities for deep, uninterrupted intellectual contemplation (Carr, 2010). Relying on automated reminders and search engines instead of our own memories may dull the mind, depriving us of the cognitive exercise previous generations received naturally (Sparrow et al., 2011). Extensive experience with smartphones and the Internet may change brain activity in older adults (Gindrat et al., 2015; Small et al., 2009), but whether these changes are good or bad is unknown. In many cases, initial excitement surrounding a new computerized cognitive intervention – purported to increase intelligence or enhance memory, attention, or information processing speed – quickly turns into scepticism as critics point out weaknesses in the methods and the data.

Which of these two visions is more accurate? How do we ensure that the future of digital technology in cognitive aging is more utopian than dystopian? In this chapter, we outline the promise of digital technology for improving cognitive assessment and support of older adults, while stressing caveats that researchers and clinicians should bear in mind. We conclude with highlights of current challenges and practical guidelines for researchers, clinicians, program developers, and other professionals aiming to integrate digital technology with cognitive assessment and intervention in older adults.

Digital Cognitive Assessment

For over a century, we have measured different aspects of individuals' cognition to compare them to "average." This is particularly useful when aiming to know whether a person is having cognitive difficulty compared to someone of a similar age, education level, gender, and other demographic characteristics. Despite the continuous availability and occasional use of technology over the past century (Wesnes, 2014), cognitive assessment still relies heavily on paper-and-pencil tests administered by an evaluator in a one-on-one session, with results later scored by hand and compared to the performance of an archival standard comparison group. Obviously, this process is time-consuming and labour-intensive, and relies on a potentially out-dated or otherwise inappropriate comparison group.

Digital technology has the potential to improve cognitive assessment. Several computerized batteries have already given us reason for optimism. Leading candidates include the NIH Toolbox (National Institutes of Health and Northwestern University, 2006-2012; Weintraub et al., 2013), the Penn Computerized Neurocognitive Battery (University of Pennsylvania, 2003-2013), and the Cambridge Brain Sciences battery (https://www.cambridgebrainsciences.com/). In healthy young and older adults, these batteries have shown item consistency and construct validity (Gur et al., 2010; Heaton et al., 2014) and proven themselves reliable, inexpensive, and efficient – possibly taking half the time to administer and score relative to traditional paper-and-pencil methods (Levine et al., 2013). Many of the tasks comprising these batteries are face-valid adaptations of classical cognitive and neuropsychological measures; others are variants of online cognitive training tasks and games (Hampshire et al., 2012; Owen et al., 2010). Moreover, digital game-like tests such as the AttentionTrip (Hassan et al., 2015), a variation on the Attention Network Test (Fan et al., 2001), can offer more engaging and comprehensive alternatives to traditional measures and may permit more refined analyses of different cognitive abilities. The current computerized batteries run on desktop computers (either web-based or from the local hard drive), but tablet- and smartphone-based alternatives are being developed (Brouillette et al., 2013).

In addition, computerized cognitive batteries may provide more accurate information about someone's performance in relation to a comparison group. This group may represent typical performance (i.e., a normative comparison) or any other feature relevant to a particular study (i.e., a reference group comprised of a certain population or age group). Traditional cognitive measures often provide comparison data that were collected at one time – sometimes decades earlier – and in one place – usually where the test developers were located. The comparison group may only consist of a few dozen cases. The norms, therefore, may no longer be appropriate in the here-and-now. Further complicating matters, normative scores on many tests of cognition may change over time. If data collection for a comparison group can proceed with little cost and effort using these new computerized test batteries (perhaps through gamified crowd sourcing; e.g., Mitroff et al., 2014), developers can construct a large, up-to-date, local, and individualized comparison group for a more accurate assessment of an individual's performance.

Computerized cognitive assessment is no panacea, of course. It may prove most appropriate as a screening tool or for use with relatively high-functioning people. As work with computerized testing batteries moves forward, it is crucial to learn whether they are comparable to traditional cognitive testing in predicting cognitive decline and the onset of age-related neurological disorders, including dementia, and in differentiating among different cognitive disorders (Parsey and Schmitter-Edgecombe, 2013; Wild et al., 2008). Computerized cognitive assessment offers enough potential benefits, however, to merit optimism.

Digital Cognitive Support and Enhancement

Pharmacology vs. Technology

The Age of Information is also the Age of Pharmacology. Billions of dollars in marketing by pharmaceutical companies every year has led our society to embrace drugs wholeheartedly. Although good data are still scarce (Partridge et al., 2011), preliminary evidence suggests that self-experimentation with nootropics ("smart drugs"), dietary supplements, and off-label use of prescription drugs is rising among students and young professionals (Bossaer et al., 2013; Emanuel et al., 2013; Franke AG et al., 2014). Depending on the substance, the goal is usually to heighten mood, or enhance attentional focus, decision-making, or memory. Interestingly, a small survey by Nature magazine suggested that people over the age of 65 are not far behind 20-year-olds in using these substances for cognitive enhancement (Maher, 2008).

Even the use of conventional drugs for cognition presents problems. Medications thought to be cognitively beneficial, including antidepressants and acetylcholine agonists, often turn out to be less effective than expected (Schwarz et al., 2012). Furthermore, drugs aimed at providing cognitive benefits often have cognitively deleterious side-effects: Heart and blood pressure medications are meant to promote brain health via cardiovascular mechanisms, but these drugs are often anticholinergic and can therefore, ironically, lead to cognitive impairment themselves (Fox et al., 2011). Other dangers of cognitive enhancers, even when taken as prescribed, include depression, hallucinations, and delirium (Cancelli et al., 2009). Side effects are especially pronounced when people take multiple medications ("polypharmacy"), which becomes more common with age (Marcum and Peron, 2012). Moreover, problems with the accessibility, delivery, and monitoring of medications have remained significant since the dawn of the medication era. Calls for better use of the current pharmacopeia (Murray and Callahan, 2003), including improved medication management and monitoring among older adults have, by-and-large, gone unheeded. Given that virtually all drugs have side effects and can be difficult to manage (leading to under- or overdose), wouldn't it be preferable to use technology as a safer – and potentially less expensive – substitute wherever possible?

Digital Cognitive Prosthetics: Technology As A Substitute for Declining Cognitive Functions

One alternative to medication is to use technology as a substitute or support for cognition. These tools are useful for everyone (i.e., not only for people with cognitive impairment), and need not be high-tech: Calendars, diaries, and pill organizers are classic methods of keeping track of past behaviour and ensuring that one remembers to carry out specific tasks when one should in future. They are inexpensive, never crash, and rarely need to be replaced (for a review, see Kapur et al., 2002).

Today, we can choose from among innumerable digital versions of these classic tools. Web-based digital calendars are commonplace, free, and can be accessed from anywhere and shared with anyone. One might be tempted to think of these digital tools as nothing more than old wine in new bottles, but they can incorporate small changes that provide major benefits to cognition and behaviour. For example, although diaries and calendars are potentially useful to memory-impaired people, they are often not as effective as they could be, because people with such disorders often forget to make regular reference to them. Something as simple as a chime or other reminder, which is built into most calendar and organizer software, is very useful to draw attention to an item. Today, most smartphones have free or low-cost applications that provide notifications and reminders not only at a certain time but – thanks to built-in global-positioning systems – also in a specific place.

Memory support can also come in the form of cues to aid autobiographical memory retrieval. Low-tech versions – for example, the photo album – have long been available. However, advantages of digital photo collections include novelty, flexibility, interactivity, and the potential for sharing (van den Hoven, 2014). Instead of merely using digital technology for autobiographical memory cuing, new technologies show the potential to replace memory. Wearable cameras that capture still images at a high rate, or record continuous video, have been available for over a decade (e.g., SenseCam; Microsoft Corporation, 2013) and more sophisticated systems (e.g., Google glass; (Google, 2014); Spectacles; (Snap Inc., 2016)) are emerging. This technology may be especially helpful to people with dementia or other forms of memory impairment (Seamon et al., 2014; Woodberry et al., 2014).

Digital technology also has the potential to revolutionize drug delivery. Numerous patents describe electronic delivery and real-time monitoring of medication (e.g., Katz and Nesbitt, 2014; van der Schaar et al., 2013; Walker et al., 1997). The aim is greater accuracy and efficiency in regulating dosage. However, these innovations often rely on the patient, at least to some extent, for administration. In older adults with cognitive impairment, faulty memory can make this dangerous. As a solution, digital pill bottles can track when the bottle is opened and remind patients by lighting up or sending digital alerts. Initial results of a company-run randomized controlled trial evaluating one example (GlowCap Vitality Inc., 2014) reported 98% medication adherence in patients who used the Internet-linked technology, compared to 71% in patients who relied on their own memory, although more recent reports suggest they might not be as effective in some cases (Volpp et al., 2017). By monitoring medication-taking behaviour and allowing offloading of cognitive functions such as memory, these technologies have the potential to increase adherence, minimizing the danger of over- or under-dose without the need for on-site healthcare practitioners (Kvedar et al., 2014).

The monitoring of health and behaviour can be even more elaborate. Smartphone sensors can automatically track and transmit data on sleep duration, physical activity, and social interaction (Campbell and Choudhury, 2012). Such monitoring applications can extend to the entire home environment and may help identify declining cognitive capacities over time, by tracking performance in activities of daily life (e.g., Dawadi et al., 2013). Futuristic devices may soon restore memory through implants that stimulate brain areas affected by injury or disease (Reardon, 2015).

Despite the convenience of digitally outsourcing many cognitive tasks, some argue that reducing the need for cognitive work is disadvantageous (Carr, 2010; Cellan-Jones, 2014). The more readily we integrate technology into daily life, the less often we have to draw on our own memory and other cognitive functions. Remembering directions, searching for knowledge in books, proofreading for errors in written works, and performing mental math may have helped maintain mental acuity in older adults in the past (Shimamura et al., 1995). If so, then outsourcing our cognitive work to digital proxies may, ironically, contribute to cognitive decline. This fear is powerful, and goes back millennia: In the Phaedrus, Socrates described the concern that the introduction of the new technology of writing would harm memory and thinking. Yet, this fear is difficult to justify with scientific evidence. In fact, some studies suggest the opposite, demonstrating that off-loading memories frees the mind to learn and remember new, more relevant information (Storm and Stone, 2014). Nevertheless, keeping the dystopian possibilities in mind, perhaps it would be best to err on the side of caution: Rather than relying on the aforementioned "bottom-up" technological tools as proxies for cognition, it may be preferable to use technology for enhancing cognitive functions with digital exercises and games. If these technologies prove effective and gain acceptance among patients (Cruz et al., 2013) and regulatory agencies (Payesko, 2017), we may one day see doctors writing prescriptions for them (Dafnis, 2014; Wernick, 2014).

Digital Cognitive Enhancement

The general use of digital technology may support independence and perceived quality of life in older adults (Mynatt, 2001). Cognitive abilities (Kaufman et al., 2014; Tun and Lachman, 2010) and affective states (Cotten et al., 2014) of older adults are positively associated with computer activity. Moreover, for improving speed of processing and episodic memory, small intervention studies suggest that learning to use digital social networks or electronic tablets may be as effective as – and perhaps even more effective than – taking part in stimulating activities of daily life and socializing (Chan et al., 2014; Myhre et al., 2016).

High engagement and appropriate level of challenge are two important components of any cognitive intervention. The balance of these two parameters has been hypothesized to generate an optimal state of consciousness, also referred to as the state of "flow" (Csikszentmihalyi, 1990). This state of focused concentration involves complete absorption in a particular goal viewed as challenging, yet attainable, distortion of one's perception of time, and the experience of engaging in an intrinsically rewarding activity. Digital media may be particularly well suited to promoting flow states by transforming mundane, repetitive cognitive tasks into enjoyable games, and titrating difficulty to best suit a user's performance.

Computerized Cognitive Training: A Booming Industry

Cognitive training is big business. Targeted non-pharmacological cognitive enhancement methods largely focus on the deliberate practice of cognitive operations, such as those involved in memory or attention, through repetition of a particular type of task or activity (Martin M et al., 2011; Rabipour and Raz, 2012). These interventions are often branded as "brain training" and have found their way beyond the clinic, embraced by individual consumers (and their employers) who wish to maintain or enhance mental acuity. Preserving mental functioning is of particular concern to middle-aged and older adults, as they begin to fear the negative cognitive effects of growing older. This demographic is the strategic target of "anti-cognitive aging" advertising by a commercial industry worth over $1 billion and projected to continue growing rapidly (SharpBrains, 2014, 2016).

Among the most prevalent forms of digital cognitive intervention is computerized cognitive training (CCT), which generally involves computerized versions of behavioural tasks used in psychological or neuropsychiatric studies. Programs such as Lumosity (Lumos Labs Inc., 2017), Cognifit (CogniFit Inc., 2014), and Brain Age (Nintendo DS, 2017) typify commercialized CCT, and are becoming very popular: Lumosity, for example, was only launched in 2007, but boasted an annual growth rate of 150% in 2013 (Lumos Labs Inc., 2013) and is now used by over 60 million people world-wide (Venkatesh, 2014).

Potential Benefits

CCT may lead to improvements in general cognitive functioning or in particular cognitive domains, such as working memory, long-term memory, attention, or speed of processing in healthy older adults (Kelly et al., 2014; Kueider et al., 2012; Reijnders et al., 2013; Volpp et al., 2017). Some studies have reported sustained enhancement of these functions compared to baseline or control groups following a no-contact period ranging from a few months (Anguera et al., 2013; Cheng et al., 2012; Zelinski et al., 2011) to several years (Wolinsky et al., 2006). Advanced Cognitive Training in Vital Elderly (ACTIVE; Rebok et al., 2014) – the most extensively studied program in healthy older adults to date – appears to yield measurable, small to medium sized improvements as long as 10 years after initial testing. Reported real-world outcomes of the ACTIVE trial include the ability to continue driving in old age, for people who scored lower on certain measures of cognitive function (Ross, Freed, Edwards, Phillips, Ball, 2016). Moreover, older adults can still benefit from CCT without having prior experience with computers or specific consoles (Kueider et al., 2012).

The benefits of CCT may vary depending on the population that undergoes training and the conditions under which the training is administered. For high-functioning older adults, the most effective approach for improving executive function and information processing may involve training with game-based software that combines multiple types of tasks (Li et al., 2016). Sometimes drawing on a technique referred to as "core working memory training" (Morrison and Chein, 2011), the combination of training tasks can include complex digital media that require adaptive problem solving with rapid working memory encoding and retrieval demands, draw on multiple modalities, and demand concentration and perseverance. Such multimodal CCT is also more engaging and fun, potentially motivating players to adhere to the program and thereby enhancing training effectiveness (**?**Drobics and Smith, 2014). In the research laboratory, older adults have demonstrated improvements in a range of cognitive abilities – including memory, processing speed, and visuospatial skills – following training with various multimodal CCT programs, particularly those designed under the direction of independent research groups rather than commercial vendors (Lampit et al., 2014). For example, a high-profile study reported improved distractibility, sustained attention, and working memory, along with enhanced patterns of neural activity related to cognitive control, following multi-task training with Neuroracer, a virtual driving game ((Anguera et al., 2013); see also (Chadick et al., 2014; Mayas et al., 2014); but for a list of insightful questions about the methods, data, and interpretations of the Neuroracer study see (Simons, 2013)).

In addition to CCT programs developed in the laboratory, commercial video games may facilitate similar, albeit specific, enhancements in cognitive performance: Correlational studies have claimed that older adults who report solving certain types of brainteasers such as Sudoku or Tetris exhibit higher speeds of visual processing compared to non-gamers (Wilms and Nielsen, 2014). However, older adults who regularly engage in these types of activities may be more open to new experiences (Jackson et al., 2012), a personality trait which may account for differences in cognitive function rather than the puzzles themselves. Action video games – including complex action games such as Medal of Honour and Space Fortress – may facilitate improvements in cognitive abilities such as processing speed and executive control in older adults (for an early example using older games, see Clark et al., 1987). The magnitude of cognitive improvement experienced through video game training, moreover, has been argued to increase with age (Toril et al., 2014), but booster sessions may be necessary for sustained benefits (Ballesteros et al., 2015).

Another important influence on the degree to which people benefit from CCT might be the context in which the training occurs. Home-based programs appear less effective than trainer-facilitated training (Wadley et al., 2006), although the degree to which improvements arise from coaching versus the act of traveling to a facility is unclear. Some form of formal coaching nevertheless seems important to web-based applications; reports of significant improvement often describe interventions with at least one supervised weekly session (Lampit et al., 2014). Trainer-mediated programs that offer general support rather than dictate specific rules may help maintain participants' confidence and motivation, and ensure their proper interaction with the program. Regularly administering CCT as part of a group, or through multi-player games that foster social interactions and a sense of competition, may enhance the effectiveness of such programs in both healthy and cognitively impaired older adults (Drobics and Smith, 2014). An example of such an integrative CCT is the ElderGames Project (Gamberini et al., 2009), a European government initiative supported by independent companies, recreation centres, and universities. Designed to prevent age-related cognitive impairment, ElderGames encourages cross-cultural and inter-generational social relationships within a CCT program administered through an interactive, multi-player tabletop. For adults with limited opportunities for regular face-to-face social interaction, virtual multiplayer games and social networks may offer at least some of the same benefits. In addition to providing social enjoyment, the added demands of communication and team-based problem solving may increase the effectiveness of single-player programs.

Alternatively, CCT may focus on simpler, domain-specific strategy training (Morrison and Chein, 2011). Rather than exercising or restoring a general cognitive skill, strategy training often aims to circumvent deficits (e.g., in working memory) resulting from injury or disease. A number of applied memory strategies appear beneficial, and are applicable to various contexts either within or independent of digital training platforms (McCabe et al., 2016). For older adults, including those who are healthy (Mowszowski et al., 2016) but especially those with cognitive impairment, strategy-based CCT may be more effective (Gross, 2017; Reijnders et al., 2013). In the domain of memory, for example, pure memory strategy training, compared to multimodal cognitive training, appears to have greater benefits for memory itself (Li et al., 2016). Teaching people domain-specific strategies yields circumscribed benefits that might not transfer to untrained abilities (Green and Bavelier, 2008); however, in rehabilitation, such specific improvement is often the primary goal. Strategy training mixed with use of engaging media, such as video games, may further benefit cognitively impaired people by increasing motivation and engagement with the task, and encouraging the deep, enjoyable concentration of "flow states" (Astell et al., 2014).

Caveats

The current evidence on CCT for older adults is conflicting, and has engendered a contentious debate among experts in the field (e.g., CognitiveTrainingData.org, 2014; The Stanford Center on Longevity, 2014). Much of the controversy centres on the rigour with which researchers and program developers have gathered and interpreted evidence of CCT's effectiveness. Notably, a number of commercial CCT programs in today's market have no scientific evidence to support them. Even when studies of a particular CCT protocol exist, they are often too few or too low-quality for meaningful interpretation. The danger of a reporting bias exists among CCT companies and, perhaps more importantly, among academic journals, where positive effects are more likely to be published than null results.

Heterogeneity in design, training and outcome measures, and inclusion criteria hinder comparisons across individual studies. Moreover, the risk of "training-to-task" exists if training closely resembles the tests used to measure changes in performance before and after an intervention. Even when the training and outcome tasks differ, it is often unclear whether improvements occur for a circumscribed type of activity (i.e., near transfer), or generalize to a broad cognitive ability, with enhancement observed in real-world measures (i.e., far transfer). The largest effects of CCT are on trained tasks and, to a lesser extent, on tasks that closely resemble them (Karbach and Verhaeghen, 2014); evidence for sustained far transfer is weak (Melby-Lervag et al., 2016), and can be difficult to evaluate in the existing literature because of methodological problems in many studies (Simons et al., 2016). Many studies lack high-quality control conditions:

Traditionally, studies have tended to include only a no-contact or wait-list control, which can account for practice effects and factors related to the passing of time or the natural progression of disease. However, studies using an "active" control, requiring the control group to perform comparably engaging tasks under the same experimental conditions as the treatment group, are methodologically superior. Use of active control groups can help isolate key components that contribute to a program's success. Unfortunately, the studies that do use an active control condition tend to compare dynamic CCT to repetitive and, arguably, less engaging control tasks (Walton et al., 2015).

In addition, active control groups are essential to account for psychological factors, including participant motivation and expectation of effectiveness (i.e., the placebo effect; Boot et al., 2013b; Motter et al., 2016). To date, studies largely attempt to minimize the influence of these psychological factors by blinding participants and experimenters to the conditions to which participants have been assigned, in hopes that similar proportions of participants will assume they are in the "intervention" condition. This can be difficult to guarantee in the case of a no-contact or wait-list control, however. Further, studies rarely assess participants' levels of and motivation directly, and at most use proxy measures of motivation such as percentage of program completed. However, studies suggest that expectations may differ based on the type of intervention, and as a function of individual characteristics such as age (Rabipour et al., 2017a; Rabipour and Davidson, 2015). High expectations of outcomes may lead participants to engage with tasks differently and invest more time in a program; researchers should explicitly measure and address potential differences in expectations when collecting and interpreting data (Motter et al., 2016). Aside from these methodological limitations, variability exists in treatment adherence across studies on cognitive interventions, particularly those merging virtual reality or gaming systems with physical activity (Miller, 2014). These caveats limit the interpretability of reported results and likely account for the vexing pattern of unsuccessful replications of initial positive findings across the literature.

A final consideration is that, even when all of the aforementioned conditions are met, the majority of studies supporting CCT assess effects under ideal, artificial conditions. For example, a trial of a program that is purported to enhance visual attention will typically measure visual attention on a computer in a quiet research laboratory, perhaps in front of a precisely calibrated simulator. However, visual attention is not only used, but also extremely important, behind the wheel of a car driving through the real – unpredictable – world. In this regard, CCT companies and program developers should instead claim that their products show the potential for, rather than proof of, real-world effectiveness.

Beyond Computer Games: Technology-Mediated Extensions to Cognitive Training

The union of cognitive interventions with digital technology has numerous potential advantages. On a large scale, data mining techniques on social and other digital media can provide numerous types of information from thousands of people and help researchers better design individual programs while gleaning insights into human behaviour and cognition (Ruths and Pfeffer, 2014). Within the scope of individual therapeutics, CCT software can calibrate the intervention to each person's capacities and change dynamically in response to performance. Digital game platforms offer the possibility of virtual coaching and immediate feedback, and can create "desirable difficulty" in the program; in other words, digital media offer the possibility of tailoring cognitive exercise to individual strengths and weaknesses, and attaining a level of challenge appropriate for each participant. Similar to the tracking of medications, CCT can discretely track treatment adherence. Furthermore, in comparison to traditional, face-to-face therapy sessions, CCT demands fewer resources, including time, money, and equipment (Wadley et al., 2006). Digital software permits multiple concurrent sessions to be directed by a single professional. Thus, web-based applications have the collective advantage of offering standardized care from the comfort and privacy of home or through group sessions, while also increasing the accessibility of treatment. Moreover, web-based CCT enables researchers to examine larger samples using fewer resources. It is common for studies to now include hundreds (e.g., Smith et al., 2009) or even thousands of participants (e.g., Owen et al., 2010).

CCT can also incorporate technologies that enable self-directed changes in brain activity and physiological responses. Through a process termed neurofeedback, participants actively learn to associate and control their own emotional reactions or behaviours with specific patterns of brain activity that are displayed on a screen, in real time (Angelakis et al., 2007; deCharms, 2008). Different approaches rely on electrical brain activity (i.e., EEG), blood-oxygenation level (i.e., fMRI or fNIRS), or a combination of these. Although the reported effects of neurofeedback are controversial and may result from placebo (Thibault and Raz, 2016; Thibault et al., 2016), older adults have improved on measures related to attention and executive function following various neurofeedback techniques (Gruzelier, 2014b). Similarly, biofeedback techniques pertaining to one's own cardiac, electrodermal, or breathing output during CCT may help control a plethora of physiological and emotional responses related to conditions such as stress, anxiety, and even cardiovascular or muscular conditions typically treated with medication (Peira et al., 2013; Prinsloo et al., 2014). Aside from monitoring brain activity, brain-computer interfaces (BCI) can couple patterns of brain activity associated with a particular command to an output on digital software, and can incorporate common cognitive tasks as part of a gamified approach (Portugal et al., 2013). Streamlined versions of this technology include NeuralPhone, which uses EEG signals, conveyed through a wireless, commercially-available headset, to drive smartphone applications (Campbell and Choudhury, 2012). Integrating neuro- or biofeedback into BCI may improve BCI functionality (Fazli et al., 2012). Influencing activity using these devices may improve learning conditions, and increase the likelihood of training-related cognitive improvements. Modulation of one's own brain activity may be particularly beneficial for those who require assistance during learning.

Regardless of health status, older adults generally require more time and effort to improve on a practiced task (Rabbitt, 1993). Software-based cognitive interventions afford older adults the time to practice on their own. Creating user-friendly game platforms can also ease the process of adapting to new technologies and render game playing more enjoyable. In addition, non-invasive brain stimulation, including transcranial magnetic stimulation and transcranial direct-current stimulation (tDCS), have the potential to enhance plasticity while performing cognitively challenging tasks, decreasing the time necessary to acquire a particular cognitive skill and increasing the magnitude of improvement within a specific timeframe (Martin et al., 2014). For instance, preliminary studies have claimed improvements in cognitive control following such stimulation (Ditye et al., 2012). Relatively affordable, portable, and – if used properly – safe and painless (Bikson et al., 2016), tDCS is a particularly appealing tool for home-based CCT or interventions involving large numbers of participants. Portable devices and mobile applications from commercial vendors such as Foc.Us (foc.us, 2017), Thync 2017, and Halo 2017 aim to leverage this technology to target consumers of all ages, promising improved mood, mental function (e.g., for gaming), and physical performance (e.g., for sports) using their headsets.

The unsupervised use of CCT and, especially, of brain stimulating devices can be problematic. What happens when experimental products appear prematurely on the commercial market? CCT applications are largely unregulated by governmental or third-party agencies (Schulke, 2013), often advertising themselves as entertainment products to avoid legal ramifications. Brain stimulation poses health risks if not used properly; however, universal guidelines do not currently exist. Short-term risks include scalp tenderness, headaches, dizziness and – however rare – mild burns or induced seizures (Davis, 2014). Potential long-term side effects related to prolonged exposure to the current (i.e., greater than 30 minutes), repeated use, incorrect settings (e.g., high intensity of current), or use in inappropriate contexts are not currently documented, but require more explicit evaluation (Bikson et al., 2016). Similarly, the safety of brain stimulation over unstudied brain areas, and when used with children and certain clinical populations, is unclear (Kadosh et al., 2012). Furthermore, studies report inconsistent findings regarding polarity effects on cognitive function (Jacobson et al., 2012). Recurrent issues in CCT research, including lack of consensus regarding optimal frequency and duration of training, as well as trial design and controls, are also pertinent to brain stimulation (e.g., Berryhill et al., 2014; Schambra et al., 2014), and to other approaches, including neurofeedback (Gruzelier, 2014a). A 2014 consensus statement – signed by more than 70 cognitive scientists – warns consumers against the overzealous claims of cognitive and lifestyle improvements made by companies (The Stanford Center on Longevity, 2014); the resulting counter-statement echoes many of the same concerns, despite concluding on a more optimistic note (CognitiveTrainingData.org, 2014). Thus, despite the potential of CCT and adjunct technologies in improving cognitive function, outstanding methodological questions and health concerns demand caution in using individual programs.

Researchers are increasingly noting flaws in CCT studies and making recommendations to promote higher quality research in future (e.g., Mowszowski et al., 2016; Simons et al., 2016). Navigating the sea of available products, however, is difficult for consumers. As marketers push the idea that CCT works for people of all ages, researchers rush to counter over-zealous claims, feeling compelled to remind the public that these products often show potential for effectiveness, rather than definitive evidence (The Stanford Center on Longevity, 2014). In January 2016, Lumos Labs received a $50 million fine for "deceiv[ing] consumers with unfounded claims that Lumosity games can help users perform better at work and in school, and reduce or delay cognitive impairment associated with age and other serious health conditions " (Federal Trade Commission, 2016). Cases against CCT companies are nevertheless rare. Many companies skirt the legal ramifications of false advertising by leading consumers to infer certain claims, rather than stating them explicitly. Advertising, testimonials, and inaccurate causal implications are so common that they are difficult to combat. Since the 1990s, for example, scientific evidence has largely suggested that crosswords and other puzzles hardly improve intelligence or general cognitive function (Hambrick et al., 1999); yet the myth that they are helpful persists. In an effort to increase scientific rigour and combat criticism, CCT companies might opt to collaborate formally with independent researchers to evaluate their programs' effectiveness.

Technology and Aging: Methodological Considerations

Convenience, and its Costs

One of the greatest benefits of digital technology is the possibility for remote (often, home-based) use. Digitally mediated programs offer not only convenience, but also peace of mind: Older adults can log in regardless of physical or geographical limitations, and need not face unpleasant or dangerous conditions to travel to a lab or clinic. Scheduling is rarely an issue, since most programs allow participants to complete their cognitive assessment or exercises whenever they wish. Costs associated with travelling and meeting with a clinician or coach are minimized. Convenience, therefore, is the most evident advantage of computerized assessment and training.

What are the potential costs? Financially, while many CCT programs are initially free or low-cost, companies can limit access to services unless users upgrade their subscriptions. Furthermore, absent a researcher or clinician providing guidance and debriefing, there is no guarantee that participants truly understand the potential risks, benefits, and personal as well as communal implications of the program (Nosek et al., 2002). Finally, although password-protected accounts offer relative privacy, the security of digitally collected and stored information can never be guaranteed. Even if program administrators do their best to ensure discretion and confidentiality or anonymity, the possibility for hackers to extract information remains for all databases and software applications – even those on secured networks. Although standards of security and privacy for electronically-transmitted health information exist, governing bodies and legislation such as the Health Insurance Portability and Accountability Act in the United States may be inadequate in ensuring that third-party developers adhere to proper data protection standards (Schulke, 2013). Moreover, guidelines on how to best protect and handle digital data differ based on jurisdiction. As a result, concerns about the protection of sensitive data remain far from trivial.

The Importance of Technology: Seniors Are Catching Up

Not surprisingly, today older adults do not use computers and virtual media as much as younger generations. According to a national survey in the United Kingdom, 13% of older adults had never used the Internet as of the first quarter of 2014, compared to a negligible percentage in younger age brackets (Office for National Statistics, 2014). The numbers are comparable in the United States, where the Pew Internet Project reported that 47% of adults over 65 years of age, and 66% of adults over 75, do not use the Internet or email(Zickuhr and Madden, 2012). Within the latter age group, perceived relevancy and lack of confidence in the ability to master new technologies are the leading reasons reported for Internet abstinence (Charness and Boot, 2009). Other factors that may contribute to technological aversion include ineffective communication and lack of accommodation for the changing cognitive and physical needs of older adults (Pew and Hemel, 2004).

Despite these statistics, the number of older adults using the Internet – including email and social networking – and electronic gadgets is increasing steadily. For example, a third of British seniors now use the Internet daily, three times more than a decade ago (Office for National Statistics, 2014; Statistics, 2013). The increases are similar across the Industrialized world (Statistics Canada, 2014; Zickuhr and Madden, 2012). Moreover, once online, many older adults will begin using the Internet on a daily basis. Organizations such as the Center for Research on Aging and Technology Enhancement (CREATE, 2012) aim to facilitate this process by studying the degree to which technological interfaces and instructional support offered by developers can be tailored to the capabilities of target users.

Do you see what I see? Cognitive and Perceptual Aspects of Aging

In healthy aging, cognitive decline is subtle and relatively specific (for a review, see Davidson and Winocur, 2017). Older adults mainly show declines in speed of perceptual and mental processing, and in aspects of attention, short- and long-term memory, and complex problem solving (i.e., aspects of executive function). These are the domains that receive the greatest focus in cognitive assessment and rehabilitation.

Several factors can exacerbate or mimic cognitive decline, even when cognitive capacities are normal. For example, low mood or depression can resemble memory impairment. Perceptual problems, such as visual or auditory limitations due to peripheral sensory loss, can masquerade as cognitive decline. In other words, older adults who have trouble seeing or hearing may be mislabeled as having cognitive difficulties. As with cognitive changes in aging, perceptual changes are relatively specific: In vision, common issues include loss of acuity and contrast sensitivity (Owsley, 2011). In hearing, loss of high-frequency acuity is especially prevalent, meaning that older adults will have greater difficulty hearing higher-pitched sounds (e.g., having more difficulty understanding speech produced by a woman than speech produced by a man).

Two additional points regarding digital technology are worth mentioning. First, an overarching problem in cognitive aging is that the costs of multi-tasking appear to be greater for older adults than for the young. Thus, any assessment, rehabilitation, or other application that has "too much going on" risks underestimating the level of performance that older adults could achieve under less-taxing circumstances. Second, in most aspects of cognitive and perceptual aging we see a wide range of individual differences: Some older adults do as well as the best young people, but others perform far below that level. Factors related to personality (e.g., openness to experience) and beliefs about intelligence may also contribute to differences in adherence to and performance on CCT programs (Double Birney, 2016). Cognitive assessment and rehabilitation tasks must therefore be constructed to allow for wide variability in performance, and extensive pilot testing might be required to ensure that scores are not at the ceiling or on the floor.

Practical Considerations for Researchers and Practitioners

What practices will help prevent, rectify, or overcome current methodological and practical challenges in providing cognitive assessment and intervention to older adults? The most fundamental considerations involve the physical and cognitive capabilities of older adults. In addition, researchers and practitioners must address the psychological barriers preventing older adults from using technology. Many older adults are intimidated by the rapid pace of digital media, and may believe themselves incapable of mastering the novel techniques and terminology required to enjoy new technologies. Such perceptions may be amplified by societal stereotypes about older generations being incapable of mastering technology. Program developers often fail to take these fears into account, and thus might not convey the potential benefits of specific programs in a language that appeals to the target population.

Together, these perceptual barriers often discourage older adults from investing the time needed to learn new technologies – even if they might have otherwise wanted to learn. On the other hand, if someone has lived an entire lifetime without computers, the Internet, and sophisticated mobile applications, explaining why such technology could improve his or her standard of living may mean little unless potential losses – becoming disconnected from the community, losing touch with loved ones, receiving sub-optimal care, etc. – are effectively communicated. Minimizing age-related stereotypes as well as other cultural or demographic differences may help counteract the fears and lack of knowledge of older adults, and ensure that as many participants as possible have an optimal experience.

For researchers, adopting scientifically rigorous methods is essential to ensuring that an intervention genuinely has the intended effects. The design of a program must, first and foremost, cater to a particular population. Older adults with cognitive or physical impairments have vastly different requirements from those who are high functioning and independent. To increase the applicability of programs to different needs and capacities, digital technologies can help monitor data on large scales (e.g., through web-based data mining) and facilitate comprehensive, retroactive analyses (e.g., meta-analytic reviews). Such analytic approaches may serve as a filter to identify which cognitive programs have shown the most potential and in what contexts, thereby optimizing investment in labour- and resource-intensive – but nevertheless essential – controlled trials for effectiveness (Howren et al., 2014). When evaluating a particular program, researchers must select an appropriate number of participants, ensure they are matched for potential confounders such as age, education level, and health status, and randomize them into appropriate comparison groups (Boot and Kramer, 2014).

Understanding different participant profiles is also crucial. For instance, the vast majority of research on computerized cognitive assessment and interventions has used white, educated, industrialized, rich, democratic (WEIRD) participants (Henrich et al., 2010). However, many non-WEIRD individuals are using these technologies. Factors that contribute to cognitive aging and patterns of digital technology use – including age-related stereotypes or daily access to and dependence on digital media – may have varying influences in different cultures (e.g., Eastern cultures that, arguably, revere the aged) and geographic locations (e.g., urban versus rural communities). Further research on cognitive aging and on digital technology for assessment and intervention with non-WEIRD older adults is needed.

Moreover, studies increasingly administer interventions using web-based media that do not require any participant or patient contact. Although convenient for both participants and researchers, remote administration of cognitive interventions introduces considerable variability in the environment in which the intervention is conducted. Given the value of offering participants such freedom, however, we argue that this is not a flaw as long as researchers can demonstrate program effectiveness under the same conditions during the study period. In order to ensure that participants are administering the intervention properly – an especially important consideration for potentially dangerous techniques such as tDCS – researchers and clinicians may consider holding a training phase during which participants learn the proper method in which to administer the intervention. Furthermore, researchers can impose a regular meeting date during which they observe participants during the intervention to ensure proper administration. These meetings can also serve as social gatherings and promote team-based training in groups.

Digital technologies offer efficient, non-invasive methods for assessing and enhancing cognitive function in older adults. Leveraging digital tools can broaden the range of data and help maximize the effectiveness of interventions. Considering these guidelines should help academics and practitioners overcome the challenges we have outlined, and ensure that the future of older adults using digital technology is more likely to be utopian than dystopian.

Acknowledgements

We wish to thank Dr. David Faust and Annick Tanguay for helpful comments on an earlier draft of this chapter.

1.4 Caveats of Computerized Cognitive Training

Few scientific fields have generated as much public intrigue and controversy as brain training. Computerized or virtual reality games advertised to enhance the brain through repeated practice of a mentally demanding task fuel a billion-dollar industry that shows no sign of abating. Nevertheless, the fundamental question remains: does brain training really work? This lingering debate highlights the darker side of brain training where, even among academics, there is no consensus on the practical benefits of brain games. The following chapter, an invited contribution to an edited volume targeting a lay audience, discusses the evidence that generated the initial hype, as well as the limitations that have led to the current controversy surrounding brain training. The chapter ends by weighing the relative merits and caveats of brain training, and provides context to help readers decide whether brain training represents a worthwhile endeavor in their lives. Providing full perspective surrounding the promise and pitfalls of brain training to non-expert audiences is particularly important with the increasing prevalence of commercial products and –sometimes deceptive or even predatory – consumer advertising. This work aims to provide a balanced view of such programs, while helping guide people to an informed decision regarding the value of available approaches.

1.5 The (Dis)Enchantment of Brain Training Games

Sheida Rabipour

School of Psychology, University of Ottawa, Ottawa, Canada

Imagine your favorite computer game – perhaps a stealthy mission to fight bad guys, a race through a tactical obstacle course, a mind-bending puzzle, or a popular team sport. Imagine losing yourself in guilt-free bliss, knowing that your virtual world of choice is also good for your brain, your mind, and even your overall health.

Few scientific fields have generated as much public intrigue and controversy as brain training. From simple brainteasers to wearable devices that monitor or stimulate brain activity, brain-training programs have enchanted researchers, clinicians, and consumers with the promise of re-engineering the brain to increase productivity, rehabilitate injury, and reverse disease. Perhaps most prominent are computerized or virtual reality games advertised to enhance the brain through repeated practice of a mentally demanding task. The ability to peer inside the living, working brain through neuroimaging techniques has taught us that our daily activities do, indeed, change the way our brain looks and functions. As a result, hundreds of programs – including the famed *BrainHQ*, *Cogmed*, *Cognifit*, *Lumosity*, and countless emerging products – fuel a billion-dollar industry (SharpBrains, 2014) that shows no sign of abating. Amid all the hype, the fundamental question remains: does brain training really work? This lingering debate highlights the darker side of brain training where, even among academics, there is no consensus on the practical benefits of brain games. And as the evidence accumulates, so has the skepticism.

The appeal of brain training is unequivocal. Many of us know the pain of seeing a loved one slip away into dementia or lose the ability to think and act independently following injury. Few people, if any, would turn down the opportunity to be a little more mentally sharp, creative, or productive. Mainstream society is competitive; we live in a culture that often applauds long work hours over personal life. Many of us feel like we need an edge. For those born without the natural abilities or social privileges of others, brain training offers a possible method of "catching up". Outside the domain of personal development, even the most skeptical of academics cannot deny the potential of various techniques to enlighten us about the mechanisms of change in the brain and body. Better yet, all this might be possible non-invasively, without requiring the surgeon's knife or the pharmacist's potion. Such enlightenment is achievable from the simple act of playing a game or slapping on some headgear, and often from the comfort and privacy of home. From all perspectives, brain training is a tantalizing prospect. But, as is often the case, if something seems too good to be true, it probably is.

Recent history has toppled brain training from its pedestal, its reputation diminished by numerous limitations and, in some cases, by outright fraud. Programs advertised to improve memory, focus, and efficiency in daily activities have rarely delivered on their promises. Some available products have no scientific evidence supporting them. Companies have received backlash, even federal lawsuits, for deceptive marketing using unfounded claims that prey on concerns surrounding aging and rehabilitation. For example, ads for *Lumosity* once dominated the media with claims of helping users remember names and birthdates, concentrate better, think faster, and "build a better brain [...] in a way that just feels like games." With millions of subscribers and the implication that their games could even stave off cognitive decline, *Lumosity*, like many other programs who made such claims, was thriving. But in early 2016, the Federal Trade Commission (FTC) of the United States filed a complaint against the creators of *Lumosity* for "deceiv[ing] consumers with unfounded claims that *Lumosity* games can help users perform better at work and in school, and reduce or delay cognitive impairment associated with age and other serious health conditions," costing the company $2 million in settlements out of a pending $50 million fine (Federal Trade Commission, 2016). The story of *Lumosity*, perhaps the most striking, is unfortunately not unique. In 2015, the FTC filed a similar complaint against the makers of *Jungle Rangers*, a program claiming to improve memory, attention, behavior, and school performance in children. These cases have served as cautionary tales to all brain-training companies who overstate the benefits of their products without substantiated scientific evidence.

Brain training draws on the allure of neuroplasticity and the vibrant brain images captured by neuroimaging techniques. Although once unfathomable (Glickstein, 2006), we now know that the brain's many neurons continuously change in response to our daily experiences and can grow more abundant through the process of neuroplasticity. The malleability of the brain is reflected in our behavior, and in our ability to adapt to our surroundings and learn to thrive in different settings. We experience this process throughout life, as we learn to handle tools (e.g., a fork and knife to eat, a pencil or keyboard to communicate) and master musical instruments, sports, or other skills that we develop throughout life. Brain imaging techniques have confirmed this phenomenon, demonstrating links between activity in particular brain areas or networks and the performance of specific tasks.

The discovery of neuroplasticity and the invention of brain imaging heralded an exciting era of possibility in brain sciences. Many jumped on the idea of leveraging the dynamics of neuroplasticity to deliberately shape performance by engaging in these types of activities, using neuroplasticity as a blanket justification for unsupported claims. Thus, the brain training industry – and controversy – was born.

In the early days of brain training, excitement seemed warranted. In both children and adults, training with computer games targeting specific mental skills seemed to improve capacities such as attention, memory, and information processing, as well as the symptoms of common behavioral disorders (Ball et al., 2002; Klingberg et al., 2005; Rueda et al., 2005). As an educational module, programs focusing on structured play or listening skills appeared to improve emotional and social skills (Barnett et al., 2008), perception of tones and literacy (Merzenich et al., 1996), and other mental capacities crucial to scholastic achievement (Diamond, 2012). Beyond improvements in behavior and performance, researchers found training-related changes in the brain, both when people performed a challenging task and at rest (Chapman et al., 2013). For example, studies showed different patterns of brain activity in people who frequently played video games compared to non-gamers (Green and Bavelier, 2008), and in people who engaged in just a few hours of mindfulness meditation training (Tang et al., 2010). These changes were alleged to underlie improvements in the control of attention. Companies, and some researchers, used such brain scans as objective proof that brain training works, without necessarily considering how sustainable these changes might be or whether other activities could induce comparable improvements. Brain training came to be viewed – and advertised – as a potential panacea for age-related pathology, psychiatric illness, and brain injury.

The early evidence that launched brain training onto its flourishing commercial trajectory has been insufficient to justify its continued success. Company websites often draw on handpicked testimonials or unrepresentative case studies to support the effectiveness of their products. The greatest evidence for brain training comes from flawed research using inappropriate methodology. Too often, small improvements in a specific lab environment have been inaccurately exaggerated into headlines hailing brain training as a cure for memory loss or distractibility, with colorful brain images to give the appearance of credibility. Even the more rigorous studies are inconsistent in choosing the type of people they study (e.g., developing children, healthy young adults, clinical populations, or those beginning to feel the mental toll of aging) as well as the tools they use to measure outcomes. Gauging the scientific literature on brain training is no easy feat.

Moreover, scientists evaluating programs have rarely taken into account individual factors that could shape outcomes. For example, in a climate of highly advertised products and vivid debates, brain-training studies have typically failed to consider how people's expectations of a program might affect the program's outcomes. In other words, a program may seem beneficial simply because people believe they will improve certain abilities, leading them to invest more time and effort engaging in a particular activity. The converse is true as well: if you don't expect an activity to enhance some aspect of your life, you are unlikely to engage with it productively enough to perceive any improvement. How can we evaluate programs without considering all the factors that influence training?

The challenges of evaluating brain training become even greater when considering the variability between existing programs. Brain training represents a wide category of products that fit into the larger context of mental fitness. In addition to computerized, targeted mental exercises, the field has grown to encompass digital technologies (e.g., virtual and augmented reality video games) and holistic lifestyle habits (e.g., mindfulness meditation), as well as more traditional forms of training typically restricted to therapeutic interventions (e.g., strategy training). Individual programs often borrow bits and pieces of other exercises, merging computer games with technology to monitor one's own brain activity (e.g., neurofeedback) or to deliver weak electric currents to the surface of the scalp (e.g., transcranial electrical stimulation), purported to accelerate learning and performance gains. The nature of different types of training, as well as the context in which they are applied makes it difficult to compare programs and determine whether support or criticism for one program applies to another.

The case of brain training highlights the pitfalls of premature commercialization before establishing effectiveness and practical societal value. For brain training to graduate beyond preliminary support, more studies will have to adopt the gold standard of randomizing large samples, using control groups that are matched in variables unrelated to the subject of study (e.g., age, education, socioeconomic background), and accounting for factors known to influence the outcomes of behavioral interventions. Objective tools such as brain imaging can serve as a powerful ally to a well-designed study. To be most worthwhile, brain training programs should lead to broad improvements that generalize to contexts outside the lab setting. The problem, however, is that many approaches do the opposite: programs may train your ability to remember a set of objects while playing a game, and may even help you remember a slightly different sequence a few minutes later, but they are less likely to help you memorize your grocery list or remember where you left those darned keys.

Despite the pitfalls of brain training, even researchers have a hard time dismissing the enterprise. In 2014, hundreds of prominent and respected academics divided themselves into two seemingly opposing camps, signing a statement either supporting (CognitiveTrainingData.org, 2014) or refuting (The Stanford Center on Longevity, 2014) the effectiveness of brain training. The statements nevertheless came to the same general conclusion: although brain-training programs have largely over-promised and under-delivered, the endeavor may still prove valuable with more rigorous research.

Context is key when considering the value of brain training. For example, high-functioning people may benefit more from complex game-based software that combines multiple types of tasks and requires adaptive problem solving compared to simpler or more specifically targeted exercises, which may work best for the rehabilitation of functions lost as a result of injury or disease. Asking whether brain training "works" is therefore a flawed and, to a certain extent, meaningless question. Arguably, the better question is whether a particular program can help achieve an overarching goal. In other words: what kind of practice or technique might benefit a particular type of person in a given circumstance?

The decision to pursue brain training is personal. Computer games may add little value if you're already concerned about declining memory or focus and have made other changes in your lifestyle – eating better, exercising more, seeking new and challenging reading material, perhaps even doing some of your own research on brain health. Similarly, if your daily activities rely heavily on technology, chances are that 15 minutes of web-based brainteasers will do little more to challenge your mental faculties. Conversely, if a technology is new to you, or if you feel isolated with scarce opportunity for socializing, digital programs may provide some of the mental stimulation you are lacking, and may further provide an opportunity to connect with other players or access a coach virtually.

Those enamored with brain training often forget that we already shape our mental and physical health in an important way. Through education, we enhance our capacity to think critically and draw associations to solve new problems; through repeated practice, we enhance our memory, perhaps to learn a new skill or memorize lengthy text; through nutritional diet and constructive lifestyle habits, we optimize our wellbeing and performance in daily activities. Brain scans have further shown that certain activities – e.g., meditating, navigating a complex terrain, learning to juggle or play a musical instrument, and playing video games – may alter brain structure and function, even in adulthood. What many consumers don't necessarily realize is that such changes occur naturally – a vulnerability that many companies bank on.

New brain training approaches are constantly emerging, but many of them remain experimental and the evidence inconclusive. Despite the initial hype and commercial success of brain training, recent evidence calls for greater scrutiny of existing modules and a shift in perspectives regarding the applicability of brain training. Yet, the need for greater scrutiny hardly means we should abandon our quest for tools and techniques that help optimize our thought and behavior. The past encourages us to exercise caution in our enchantment, without letting it wane into disillusionment.

Additional Readings

An overview of brain training approaches and applications in research, medicine, education, parenting, and industry: Rabipour, S. & Raz, A. Training the brain: Fact and fad in cognitive and behavioral remediation. Brain and Cognition 79, 159-179, doi:10.1016/j.bandc.2012.02.006 (2012)

An academic review and critique of brain training methods in science: Simons, D. J. et al. Do “Brain-Training” Programs Work? Psychological Science in the Public Interest 17, 103-186, doi:10.1177/1529100616661983 (2016)

A study of people’s expectations of brain training, and why they matter: Rabipour, S., Andringa, R., Boot, W. R. & Davidson, P. S. R. What Do People Expect of Cognitive Enhancement? Journal of Cognitive Enhancement, 1-8, doi:10.1007/s41465-017-0050-3 (2017)

A reader-friendly, academic review of physical and cognitive enhancement in aging: Rabipour, S., Miller, D., Taler, V., Messier, C. & Davidson, P. S. R. in Handbook of Gerontology Research Methods: Understanding Successful Aging (Routledge, 2017)

1.6 Expectation Effects in Cognitive Enhancement

As outlined above, the literature on cognitive enhancement interventions is controversial. Methodology in previous studies has been largely flawed, with little consensus on training schedules and parameters (i.e., intervention “dose”), unrepresentative outcome measures, small samples, and insufficient control conditions. Importantly, studies – particularly those that have reported the largest effects – have often failed to include active control groups that would help distinguish training effects from other, non-specific factors such as the placebo effect.

Factors unrelated to an intervention can greatly impact outcomes. For example, the medical literature is rife with examples of placebo-mediated responses – i.e., genuine psychological or physiological effects attributable to receiving a substance or undergoing a procedure, but not due to the inherent powers of that substance or procedure (Stewart-Williams and Podd, 2004). Notably, studies have shown that the mere expectation of symptom improvement – for example, in the treatment of anxiety or pain, as well as in the measurement of cognitive performance – can generate strong psychological and physiological effects that lead to measurable improvements in symptomatology (Benedetti et al., 2011; Benedetti, 2014). The reverse appears true as well, with studies showing little change or even worsening of symptoms based on neutral or negative expectations of treatment effectiveness (Benedetti, 2014). Such expectations may arise through verbal communication, knowledge or observation of treatment effects, or belief of treatment received. Expectation-mediated placebo effects, moreover, appear reduced in conditions where activity in the prefrontal cortex is impaired, suggesting an important role of frontal-executive networks in the placebo response (Benedetti et al., 2006; Benedetti, 2014). Thus, through the placebo effect, expectations can greatly impact outcomes independently of a treatment or an intervention.

Expectations can also influence outcomes through other types of social effects. Knowledge of being observed – in the context of a study or clinical trial, for example – can lead people to alter their behaviour and experience clinical improvements via the Hawthorne effect (McCambridge et al., 2014; Schwarz et al., 2016). Ageist stereotypes can negatively impact cognitive performance in older adults when they are internalized and activated during performance of memory and other cognitive tests (Barber and Mather, 2013). Thus, expectations and perceptions can shape behaviour to either benefit or disadvantage outcomes irrespective of actual ability.

Accounting for expectation-mediated outcomes is crucial to determining the true effectiveness of an intervention. In the context of cognitive enhancement interventions, more recent studies have made greater efforts to account for placebo effects and other non-specific factors that may impact outcomes. Most commonly, researchers have paid closer attention to blinding to remove the potential influence of participant and experimenter biases and expectations, and have included active control conditions to account for placebo effects. However, such measures may be insufficient: a recent article pointed out that active control groups cannot adequately measure or control for expectation effects, because people in different groups have different expectations – a limitation that the researchers argued to be a "fundamental design flaw that potentially undermines any causal inference" in studies of cognitive intervention (Boot et al., 2013b). The researchers demonstrated that differences in perceived benefits correlated with differences in performance gains, wherein participants tended to improve on outcomes they expected the intervention to benefit the most. Despite this pivotal insight, studies have scarcely taken appropriate measures to evaluate, control for, or rule out the potential influence of expectations on their outcomes. Participant expectations therefore remain a largely unaddressed confound in cognitive enhancement interventions.

1.7 Original Contribution of Thesis

The work presented in this thesis directly addresses many of the current limitations in cognitive intervention research and explicitly examines a largely ignored potential confound: the effect of participant expectations on intervention outcomes. In the context of this thesis, we define expectations as conscious perceptions or explicit beliefs regarding intervention outcomes, which may deliberately inform decision-making or incidentally influence behaviour (Schwarz et al., 2016).

Throughout the studies presented below, we sought to determine: i) whether people have specific expectations of cognitive interventions (e.g., based on media ads, knowledge, experience, etc.); ii) whether expectations of outcomes can be primed through written messages; iii) whether expectations influence engagement with and/or perceptions of cognitive interventions; and iv) whether expectations can influence intervention outcomes. The following sections describe the creation and validation of the Expectation Assessment Scale, a novel tool to assess expectations of outcomes, and the use of this tool in registered clinical trials of cognitive enhancement interventions. These studies are the first to explicitly evaluate and prime expectations of outcomes in this context.

2 Assessing Expectations of Cognitive Enhancement Interventions

Failure to account for participant expectations, and their potential influence on intervention outcomes, represents a major problem with most studies of brain training. One possible contributor to this sparsity of expectation assessment is the lack of a standardized tool or approach to measuring participant expectations. The following series of studies represents a first attempt to create a tool for relatively easy incorporation in studies of cognitive enhancement.

In this work, the authors examined expectations of outcomes of cognitive enhancement interventions using the Expectation Assessment Scale (EAS) and validated its use for measuring and priming expectations of outcomes in the context of computerized cognitive training and non-invasive brain stimulation. The first of these studies, a brief report published in *Behavioural Brain Research*, describes the initial creation of the EAS based on a pre-existing survey used to first identify the problematic lack of expectation assessment (Boot et al., 2013b), and a preliminary evaluation of expectations in young and older adults. The second study, published in the *Journal of Cognitive Enhancement*, is a collaborative study of expectations both cognitive training and non-invasive brain stimulation with Boot and colleagues at Florida State University. The final study of this section, published in the *Journal of Cognitive Enhancement* as a follow-up to the previous article, is a validation analysis of the cognitive training (EAS-CCT) and non-invasive brain stimulation (EAS-NIBS) versions of the EAS. Full versions of these surveys appear in Appendix A.

Our studies show that people are somewhat optimistic of cognitive training but more uncertain about the effectiveness of brain stimulation. Moreover, we found that expectation ratings can increase or decrease based on written information, and that ratings on the EAS are valid based on internal consistency. This work represents a first step towards creating a validated and standardized method of evaluating, as well as priming, expectations of outcomes in the context of cognitive interventions.

2.1 Do You Believe in Brain Training? A questionnaire about expectations of computerised cognitive training

Sheida Rabipour[1], Patrick S. R. Davidson[1,2,3],

[1]School of Psychology, University of Ottawa, Ottawa, Canada

[2]Bruyère Research Institute, Bruyère Continuing Care, Ottawa, Canada

[3]Heart and Stroke Foundation of Ontario Canadian Partnership for Stroke Recovery, Ontario, Canada

Abstract

"Brain training" (i.e., enhancing, rehabilitating, or simply maintaining cognitive function through deliberate cognitive exercise) is growing rapidly in popularity, yet remains highly controversial. Among the greatest problems in current research is the lack of a measure of participants' expectations, which can influence the degree to which they improve over training (i.e., the placebo effect). Here we created a questionnaire to measure the perceived effectiveness of brain-training software. Given the growth in advertising of these programs, we sought to determine whether even a brief positive (or negative) message about brain training would increase (or decrease) the reported optimism of participants. We measured participants' expectations at baseline, and then following exposure to separate, brief messages that such programs have either high or low effectiveness. Based on the knowledge they have gleaned from advertising and other real-world sources, people are relatively optimistic about brain training. However, brief messages can influence reported expectations about brain-training results: Reading a brief positive message can increase reported optimism, whereas reading a brief negative message can decrease it. Older adults appear more optimistic about brain training than young adults, especially when they report being knowledgeable about brain training and computers. These data indicate that perceptions of brain training are malleable to at least some extent, and may vary depending on age and other factors. Our survey can serve as a simple, easily-incorporated tool to assess the face validity of brain training interventions and to create a covariate to account for expectations in statistical analyses.

Keywords

Active control; Brain training; Demand characteristics; Expectation; Intervention design; Placebo effect; Research methods.

Brain training (i.e., enhancing, rehabilitating, or simply maintaining cognitive function through deliberate cognitive exercise) has generated great hope among researchers and the public, yet also fears of hype. On the one hand, myriad studies have described significant improvement in a variety of cognitive functions (e.g., working memory (WM), speed of information processing, control of attention, and memory) following even brief periods of training in healthy young adults, older adults (Anguera et al., 2013; Legault and Faubert, 2012), children (Klingberg et al., 2002; Diamond, 2012), and various clinical populations (Klingberg, 2010; Bahar-Fuchs et al., 2013). Improvements have been reported following many different types of interventions, ranging from targeted cognitive exercises (e.g., Skidmore et al., 2011, or other unitary training modules (Jobe et al., 2001)) to more integrative or holistic approaches (e.g., video games; Rabipour and Raz, 2012). Companies target consumers of all ages and cater to individuals across the spectrum of mental acuity with a variety of products, ranging from hi-tech products or software marketed under the rubric of "entertainment" to complex programs designed for clinical therapy. The promise of brain training enhancing cognitive functioning has created a booming scientific field and a billion-dollar commercial industry, neither of which shows any sign of abating (SharpBrains, 2013).

On the other hand, several high-profile negative findings (Owen et al., 2010) and critiques of brain-training research methods (Rabipour and Raz, 2012; Morrison and Chein, 2011) have tempered the enthusiasm of many researchers (The Stanford Center on Longevity, 2014). One major methodological limitation is insufficient experimental control (Shipstead et al., 2012). Few studies, if any, have addressed the potential impact of participant expectations on brain training results (e.g., via the placebo effect), despite evidence for ubiquitous effects of expectations elsewhere (Finniss et al., 2010): In several psychiatric conditions, patients who begin with higher expectations of the effectiveness of their medications show greater improvement (Amanzio and Benedetti, 1999; Rutherford et al., 2010). Patient expectations may even influence brain stimulation outcomes (Keitel et al., 2013; Mercado et al., 2006).

Little is known about expectations of brain training, but what little evidence there is indicates that expectations are important: Market surveys suggest that approximately half of those who engage in brain training believe they are achieving positive results (SharpBrains, 2013). Patterns of improvement on perceptual and cognitive tasks following action and problem-solving video game training fit with what independent observers would predict (Boot et al., 2013a; Green et al., 2014). Furthermore, advertisements of brain training often target older adults with the promise of preventing or attenuating cognitive decline. Despite the particular importance – and promise – of brain training research in older adults (Anguera et al., 2013; Jobe et al., 2001; Rebok et al., 2014), their levels of expectation are currently unknown. Given the influence of expectations on other intervention outcomes, and the recent surge in consumer marketing of brain training, an investigation of people's expectations of brain training seemed timely (Green et al., 2014).

In the present study, we created a questionnaire to evaluate perceptions and expectations of brain training; for greater precision, we used the term "cognitive training" in our experimental protocol. We examined five main questions: i) Do people tend to have neutral, optimistic, or pessimistic expectations of brain training?; ii) Can a brief message touting (or disputing the claims of) the effectiveness of brain training lead participants to report greater (or reduced) optimism?; iii) Are older adults particularly optimistic about brain training, relative to young adults?; iv) Is perceived effectiveness affected by proposed frequency and dosage of training?; v) Might any other individual characteristics be associated with higher (or lower) expectations?

We administered a web-based survey to 499 participants, including young (n = 380 [275 women]; age M = 19.84, SD = 2.58), middle-aged (n = 15 [10 women]; age M = 47.40, SD = 7.52), and older adults (n = 104 [68 women]; age M = 69.88, SD = 5.27), recruited from the community via flyers, advertisements, and word-of-mouth. We also recruited young adults from the University of Ottawa's Integrated System of Participation in Research for undergraduate students. Participants recruited from the community received no compensation for completing the survey; young adults recruited from the participant pool received minimal course credit (.5 points) for their participation, and were free to choose this study from among several alternatives. The University of Ottawa Research Ethics Board approved this study. Participants anonymously answered questions about their perceptions of the effectiveness of computerized cognitive training. We provided all participants with the same definitions of "cognitive function", "cognitive training", and "computerized cognitive training" before beginning the survey. We performed all analyses (including analyses of variance [ANOVAs] and Pearson correlations) using IBM SPSS Statistics, Inc.

What do people expect from brain training?

We asked participants to rate how successful they believed computerized cognitive training would be at improving their general cognitive function, on the basis of their existing knowledge. All ratings were made on a scale from 1-7 (1 = "completely unsuccessful," 2 = "fairly unsuccessful," 3 = "somewhat unsuccessful," 4 = neutral/"I have absolutely no expectations," 5 = "somewhat successful," 6 = "fairly successful," 7 = "completely successful"). The mean baseline rating of expectations was 4.89 (SD = 1.16), falling between neutral and "somewhat successful," revealing that, based on the knowledge they have gleaned from advertising and other sources in the real world, people are optimistic about "brain training." A frequency analysis concurred, showing that the majority of respondents to this question believed that cognitive training would be "somewhat", "fairly", or "completely" successful (346/499 = 69

Can a brief message touting (or disputing the claims of) the effectiveness of brain training lead participants to report greater (or reduced) optimism?

Following the baseline question, which all respondents answered solely on the basis of their pre-existing knowledge, we presented 441 of our participants with a pair of scenarios in counterbalanced order.

One scenario implied that brain training has high effectiveness (High Expectation Message; Fig. 1A), and the other implied that such programs have low effectiveness (Low Expectation Message); see below. In an initial version (Version I; n = 89) of the survey, the Low Expectation Message was relatively mild, simply prescribing caution when considering information about cognitive training (Fig. 1B). However, because few people – especially older adults – appeared to heed the warning of the "Low Expectation" message, we altered that message to describe cognitive training in a more negative way in Version II (Fig. 1C; n = 352). The messages and corresponding citations in both versions of the questionnaire were comparable in length, format, and reading level.

Overall, participants reported believing the High Expectation Message, with ratings indicating an increase in estimated effectiveness compared to baseline (Version I: $t(90) = 3.82$, $p < .001$; Ms = 5.22 and 4.78, SDs = 1.10 and 1.06, respectively; Cohen's $d = .41$; Version II: $t(361) = 7.11$, $p < .001$; Ms = 4.88 and 5.36, SDs = 1.20 and 1.17, Cohen's $d = .41$; Fig. 2). In contrast, the low expectation scenario led participants to downgrade their expectations compared to baseline (Version I:

(A) High Expectation Message:
You are about to begin a cognitive training program designed by neuroscientists, based on work proven effective in published studies. Research shows that this program can improve mental functions such as memory, concentration, learning, and reasoning, similarly to the way physical exercise improves muscle tone and performance. Just like training your body, training your brain can help you feel better. The program adapts to your performance, creating training sessions that are optimal for your personal needs – just like a personal trainer at the gym. In other words, the program can provide the benefits you hope to achieve with cognitive training. Cognitive training works through neuroplasticity, a process through which your brain changes itself in response to certain types of activity. Research shows that cognitive training can produce real changes after just a few hours, and can last up to several years. Below is a brief list of key points from scientific articles on cognitive training (citations provided for your reference):

"Several studies indicate that attention training using computer based exercises can lead to improved attention in children and adults." Tang & Posner, Trends in Cognitive Science, 2010

"This study offers neural and behavioural evidence of generalized positive effects from video game training on cognitive control abilities of older adults." Anguera et al., Nature, 2013

"Older adults who underwent a brief course of brain exercises saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the course ended, according to results from the largest study ever on cognitive training." Steenhuysen, Reuters, 2014.

(B) Low Expectation Message – Version I:
You are about to begin a cognitive training program designed by scientists, based on theories from published studies. The controversial research states that brain exercise might improve mental functions such as memory, concentration, learning, and reasoning. Companies compare cognitive training to improving muscle tone and performance through physical exercise. Other unscientific sources claim that, just like training your body, training your brain can help you feel better. These claims, however, are not proven scientifically. The levels of the program increase at a standard rate, like most computer games. Some claim that this process has the potential to benefit your brain activity through neuroplasticity. In fact, neuroplasticity refers to any change in the brain, both positive and negative, that results after any kind of interaction. Therefore, the effects of neuroplasticity are not specific to cognitive training; they occur naturally. Skeptics argue that cognitive training cannot produce any real change, and that possible, small improvements would not last that long. Below is a brief list of key points from scientific articles on cognitive training (citations provided for your reference):

"The largest trial to date of 'brain-training' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […] A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning." Katsnelson, Nature News, 2010.

"[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity." Shipstead et al., Psychological Bulletin, 2012

"Available evidence regarding cognitive training remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from cognitive training." Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

(C) Low Expectation Message – Version II:
You are about to begin a cognitive training program, designed based on unconfirmed scientific theories. Controversial theories state that brain exercise might improve mental functions. Companies and other unscientific sources exploit these theories by claiming that, just like training your body, training your brain can help you feel better. These claims are not proven scientifically. No program has been able to prevent or even slow down the death of neurons resulting from age, injury, or disease; this process is believed to cause mental decline. Cognitive training cannot produce any real change, academics argue, and even the perception of improvement would not last. Below is a brief list of key points from scientific articles on cognitive training (citations provided for your reference):

"The largest trial to date of 'brain-training' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […] A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning." Katsnelson, Nature News, 2010.

"[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity." Shipstead et al., Psychological Bulletin, 2012

"Available evidence regarding cognitive training remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from cognitive training." Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

Figure 1. (A) High expectation and (B), (C) low expectation messages used in the web-based survey.

$t(90) = 2.06$, $p = .04$; $M = 4.41$, $SD = 1.43$, Cohen's $d = .29$; Version II: $t(361) = 10.18$, $p < 0.001$; $M = 3.93$, $SD = 1.55$, Cohen's $d = .69$). Simple, yet direct, written messages containing evidence advocating for or against brain training can, respectively, increase or decrease people's reported initial optimism regarding such programs. This notion was supported in the reactions of respondents to the High and Low Expectation messages in comments made at the end of each version of the survey:

19-year old man: *"The use of scientifically backed data in peer reviewed journals make claims by researchers much more authentic. As a result, my neutral position was swayed somewhat to either side based on the evidence. However, I am aware that the messages did not say that all studies supported their data, and the fact that some of the sample study sizes [sic] were not very large also failed to convince me wholeheartedly. "*

23-year old woman: *"The messages stating that there are no findings of positive results of computer programs used for cognitive training shifted my mindset to believe that the training was a complete waste of time and I immediately felt resigned to failure. Regardless of the actual study results, if I believe it will fail I will not attribute [sic] any real cognitive effort or my full attention to the task, the [sic] eliminating a chance for any improvement. The positive messages made me feel that the program has the opportunity to work and that I could control the level of effectiveness with my degree of commitment."*

60-year old woman: *"The messages were quite powerful in shaping expectations."*

76-year old man: *"Although my tendency is to believe that such exercises will be positive in cognitive training, the last group of messages [i.e., the Low Expectation message] have shaken my confidence and have made me question my previous belief."*

Although many participants expressed that a simple brief message could sway their opinion of brain training (e.g., above), we also encountered respondents who were more likely to respond based on their instincts, regardless of the information presented in the high and low expectation scenarios:

20-year old woman: *"[The messages were] somewhat [influential on my expectations], but my main influence was my own perception of cognitive training."*

69-year old man: *"I would think that computerized training would be the*

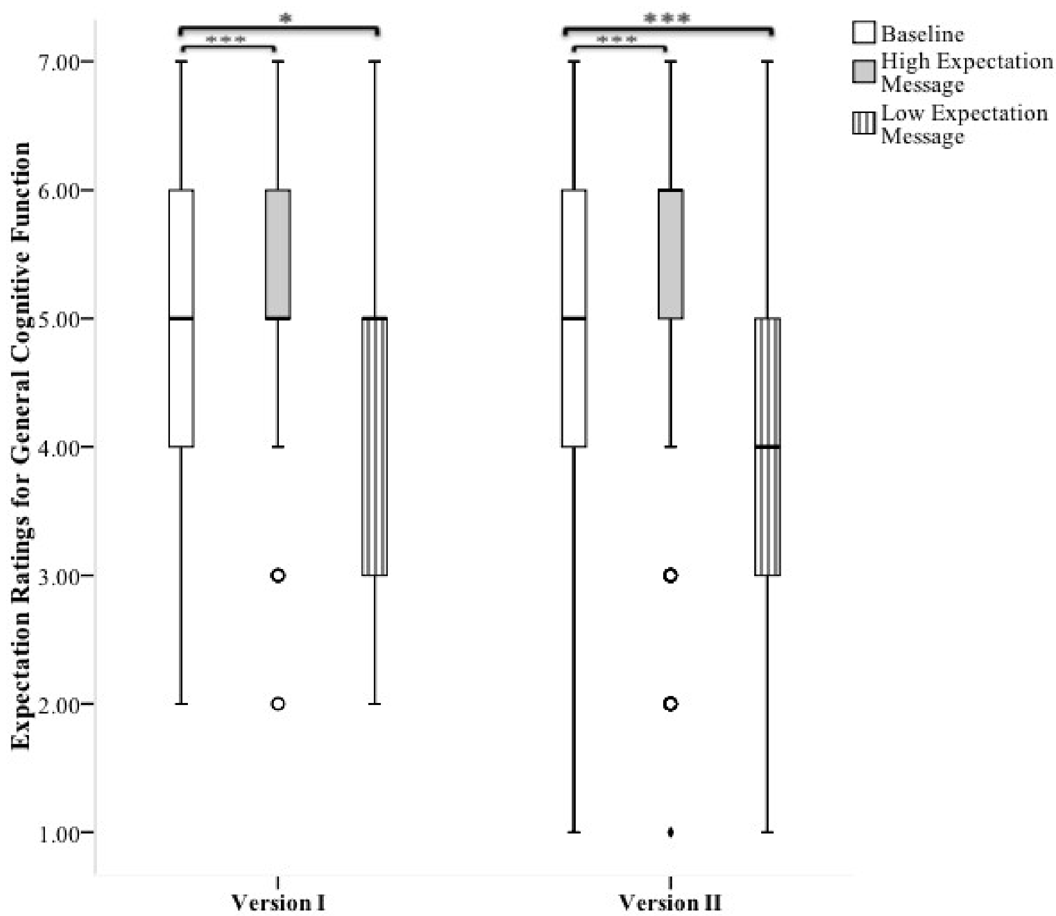


Figure 2. Boxplots showing expectation ratings in versions I and II of the web-based survey. Respondents rated their expectations of the cognitive benefits of "brain training" under three scenarios: At baseline, following a message meant to creat high expectations, and following a message meant to creat low expectations. Compared to baseline, ratings were significantly higher after reading the high expectation message and lower after reading the low expectation message, in both versions of the survey *p<0.05.

most helpful for me."

76-year old woman: *"I didn't put much faith in the negative messages however I was more encouraged by the positive ones."*

87-year old man: *"I would think that at my age, any exercise of the brain would be a great help. The messages did not have an influence on what I thought."*

Herein lies the challenge for consumers of brain training products. How does one weigh and assimilate new information about the possible benefits, while avoiding credulity at one extreme and closed-mindedness at the other? The tendency to maintain personal beliefs despite strong evidence to the contrary, even with conscious awareness of irrationality, is a problem in many contexts, including health. One notable example is the autism-vaccine misconception (Nyhan et al., 2014), which persists in mainstream society despite ample evidence for its inaccuracy. Thus, while expectations may be modifiable in hypothetical scenarios, strongly held preconceptions may have a greater impact on real world behaviour.

Are older adults particularly optimistic about brain training, relative to young adults?

The prevalence of brain training advertisements targeting older adults motivated us to explore potential differences in expectations between older and young adults. Note that we excluded middle-aged adults from age-related analyses because there were comparably few responders in that group. We saw several indications of age differences: First, an ANOVA on version I of the survey revealed a significant interaction between age and expectation condition (F(2, 170) = 16.15, p < .001, η_p^2 = .16), with older adults reporting higher expectations compared to young adults in response to the Low Expectation Message (t(87) = 5.12, p < .001; M_*old* = 5.59, SD_*old* = 1.14; M_*young* = 4.00, SD_*young* = 1.30; Cohen's d = 1.27).

Second, after reading both the High and Low Expectation Messages in Version II of the survey (Fig. 1), a larger percentage of older adults (38/55 = 69%) reported that the High Expectation Message was convincing enough to shape their expectations, compared to young adults (106/252 = 42%; X^2 = 23.93, p = .001). Perhaps more importantly, a smaller proportion of older adults (27/52 = 52%) believed that the Low Expectation Message was convincing, compared to young adults (124/186 = 67%; X^2 = 19.15, p = .004). Responses did not significantly differ based on the order in which messages appeared.

Third, after asking respondents about their expectations regarding general cognitive function in Version II of the survey, we probed further in 187 young and 52 older adults, asking about expectations in six specific domains: memory, concentration, distractibility, reasoning ability, multitasking ability, and performance in everyday activities. When initially asked about general cognitive function, older adults who completed this version of the survey remained slightly more optimistic after reading both the High and the Low Expectation Messages. Moreover, for several of the specific domains, older adults reported being more optimistic about the potential of brain training than young adults: concentration (F(1, 234) = 7.02, p = .009, η_p^2 = .03; Fig. 3A), distractibility (F(1, 234) = 10.74, p = 0.001, η_p^2 = .04; Fig. 3B), reasoning (F(1, 234) = 4.13, p = 0.04, η_p^2 = .02; Fig. 3C), and marginally so for performance in daily activities (F(1, 231) = 2.84, p = .093, η_p^2 = .012; Fig. 3D).

In summary, older adults reported greater optimism compared to young adults regarding brain training, and maintained higher expectations after reading a pessimistic message about brain training. This age-group difference might be related to

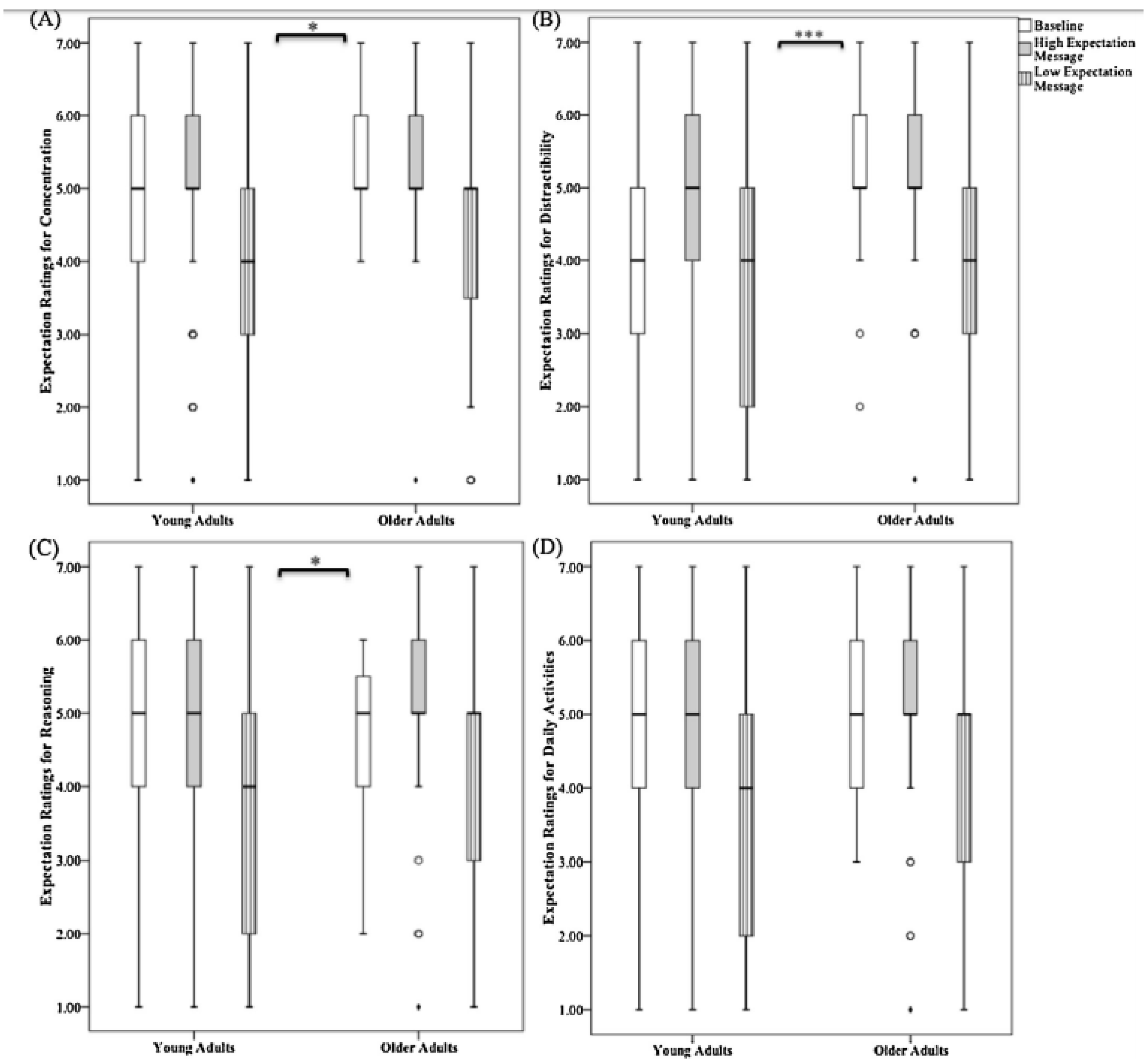


Figure 3. Boxplots showing expectation ratings of the web-based survey in young and older adults. Compared to young adults, older adults report higher expectations of improvement in (A) concentration, (B) distractibility, (C) reasoning, and (D) performance in daily activities. $*p<0.05$; $***p<0.001$.

our sampling. Whereas we recruited many of the young adults from the university participant pool in return for course credit, thereby creating an incentive to participate irrespective of the benefits of brain training, older adults who participated in our study may have been inherently motivated to complete this type of intervention. Nevertheless, members of the general public who purchase commercialized programs are likely to have similar expectations of post-training benefits. Thus, even if the older adults in our study did have particular interest in the effectiveness of brain training, this would likely render our sample more representative of the relevant populations. A good follow-up approach would be to administer this survey to nationally and internationally representative samples of young and older adults, and determine whether the age-related patterns of optimism replicate. If older adults are genuinely more optimistic about cognitive training, this may merely indicate their greater exposure to positive messages about cognitive training in the media. Objectively measuring the respondents' exposure to media messages about cognitive training would be a useful way to address this question in future. Greater optimism of older adults about brain training might instead exemplify a possible bias towards optimism and positivity in general (Chowdhury et al., 2014).

Do people predict differences in effectiveness based on frequency and dosage?

In both versions of the survey, we provided participants a choice of three hypothetical weekly training schedules, each amounting to 25-30 hours of training over 10 weeks, and asked participants to rank the order in which they believed the schedules would be most effective. The majority of both young (149/292 = 51%) and older adults (57/79 = 72%) believed that training for 30 minutes five times per week would be most effective, followed by training for 60 minutes three times per week, and finally training for 90 minutes twice per week.

What other individual characteristics might be associated with having higher (or lower) expectations?

Our exploration of individual differences in responses revealed that expectations of brain training were associated with self-rated prior knowledge about brain training and computer proficiency: older adults who reported having at least some prior knowledge of cognitive training held higher expectations at baseline (M = 5.27, SD = 1.00) than did those who professed no knowledge of brain training ($t(69) = 2.11$, $p = .038$;

M = 4.77, SD = .97, Cohen's d = .51), perhaps a testament to the power of advertising. Furthermore, older adults who spend more than two hours on the computer daily were significantly more optimistic at baseline (M = 5.22, SD = .83) compared to those who only spent 3-5 hours per week ($t(48) = 2.53$, $p = .015$; M = 4.43 SD = 1.34, Cohen's d = .81). In addition, older adults who reported using software-based entertainment (e.g., video or computer games, web-based applications) rated significantly higher expectations at baseline ($t(72) = 3.41$, $p = .001$; M = 5.39, SD = .97, Cohen's d = .80) compared to those who did not (M = 4.64, SD = .93). Similarly, young adults with computerized gaming experience had greater optimism at baseline ($t(204) = 2.66$, $p = .009$; M = 5.10, SD = 1.03, Cohen's d = .38) compared to those with no such experience (M = 4.66, SD = 1.33). We did not find significant sex differences in expectation ratings for cognitive training in either young or older adults. Ratings, either at baseline or following the High or Low Expectation Message, did not change in relation to a person's level or type of education, medications taken, or concerns about declines in their cognitive abilities.

Do people believe in "brain training?"

Overall, we found that people are relatively optimistic, albeit somewhat uncertain, about brain training, based on the knowledge they have gleaned from advertising and other sources in the real world. Moreover, training for brief periods more frequently seems more effective to them than does training for longer amounts of time, less often. Expectations, an important constituent of the placebo effect (Benedetti et al., 2011; Colloca and Miller, 2011), may influence how people respond to brain training and account for at least some of the positive findings in the brain training literature and success of the commercial market. A rich literature on such concepts as the Hawthorne effect (McCambridge et al., 2014) and the use of expectations to enhance therapeutic effects (Finniss et al., 2010; Howick et al., 2013) supports the role of psychological or environmental factors in altering behaviour and biology (Amanzio and Benedetti, 1999; Rief et al., 2009).

Brain training studies rarely account for participants' expectations, despite extensive evidence for their importance in other areas (Amanzio and Benedetti, 1999; Keitel et al., 2013; Mercado et al., 2006; Rutherford et al., 2010). Our survey can serve as a simple, easily incorporated tool to assess the face validity of brain training interventions. This tool may also help us identify the reasons for which some people benefit from interventions to a greater extent than others. In this regard, our survey could be used to create a covariate to account for expectations in statistical analyses of training effects in future work.

As in any survey, it is possible that our respondents simply provided the ratings they believed we wanted (i.e., "demand characteristics"). Thus, for better evidence of the causal influence of expectations on brain training results, we are beginning a trial in which we manipulate expectations using a balanced-placebo design (Rohsenow and Marlatt, 1981). In this version of a randomized double-blind placebo-controlled trial, the treatment and placebo control groups are each sub-divided in two: Half are told they are in the treatment condition and the other half are told they are in the placebo control group. This method can help tease apart expectation from treatment effects. Importantly, however, this approach could still benefit from measuring expectations at different stages of the study: The present data suggest that most participants will be optimistic at the outset of any brain training study, and some will be more optimistic than others. Furthermore, some participants may be more convinced than others of what they are told by the experimenters. Thus, assessing participants' expectations before, during, and after brain training will likely prove useful in future studies, no matter whether the design is correlational or experimental.

Acknowledgements

We thank Cassandra Morrison, Jessica Crompton, and Lara Geinoz for helping with data collection; Dr. Walter Boot for helpful comments on an earlier draft of the manuscript; and the Natural Sciences and Engineering Research Council (NSERC, Discovery Grant), Ontario Graduate Scholarships, and Fonds de Recherche Québec – Santé for support.

2.2 What Do People Expect of Cognitive Enhancement?

Sheida Rabipour[1], Ronald Andringa[2], Walter R. Boot[2], Patrick S. R. Davidson[1,3,4],

[1]School of Psychology, University of Ottawa, Ottawa, Canada

[2]Department of Psychology, Florida State University,Tallahassee, USA

[3]Bruyère Research Institute, Bruyère Continuing Care, Ottawa, Canada

[4]Heart and Stroke Foundation of Ontario Canadian Partnership for Stroke Recovery, Ontario, Canada

Abstract

Enhancing cognitive function through mentally challenging exercises ("brain training") or non-invasive brain stimulation (NIBS) is an enticing yet controversial prospect. Although use of these methods is increasing rapidly, their effectiveness remains questionable. Notably, cognitive enhancement studies have typically failed to consider participants' expectations. However, high expectations could easily make brain-training approaches appear more effective than they actually are. We addressed this major gap in the literature by assessing the perceived effectiveness of brain training and NIBS in a series of surveys. Our results suggest that people are optimistic about the possibilities of cognitive enhancement, particularly through brain training. Moreover, reading a brief message implying high or low effectiveness of such methods can raise or lower expectations, respectively, suggesting that perceptions of brain training are malleable – at least in the short term. Measuring expectations in brain training and NIBS is important to determining whether these cognitive enhancement methods truly are effective.

Keywords

Brain training; Cognitive enhancement; Demand characteristics; Expectation; Intervention design; Non-invasive brain stimulation; Placebo effect.

Introduction

Cognitive enhancement is a tantalizing prospect. Techniques such as "brain training" (i.e., mentally challenging computer exercises; Rabipour and Raz, 2012) and non-invasive brain stimulation (NIBS; i.e., electrical stimulation through the scalp using Transcranial Magnetic Stimulation, Direct Current Stimulation, or related techniques; Miniussi et al., 2013) have recently emerged to improve or maintain cognitive functioning. These methods are exciting to many researchers and clinicians, and gaining popularity among consumers: Market research suggests that digital health applications, largely comprised of brain training games, are worth over $1 billion in the United States and will grow rapidly (SharpBrains, 2014). Brain stimulation has similarly inspired a booming industry and mounting do-it-yourself (DIY) user community (201, 2015) despite concerns over safety and regulation (Carter and Forte, 2016; Farah, 2015; Jwa, 2015).

Determining whether these products actually work is challenging (Moreau et al., 2016; Simons et al., 2016). Crucially, psychological factors – including a person's motivations for pursuing cognitive enhancement, prior experience with such products, expectations of outcomes, and subjective assessment of performance – can influence the apparent effectiveness of cognitive enhancement via biased sampling, placebo effects, or Hawthorne-like effects (Gross, 2017; Schambra et al., 2014; Schwarz et al., 2016). The few studies that have broached these problems suggest they can be substantial (Boot et al., 2013a; Foroughi et al., 2016).

Given the potential influence of expectations on brain training and stimulation trials, understanding how people perceive these cognitive enhancement methods is crucial. Previously, we found that people generally believe brain training to be effective (Rabipour and Davidson, 2015, for similar findings, see (Torous et al., 2016)). Interestingly, older adults (OA) appeared to be more optimistic than young adults (YA). Here we sought to replicate and extend our previous work by assessing perceptions of brain training and NIBS. We further sought to determine whether information implying high or low program effectiveness could measurably change people's expectations compared to their prior beliefs. Finally, we also examined whether certain individual characteristics might be associated with expectations. Because older adults are prominent targets of the cognitive enhancement industries (e.g., Lumos Labs Inc., 2017; Nintendo DS, 2017; Posit Science Inc., 2017), we paid particular attention to age.

Materials and Methods

Experimental Design

Study 1: Expectations of Brain Training

We surveyed people about their expectations of brain training in two separate studies, using the Expectation Assessment Scale (Rabipour and Davidson, 2015; Rabipour et al., 2018a). On a scale from 1-7 (1 = lowest expectation; 4 = no expectation/neutral; 7 = highest expectation), we asked responders to rate how successful they expected “computerized cognitive training” or “non-invasive brain stimulation” to be at improving various cognitive domains. This survey reflects the degree to which people might be influenced by readily available and highly propagated information about brain training, at least in the short term.

Study 1a We surveyed 110 people at baseline (53 women, one participant excluded due to incomplete responses; Table 1A). We recruited young adults from the student subject pool at Florida State University and older adults from the community in Tallahassee, Florida. Whereas the YA were recruited only to complete the survey in exchange for course credit, the OA participated in the context of a brain training intervention (Souders et al., 2017) and received monetary compensation (100 USD).

Table 1 Participant demographics for Study 1a and b, respectively

		Age	Years of education	Number of women
A)	YA (n = 50)	19.58 (± 1.23)	13.60 (± 0.90)	28
	OA (n = 59)	72.35 (± 5.20)	16.47 (± 1.50)	25
B)	YA (n = 110)	26.99 (± 1.23)	15.39 (± 2.19)	65
	MA (n = 54)	45.63 (± 7.14)	15.70 (± 1.88)	35
	OA (n = 93)	68.22 (± 5.90)	15.15 (± 1.98)	70

Study 1b

We surveyed an additional 263 people (175 women, six participants dropped due to incomplete responses; Table 1B) about their expectations, first at baseline and then again after reading two messages in counterbalanced order; i) a message implying that brain training is highly effective (High Expectation condition) and ii) another implying that brain training is ineffective (Low Expectation condition; for greater detail, see Rabipour and Davidson, 2015). Asking participants to respond to the same questions under different conditions enables an examination of the extent to which expectation ratings may change, at least in the short term, based on information received. As a buffer between the High and Low Expectation conditions, we also asked participants to rate their expectations after reading a third “neutral” message with no implication of effectiveness, directly after responding to the first expectation condition they received. Response patterns under this neutral condition were consistent with those of the preceding condition received. We therefore did not include responses from the neutral condition in our analyses.

Participants were recruited from undergraduate psychology courses at the University of Ottawa through ads and flyers, and via web-based recruitment, including Amazon Mechanical Turk and Qualtrics.

Study 2: Expectations of Non-Invasive Brain Stimulation

We surveyed 516 people about their expectations of NIBS (272 women, 88 participants did not report age or sex; Table 2) using a modified version of the survey in Study 1. We defined NIBS as "a form of brain stimulation that delivers weak currents through the surface of the scalp over a brain region, aiming to improve cognitive or motor function." We recruited young and middle-aged adults using the same methods as in Study 1b. We excluded the concentration domain in our analyses due to low number of responses.

Table 2 Participant demographics for Study 2

	Age	Years of education	Number of women
YA (n = 300)	23.19 (± 5.39)	14.11 (± 4.72)	190
MA (n = 50)	45.28 (± 6.70)	15.10 (± 2.48)	31
OA (n = 78)	66.58 (± 5.34)	14.64 (± 2.50)	51

Statistical Analysis

Our analyses included chi-square, t-tests, and repeated-measure analysis of variance (ANOVA), comparing responses for each expectation condition (baseline, high, low) and cognitive domain (general cognitive function, memory, concentration, distractibility, reasoning ability, multitasking ability, performance in everyday activities), across age (YA, MA, OA) and the order in which the expectation conditions were delivered. We applied Greenhouse-Geisser corrections for sphericity where applicable. We reported our results of multiple t-tests with adjusted alpha levels using the Holm-Bonferroni approach, to account for unequal sample sizes. Following ANOVA, we computed post-hoc analyses with unadjusted alpha levels.

Results

Study 1: Expectations of Brain Training

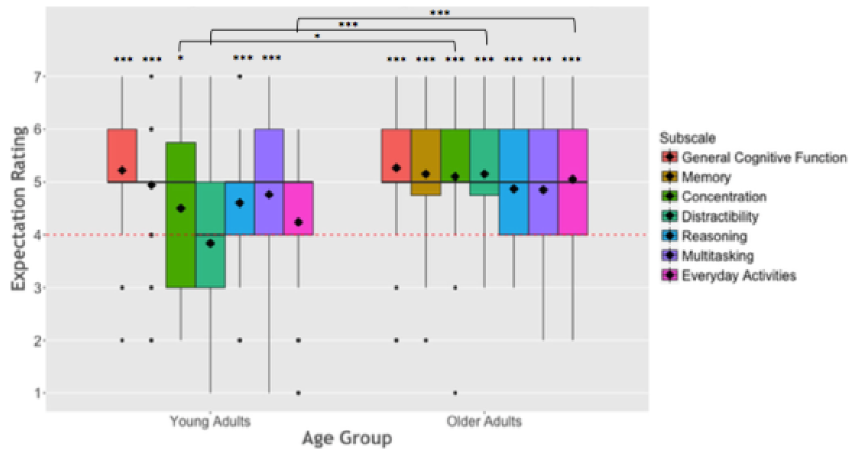
Study 1a: People are Optimistic About Brain Training at Baseline

Given the possibility of OA having higher expectations than YA (Rabipour and Davidson, 2015) we analyzed age groups separately. Overall, both age groups were optimistic (Fig. 1). Whereas OA rated their expectations significantly higher than neutral for all cognitive domains ($t(58) \geq 6.028$, $p<0.0001$, Cohen's $d \geq 1.58$), YA were optimistic (i.e., ratings higher than neutral) about general cognitive function ($t(49)=9.984$, $p<0.0001$, Cohen's $d=2.85$, CI=0.97-1.47), memory ($t(49)=6.95$, $p<0.0001$, Cohen's d=1.99, CI=0.67-1.21), concentration ($t(49)=2.519$, $p=0.015$, Cohen's $d=0.72$, CI=0.10-0.90), reasoning ability ($t(49)=3.096$, $p=0.003$, Cohen's $d=0.88$, CI=0.21-0.99), and multitasking ($t(49)=3.569$, $p=0.001$, Cohen's d=1.02, CI=0.33-1.19), but not for distractibility and performance in everyday activities.

Repeated measures analysis of variance (ANOVA) directly comparing age groups (YA versus OA) across the seven cognitive domains revealed a significant main effect of age ($F(1,107)=8.414$, $\eta_p^2=0.073$, $p=0.005$), cognitive domain ($F(5.15,550.85)=9.467$, p2=0.081, $p<0.0001$), and interaction ($F(5.15,550.85)=8.019$, $\eta_p^2=0.070$, $p<0.0001$). Further investigation of these interactions revealed that, compared to YA, OA reported significantly higher expectations of improvement in distractibility ($t(86).02=5.601$, $p<0.0001$, Cohen's $d=1.08$, CI=0.847-1.778) and performance in everyday activities ($t(107)=3.45$, $p=0.001$, Cohen's $d=0.66$, CI=0.345-1.277) following cognitive training.

Notably, at least 92% of participants reported being confident in their expectations of each cognitive domain at baseline. Age differences in reported confidence were not significant after correcting for multiple comparisons. Similarly, we did not find significant differences in the baseline ratings of YA, MA, or OA based on reported confidence.

Fig. 1 Expectation ratings in YA and OA at baseline. Whereas ratings generally varied between 4 and 5 in YA, the distribution of responses surrounded 5/"somewhat successful" in OA. Dashed line indicates the neutral point (score of 4) on the survey scale. Dashed lines are drawn across the neutral point (rating of 4). Bold lines represent the group medians; diamonds represent the group means. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$



Study 1b: Expectations of Brain Training are Malleable

Expectations were similarly optimistic at baseline for all cognitive domains in YA (t(109)≥2.685, p≤0.008, Cohen's d≥0.51; Fig. 2A), MA (t(53)≥2.709, p≤0.009, Cohen's d≥0.74; Fig. 2B), and OA (t(92)≥3.964, p<0.0001, Cohen's d≥0.83; Fig. 2C) who completed the questionnaire under the three different conditions. Ratings were significantly above neutral under the High Expectation condition for all cognitive domains in YA (t(109)≥5.03, p<0.0001, Cohen's d≥0.96), MA (t(53)≥3.37, p≤0.001, Cohen's d≥0.93), and OA (t(93)≥4.448, p<0.0001, Cohen's d≥0.92). Under the Low Expectation condition, ratings were significantly below neutral for concentration (M=3.64, SD=1.42, t(109)=2.688, p=0.008, Cohen's d=0.51, CI=0.10-0.63) and distractibility (M=3.55, SD=1.43, t(109)=3.331, p=0.001, Cohen's d=0.64, CI=0.18-0.73) in YA. In MA and OA, ratings under the Low Expectation condition were not significantly different from neutral.

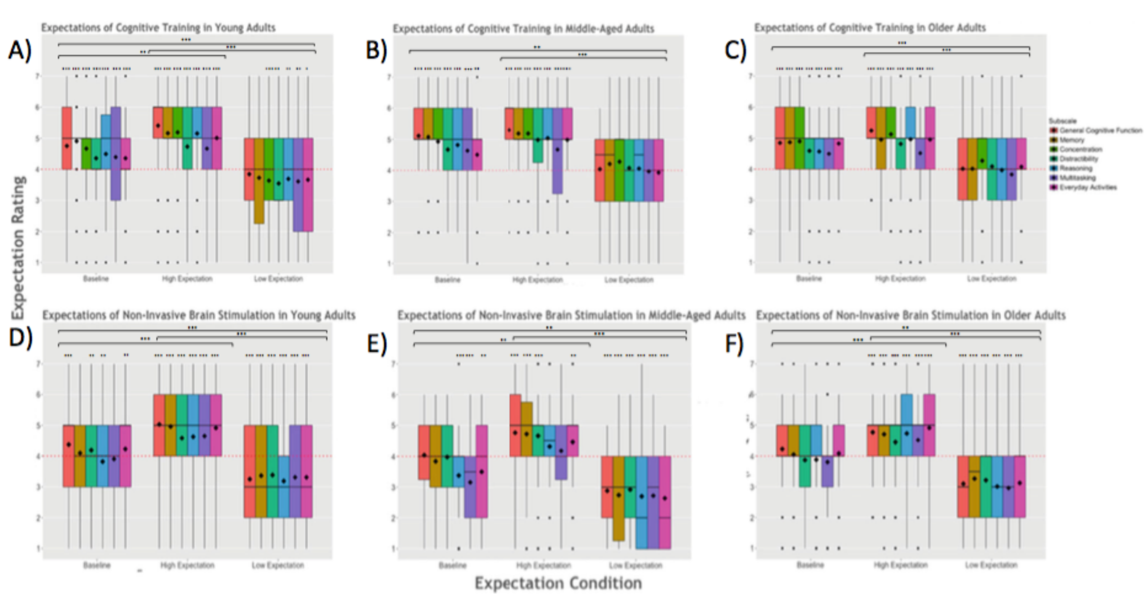


Fig. 2 Expectations of computerized cognitive training and non-invasive brain stimulation across conditions in **a**,**d** YA, **b**,**e** MA, and **c**,**f** OA. Expectation ratings consistently increase relative to baseline in the High Expectation condition and decrease relative to baseline in the Low Expectation condition. Dashed lines are drawn across the neutral point (rating of 4). Bold lines represent the group medians; diamonds represent the group means. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$

The majority of participants were confident in their expectations for each cognitive domain at baseline (≥86%), and under the High ≥86%) and Low (≥83%) Expectation conditions. Under the Low Expectation condition, a greater percentage of OA (86/93=92%) reported confidence in their expectations for general cognitive function compared to YA (84/110=76%, X^2=9.607, p=0.002) and MA (42/54=78%, X^2=6.555, p=0.01). Age differences in reported confidence were not significant at baseline or under the High Expectation condition after correcting for multiple comparisons.

Repeated measures ANOVA comparing age groups and the order in which participants read the expectation messages across the seven cognitive domains, under the three expectation conditions revealed a significant 3-way interaction between age, order, and condition (F(3.54,444.64)=4.062, η_p^2=0.31, p=0.005). Further investigation of this effect by age revealed, in YA, a main effect of condition (F(1.65,178)=85.724, η_p^2=0.443, p<0.0001), cognitive domain (F(4.76,513.74)=5.95, η_p^2=0.052, p<0.0001), and an interaction between domain and order (F(4.76,513.74)=4.948, η_p^2=0.044, p<0.0001), condition and order (F(1.65,178)=4.628, η_p^2=0.041, p=0.016), as well as condition and domain (F9.08,980.72=3.255, η_p^2=0.029, p=0.001; Fig. 2A).

Specifically, ratings of YA significantly increased relative to baseline for all cognitive domains under the High Expectation condition (t(109)≥ 2.348, p≤0.021, Cohen's d≥0.22) and decreased relative to baseline under the Low Expectation condition (t(109)≥ 4.79, p<0.0001, Cohen's d≥0.47). Moreover, YA who first received the High Expectation condition rated higher expectations of general cognitive function (M_1 = 5.65±10.84, M_2 = 5.05±10.34, t(108)=2.52, p=0.015, Cohen's d=0.93, CI=0.122-1.078) after reading the High Expectation message, and lower expectations of multitasking function after reading the Low Expectation message (M1=3.36±11.42, M2=4.08±11.85, t(108)=2.267, p=0.025, Cohen's d=0.44, CI=0.09-1.346) compared to those who first received the Low Expectation condition, respectively.

In MA (Fig. 2B) and OA (Fig. 2C), responses showed a main effect of condition (MA: F(1.65,85.82)=23.117, η_p^2=0.308, p<0.0001; OA: F(1.93,175.95)=40.604, η_p^2=0.309, p<0.0001), cognitive domain (MA: F(4.07,211.45)=4.001, η_p^2=0.071, p=0.004; OA: F(4.61,419.46)=9.501, η_p^2=0.095, p<0.0001), and an interaction between condition and order (MA: F(1.65, 85.82)=3.78, η_p^2=0.068, p=0.034; OA: F(1.93,175.95)=9.528, η_p^2=0.095, p<0.0001). Responses of MA also demonstrated an interaction between condition and domain (F(8.53,443.39)=2.15, η_p^2=0.04, p=0.027). Relative to baseline, MA expectation ratings significantly increased under the High Expectation condition for performance in everyday activities ($M_baseline$ = 4.5±11.36, M_High = 4.98±1

1.34, t(53)=2.854, p=0.006, Cohen's d=0.39, CI=0.143-0.82), and decreased significantly under the Low Expectation condition for all cognitive domains (t(53)$\geq$ 3.287, p$\leq$0.002, Cohen's $d\geq$0.46). MA who received the High Expectation condition first rated higher expectations of general cognitive function after reading the High Expectation message (M_1 = 5.67$\pm$10.92, M_2 = 4.93$\pm$11.49, t(52)=2.196, p=0.033, Cohen's d=0.60, CI=0.064-1.418).

In OA, ratings significantly increased relative to baseline under the High Expectation condition for general cognitive function ($M_baseline$ = 4.85$\pm$11.22, M_Higher = 5.25$\pm$11.04, t(92)=2.907, p=0.005, Cohen's d=0.31, CI=0.126-0.67), and decreased significantly under the Low Expectation condition for all cognitive domains (t(92)$\geq$ 3.101, p$\leq$0.003, Cohen's $d\geq$0.49). OA who first received the High Expectation condition rated higher expectations for general cognitive function, memory, concentration, reasoning ability, multitasking ability, and performance in everyday activities (t(91)$\geq$ 2.22, p$\leq$0.029, Cohen's $d\geq$0.46) after reading the High Expectation message, and higher expectations for all cognitive domains after reading the Low Expectation message (t(91)$\geq$3.023, p$\leq$0.003, Cohen's $d\geq$0.63).

We found significant differences based on order in baseline ratings of distractibility and multitasking in YA, and reasoning ability in OA. These, however, suggest a chance finding unrelated to our experimental manipulation.

We further probed the degree to which participants believed the expectation messages were convincing, and whether the messages were persuasive enough to change their initial expectations for the general cognitive function domain (Table 3). The majority of participants (72%) believed the High Expectation condition was convincing, with 58% reporting that the message was persuasive enough to change their initial perceptions. Similarly, 62% of participants believed the Low Expectation condition was convincing, with 56% reporting that the message was persuasive enough to change their initial perceptions. However, the information in the Low Expectation condition was less compelling to OA compared to YA (71/110=65%), who were significantly less swayed by this pessimistic message (41/93=44%; X^2=8.529, p=0.003). Ratings of convincingness were significantly higher under the High compared to the Low Expectation condition (F(1,251)=7.498, η_p^2=0.029, p=0.007), and significantly interacted with the order in which participants received the High and Low Expectations conditions (F(1,251)=5.763, η_p^2=0.022, p=0.017). Specifically, participants who first received the High Expectation condition were more convinced by the High Expectation message, compared to participants who first received the Low

Expectation condition (M1=5.22±11.23, M2=4.61±11.60, t(190.12)=3.33, p=0.001, Cohen's d=0.43, CI=0.25-0.975).

Table 3 Percentage of participants who reported that the High and Low Expectation messages were convincing and persuasive enough to change their initial perceptions, respectively, based on the order in which they received each condition

	High Expectation condition first				Low Expectation condition first			
	High message		Low message		High message		Low message	
	Convincing	Persuasive	Convincing	Persuasive	Convincing	Persuasive	Convincing	Persuasive
YA	83	64	68	68	52	53	63	58
MA	85	59	74	59	52	52	59	63
OA	82	57	53	41	57	57	52	48

With regard to intervention schedule, participants largely believed cognitive training at higher frequency with lower session duration (i.e., 30 minutes, three times per week) to be most effective (65%) and convenient (59%).

Individual Differences in Expectations of Brain Training at Baseline

Based on our previous study (Rabipour Davidson, 2015), we examined individual characteristics hypothesized to correlate with expectations of cognitive training at baseline. Nearly all participants (90%) reported having at least some exposure to cognitive training, either through media advertisements (31%), general knowledge of different programs or practices (59%), or personal experience (18%). Participants with at least some knowledge of different programs or practices reported higher expectations of general cognitive function (M_1=5.05±11.10, M_2=4.57±11.30, t(201.82)=3.13, p=0.002, Cohen's d=0.25, CI=0.178-0.785), memory (M1=5.12±11.01, M2=4.64±11.17, t(253)=3.460, p=0.001, Cohen's d=0.44, CI=0.205-0.745), concentration (M_1=4.99±11.12, M_2=4.51±11.20, t(253)=3.269, p=0.001, Cohen's d=0.41, CI=0.19-0.765), and reasoning ability (M_1=4.78±11.24, M_2=4.28±11.34, t(253)=3.081, p=0.002, Cohen's d=0.39, CI=0.065-0.776), compared to those with no knowledge, respectively. Baseline ratings did not significantly differ based on exposure to media advertisements or personal experience.

Finally, participants with confidence in their ratings at baseline reported higher expectations of memory (M_1=5.00±11.08, M_2=4.32±11.22, t(242)=3.059, p=0.002, Cohen's d=0.59, CI=0.240-1.108), concentration (M1=4.92±11.14, M2=4.03±11.21, t(242)=4.127, p<0.0001, Cohen's d=0.76, CI=0.465-1.314), and reasoning ability (M_1=4.66±11.29, M_2=3.83±11.34, t(242)=2.980, p=0.003, Cohen's d=0.63, CI=0.282-1.379). Baseline ratings did not significantly differ based on sex, country of residence, country in which participants grew up, education level, computer exposure, programming experience, medications taken, or concern over declining mental status.

Study 2: People are Uncertain About the Effects of Non-Invasive Brain Stimulation

Participants were uncertain about the effectiveness of non-invasive brain stimulation at baseline, with ratings near the neutral point. After Holm-Bonferroni corrections for multiple comparisons, baseline ratings in YA were significantly above the neutral point only for general cognitive function (M=4.37±11.33, t(303)=4.844, p<0.0001, Cohen's d=0.56, CI=0.22-0.52), but no different from neutral for memory, distractibility, reasoning ability, multitasking ability, and performance in everyday activities (Fig. 2D). In MA, baseline ratings were, surprisingly, significantly below the neutral point for multitasking ability (M=3.16±11.45, t(49)=4.102, p<0.0001, Cohen's d=1.17, CI=0.43-1.25) and reasoning ability (M=3.38±11.38, t(49)=3.169, p=0.003, Cohen's d=0.91, CI=0.23-1.01, and no different from neutral for general cognitive function, memory, distractibility, and performance in everyday activities after correcting for multiple comparisons (Fig. 2E). Baseline ratings in OA did not significantly differ from neutral in any of the cognitive domains (Fig. 2F). Under the High Expectation condition, ratings were significantly above neutral for all cognitive domains in YA (t(301)≥7.000, p<0.0001, Cohen's d≥0.81) and OA (t(77)≥2.827, p≤0.006, Cohen's d≥0.64), and for general cognitive function (M=4.76±11.41, t(49)=3.817, p<0.0001, Cohen's d=0.91, CI=0.36-1.16), memory (M=4.72±11.40, t49=3.636, p=0.001, Cohen's d=1.04, CI=0.32-1.12), and distractibility (M=4.66±11.30, t(49)=3.581, p=0.001, Cohen's d=1.02, CI=0.29-1.03) in MA. Ratings were significantly below neutral for all cognitive domains under the Low Expectation condition in YA (t(302)≥6.382, p<0.0001, Cohen's d≥0.73), MA (t(49)≥.301, p<0.0001, Cohen's d≥0.09), and OA (t(77)≥4.052, p<0.0001, Cohen's d≥0.92).

Despite providing a wide range of expectation ratings across domains, the majority of YA (≥74%), MA (≥70%), and OA (≥83%) reported being confident in their baseline ratings for each cognitive domain. Similarly, the majority of participants reported confidence in their ratings for all cognitive domains under the High (YA: ≥79%, MA: ≥80%, OA: ≥89%) and Low Expectation conditions (YA: ≥84%, MA: ≥86%, OA: ≥91%).

Repeated measures ANOVA comparing age groups and the order in which participants read the expectation messages across six cognitive domains and under the three expectation conditions revealed a significant main effect of expectation condition (F(1.63,687.46)=198.218, η_p^2=0.32, p<0.0001) and of cognitive domain (F(4.43,1870.59)=12.774, η_p^2=0.029, p<0.0001), and significant interactions between condition and domain (F(9.22, 3889.79)=4.665, η_p^2=0.011, p<0.0001), as well as age and domain (F(8.87,1870.59)=2.128, η_p^2=0.01, p=0.025). Further investigation of these interactions revealed a significant increase in expectation ratings for all cognitive domains, relative to baseline, under the High Expectation condition (YA: t(301)≥4.457, p<0.0001, Cohen's *d*≥0.26; MA: t(49)≥3.385, p≤0.001, Cohen's *d*≥0.48; OA: t(77)≥3.848, p<0.0001, Cohen's *d*≥0.44) and a significant decrease in ratings, relative to baseline, under the Low Expectation condition (YA: t(302)≥6.198, p<0.0001, Cohen's *d*≥0.36; MA: t(49)≥2.344, p≤0.023, Cohen's *d*≥0.33; OA: t(77)≥3.5, p≤0.001, Cohen's *d*≥0.40).

Individual Differences in Expectations of Non-Invasive Brain Stimulation at Baseline

In contrast to brain training, less than half of participants had general knowledge (42%) or familiarity with media reports of NIBS (23%), and only 8% of participants had any prior experience with NIBS. Participants who reported having at least some prior knowledge of NIBS were significantly more optimistic in their expectations of memory at baseline (M_1=4.27±11.47, M_2=3.88±11.28, t(326.14)=2.755, p=0.006, Cohen's *d*=0.28, CI=0.11-0.657), compared to those who reported no prior knowledge of NIBS, respectively. Baseline ratings did not significantly differ based on factors such as sex, country of residence, country in which participants grew up, education level, computer exposure, computer programming, experience with brain stimulation, or concern over declining mental status.

Discussion

Psychological factors such as expectancy may influence the outcomes of cognitive enhancement (e.g., through placebo effects). Nevertheless, trials of brain training and NIBS methods have rarely included measures or appropriate controls to account for participants' expectations (Simons et al., 2016). Here we found that people are relatively optimistic about brain training but uncertain about NIBS outcomes, when initially asked (i.e., in the baseline condition). Researchers comparing such training to other types of interventions should explicitly address this distinction when collecting and interpreting data: For example, participants may simply show greater effects of brain training than NIBS in a head-to-head comparison because of differences in expectations. Optimism about brain training may have resulted from aggressive marketing and positive media coverage (CognitiveTrainingData.org, 2014; Farah, 2015; Koroshetz, 2015; Rabipour and Davidson, 2015; Simons et al., 2016; The Stanford Center on Longevity, 2014; Walsh, 2013). As advertising and public awareness of NIBS increase, we may witness an increase in expectations of those techniques as well.

The reported expectations of participants rose or fell in the short term, in response to information implying high or low intervention effectiveness, respectively. This finding implies, on the one hand, that scientists should consider potential sources of inadvertent bias or priming of participants with recruitment information, consent forms, and other study documents (Foroughi et al., 2016). Random assignment and double blinding can reduce the potency of such confounding factors (Rabipour et al., 2017b). On the other hand, researchers may wish to consider deliberately manipulating expectations of brain training and NIBS with a "balanced-placebo" design (as has been done with drugs; Sahakian and Morein-Zamir, 2007) to tease apart treatment and expectation effects (Boot et al., 2013a).

Individual factors such as age and prior exposure to an intervention may also influence expectations of outcomes. Although the age differences observed in Study 1a may result from differential recruitment of YA and OA, our findings replicate our original study and are therefore unlikely to result from a recruitment confound (Rabipour and Davidson, 2015). Notably, we found that OA report higher optimism towards cognitive enhancement under certain circumstances, and remain confident in their initial beliefs regardless of information provided – even when presented with evidence urging skepticism regarding outcomes. We further observed a hint of interaction between age and short-term expectation-setting: OA who first received positive information about cognitive enhancement remained more optimistic about outcomes, even under the Low Expectation condition, compared to YA. Moreover, while the majority of participants believed that the information received under both the High and Low Expectation conditions was convincing, fewer OA were convinced by the pessimistic message compared to YA. Together, these findings suggest that initial exposure to positive information may inflate expectations or reduce skepticism towards cognitive enhancement in certain populations.

Understanding participants' expectations of outcomes is necessary to determine whether cognitive enhancement approaches such as brain training and NIBS are truly effective. In addition to placebo effects, these results have implications for adoption and adherence to cognitive training interventions, particularly for older adults.In order for an intervention to be successful, the intervention should be effective, but participants must also be willing and able to engage with the intervention for an extended period of time. The perceived benefit of an intervention can influence both of these, including people's willingness to begin an intervention and adhere to the program until completion. Poor intervention adherence remains an issue in therapeutic settings, as well as in the context of brain training. For example, Boot et al. (2013a) found that adherence to a digital game-based intervention was very low. Moreover, expectations of the benefits of this specific intervention were low compared to a more explicit brain-training program that was adhered to much better, and which participants believed would help their everyday functioning. Our research represents a first step towards understanding the link between such perceptions and the way people respond to cognitive interventions, and predicting whether or not participants might adhere to such programs.

Measuring expectations before, during, and after a cognitive enhancement intervention may help explain intervention effects (or lack thereof). We found that people generally believe in the efficacy of brain training, but that there are also individual differences in belief.Our study suggests caution in interpreting any existing evaluations of brain training and NIBS that have not taken expectations into account (e.g., CognitiveTrainingData.org, 2014; Federal Trade Commission, 2015; Steenbergen et al., 2016; The Stanford Center on Longevity, 2014; Underwood, 2016). Our survey offers a simple, face-valid, and internally consistent way to do so (Rabipour et al., 2018b).

Author Contributions

S.R. and P.S.R. designed the study and developed the instrument based on previous work from W.R.B. Data collection in Ottawa and via web-based tools was performed by S.R. and P.S.R., while R.A. and W.R.B. collected data from Tallahassee. S.R. and P.S.R. analyzed the data, drafted the document, and finalized it based on edits from R.A. and W.R.B. All authors approved the final version of the manuscript for submission.

Acknowledgements

We thank Thomas Vitale for help with data collection as well as members of the Neuropsychology Laboratory at the University of Ottawa and Boot Lab at Florida State University. We also acknowledge the Natural Sciences and Engineering Research Council of Canada, the Fonds de Recherche Québec-Santé, the Ontario Graduate Scholarships, and the National Institute on Aging-National Institutes of Health (NIA 2P01AG017211-16A1, Project CREATE IV-Center for Research and Education on Aging and Technology Enhancement) for their support of this work.

2.3 Measuring Expectations of Cognitive Enhancement: Item Response Analysis of the Expectation Assessment Scale

Sheida Rabipour[1], Patrick S. R. Davidson[1,2,3], Elizabeth Kristjansson[1],

[1]School of Psychology, University of Ottawa, Ottawa, Canada

[2]Bruyère Research Institute, Bruyère Continuing Care, Ottawa, Canada

[3]Heart and Stroke Foundation of Ontario Canadian Partnership for Stroke Recovery, Ontario, Canada

Abstract

Interventions aiming to enhance cognitive functions (e.g., computerized cognitive training and non-invasive brain stimulation) are increasingly widespread for the treatment and prevention of cognitive decline. Drawing on the allure of neuroplasticity, such programs comprise a multi-billion dollar industry catering to researchers, clinicians, and individual consumers. Nevertheless, cognitive enhancement interventions remain highly controversial due to uncertainty regarding their mechanisms of action. A major limitation in cognitive enhancement research and practice is the failure to account for expectations of outcomes, which can influence the degree to which participants improve over an intervention (i.e., the placebo effect). Here we sought to evaluate the psychometric properties of the Expectation Assessment Scale (EAS), a questionnaire we created to measure the perceived effectiveness of computerized cognitive training and non-invasive brain stimulation. We delivered a web-based version of the EAS probing expectations of either computerized cognitive training or non-invasive brain stimulation. We assessed uni-dimensionality of the EAS using Principal Components Analysis and assessed item properties with a graded Item-Response model. Responses on the EAS suggest good validity based on internal structure, across all subscales and for both computerized cognitive training and non-invasive brain stimulation. The EAS can serve as a reliable, valid, and easily incorporated tool to assess the validity of cognitive enhancement interventions, while accounting for expectations of intervention outcomes. Assessing expectations before, during, and after cognitive enhancement interventions will likely prove useful in future studies.

Keywords

Brain training; Cognitive enhancement; Demand characteristics; Expectation; Intervention design; Item-response theory; Non-invasive brain stimulation; Placebo effect; Research methods.

Introduction

Interventions aiming to enhance cognitive functions are ubiquitous in mainstream society. In particular, techniques involving computerized cognitive training and non-invasive brain stimulation are increasingly widespread for the treatment and prevention of cognitive decline. Drawing on the allure of neuroplasticity, such programs comprise a multi-billion dollar industry catering to researchers, healthcare professionals, educators, and individual consumers (SharpBrains, 2013, 2016). Nevertheless, cognitive enhancement interventions remain highly controversial due to inconsistent reports of effectiveness and uncertainty regarding their mechanisms of action (Boot and Kramer, 2014; Simons et al., 2016).

A major limitation in cognitive enhancement research and practice is the failure to account for expectations of outcomes, which can influence the degree to which participants improve over an intervention (i.e., the placebo effect). The few studies that have examined expectations in the context of cognitive training suggest they may represent an important factor (**?**Foroughi et al., 2016). No standardized tool exists to measure expectations in the context of cognitive enhancement interventions.

Here we sought to evaluate the psychometric properties of the Expectation Assessment Scale (EAS), a questionnaire we created and are using in our intervention research to measure the perceived effectiveness of computerized cognitive training (CCT) and non-invasive brain stimulation (NIBS). We report our analyses of participant responses elsewhere (Rabipour et al., 2017a).

Materials and Methods

We developed the EAS in two steps: i) we created an initial version of the EAS based on questions used by Boot et al. (2013a); ii) following an examination of responses on this initial version, we refined the questions to create the current scale (Rabipour and Davidson, 2015). As previously described (Rabipour and Davidson, 2015), the scale comprises seven items, representing expected outcomes for seven cognitive domains: i) "general cognitive function", ii) "memory", iii)"concentration", iv) "distractibility", v) "reasoning ability", vi) "multitasking ability", and vii) "performance in everyday activities" (see Supplementary Material). All participants responded based on the same wording, with no additional information provided. Responses were recorded on a 7-point likert scale.

Participants

We delivered a web-based version of the EAS probing expectations of either CCT (Study 1) or NIBS (Study 2). Participants were recruited from the student participant pool at the University of Ottawa (UO) and Florida State University (FSU), through ads and flyers (community recruitment), and via web-based recruitment, including Amazon Mechanical Turk (MTurk) and Qualtrics (Table 1). As previously reported (Rabipour et al., 2017), although the majority of participants were recruited solely to complete the survey, the 50 OA recruited from FSU participated in the context of a brain training intervention (Souders et al., 2017).

Table 1 Composition of participant samples (n women) in study 1 and study 2. As previously reported (Rabipour et al. 2017), 88 participants from study 2 did not report age or sex

		UO	FSU	Community	MTurk	Qualtrics
Study 1	YA	143 (112)	50 (28)	213 (153)	94 (28)	–
	MA	–	–	21 (17)	46 (27)	–
	OA	1 (0)	60 (26)	100 (69)	8 (6)	59 (44)
Study 2	YA	171 (141)	–	–	129 (49)	–
	MA	3 (3)	–	–	47 (28)	–
	OA	–	–	–	11 (6)	67 (45)

Data Analysis

Item Response Theory (IRT) is a 'model-based approach' to item and trait analysis (Embretson and Reise, 2000). Compared to reliability statistics provided by Classical Test Theory, IRT has numerous advantages, including better estimates of item- and test-level reliability through the marginal reliability for response pattern score. Importantly, it provides standard errors of measurement for each level of the examined trait (for discussion and examples, see Foster et al., 2017; Kim and Feldt, 2010; Shu and Schwarz, 2014). Moreover, compared to confirmatory factor analytic methods, IRT is more robust and informative when examining the equivalence of a particular scale (Meade and Lautenschlager, 2004).

We first assessed uni-dimensionality using Principal Components Analysis (PCA). We then assessed item properties with a uni-dimensional Graded Item-Response model (Samejima, 1997). To determine model fit, we used the root mean square error of approximation (RMSEA) and Chi-Square (X^2). RMSEA chooses optimal parameters estimates to examine how well the unknown model fits the population covariance matrix (Hooper et al., 2008). RMSEA values of 0.06 or lower indicate acceptable model fit. However, due to criticisms of the RMSEA and other fit indices (Hayduk et al., 2007; Squires et al., 2013), we have also reported X^2 values for model fit.

We conducted our analyses using SPSS version 24, R Studio version 3.1.1, and IRTPRO version 2.1 (Cai et al., 2011).

Study 1: Expectations of Computerized Cognitive Training

We evaluated expectations of CCT outcomes on two separate occasions: i) as part of our initial development of the survey, evaluating 422 participants (305 women; M=29.67 years of age, SD=19.76), and ii) as a replication in 373 participants (229 women; M=46.13 years of age, SD=21.81). We excluded responses from 153 participants with incomplete or incomparable responses due to their completion of initial version of the survey, as well as 23 outliers identified based on a Mahalanobis distance greater than 22.46, for a final sample of 619.

Study 2: Expectations of Non-Invasive Brain Stimulation

We evaluated expectations of NIBS outcomes in 516 respondents (299 women; M=32.22 years of age, SD=17.48). We excluded 96 participants with inappropriate or incomplete responses, as well as 7 outliers based on a Mahalanobis distance greater than 20.52, for a final sample of 413. We probed expected outcomes for six cognitive domains (i.e., six items): "general cognitive function", "memory", "distractibility", "reasoning ability", "multitasking ability", and "performance in everyday activities"; we dropped the "concentration" item due to a technical error leading to insufficient number of responses.

Because we have also used the EAS in studies of expectation priming (e.g., see Rabipour et al., 2017a; Rabipour and Davidson, 2015), we also examined the psychometric properties of the EAS when delivered under conditions where participants were primed to report high or low expectations of outcomes.

Results

PCA confirmed the uni-dimensionality of both versions of the EAS, with a ratio of 3.5 and 3.62 between the first and second eigenvalues for the CCT and NIBS scales, respectively. Moreover, all items on each version of the EAS loaded strongly onto a single cognitive domain factor (Table 2). We therefore did not perform confirmatory factor analyses.

Table 2 Principal component analysis for the CCT and NIBS versions of the EAS. Factor loadings suggest all items load strongly onto a single cognitive domain factor

Cognitive domain	λ_1	s.e.
a) CCT		
General cognitive function	0.81	0.04
Memory	0.80	0.04
Concentration	0.79	0.04
Distractibility	0.66	0.05
Reasoning ability	0.69	0.05
Multitasking ability	0.64	0.05
Performance in everyday activities	0.71	0.05
b) NIBS		
General cognitive function	0.75	0.05
Memory	0.85	0.04
Distractibility	0.69	0.06
Reasoning ability	0.83	0.04
Multitasking ability	0.82	0.04
Performance in everyday activities	0.85	0.04

Expectations of Computerized Cognitive Training

The hypothesized IRT model for the CCT version of the EAS (EAS-CCT) showed good fit (RMSEA=0.04; M^2_{749}=1563.26, P=0.0001). Furthermore, item fit statistics demonstrated that all items fit well with the model (Table 3).

Table 3 Item fit statistics for the EAS-CCT

Cognitive domain	X^2	*d.f.*	Probability
General cognitive function	90.95	67	0.0274
Memory	99.53	61	0.0013
Concentration	106.32	65	0.0009
Distractibility	142.14	80	0.0001
Reasoning ability	108.81	80	0.0178
Multitasking ability	119.67	84	0.0064
Performance in everyday activities	114.08	82	0.0111

Table 4 Item characteristics for the EAS-CCT. Item discrimination and threshold parameters for the EAS-CCT. Items demonstrate good model fit

Cognitive domain	a	*s.e.*	b_1	*s.e.*	b_2	*s.e.*	b_3	*s.e.*	b_4	*s.e.*	b_5	*s.e.*	b_6	*s.e.*
General cognitive function	[7]2.34	0.18	−3.41	0.33	−2.20	0.14	−1.56	0.10	−0.77	0.06	0.48	0.07	2.08	0.14
Memory	[14]2.27	0.18	−3.46	0.34	−2.44	0.17	−1.73	0.11	−0.95	0.07	0.56	0.07	2.29	0.15
Concentration	[21]2.22	0.17	−3.46	0.34	−2.32	0.16	−1.43	0.09	−0.70	0.06	0.67	0.07	2.31	0.15
Distractibility	[28]1.51	0.12	−3.44	0.31	−2.32	0.18	−1.24	0.10	−0.23	0.07	1.15	0.11	2.96	0.23
Reasoning ability	[35]1.64	0.13	−3.07	0.25	−2.19	0.16	−1.42	0.11	−0.37	0.07	0.85	0.09	2.72	0.20
Multitasking ability	[42]1.42	0.11	−3.31	0.29	−2.24	0.17	−1.40	0.11	−0.39	0.07	0.85	0.10	2.37	0.19
Performance in everyday activities	[49]1.72	0.13	−3.13	0.26	−2.10	0.15	−1.43	0.10	−0.38	0.07	0.98	0.09	2.52	0.18

IRT analysis yielded a high reliability of 0.87 for responses on the EAS-CCT. The items with the highest discrimination (i.e., ability to discriminate between high and low expectancy traits) in expectations of CCT were "general cognitive function" (2.34), "memory" (2.27), and "concentration" (2.22); other items had lower discrimination (Table 4). The item information curves show that each item is reliable at each level of the trait, with higher peaks representing higher discrimination on the item (Figure 1). For example, the "memory" item (Figure 1b) is the most discriminating item with particularly good reliability at the lower end of the expectation spectrum. Conversely, the "multitasking" item demonstrates the lowest discrimination across all levels of expectancy (Figure 1f). Comparing all the item information curves shows that the items with lowest discrimination provide the same amount of information across all levels of expectancy. The total information curve shows that the EAS-CCT is more reliable at lower levels of expectancy.

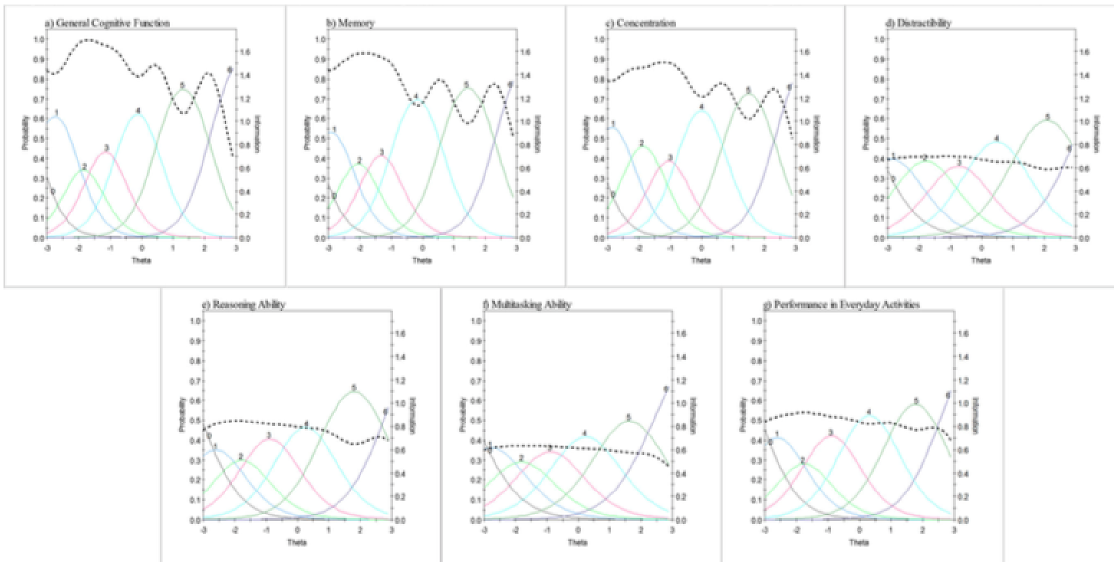


Fig. 1 Category characteristic and item information curves (dashed line) for the EAS-CCT. Results suggest the CCT version of the EAS discriminates responses well at all levels of the trait, for all included subscales (**a**–**g**). Category characteristic curves show the best discriminability in the "general cognitive function" subscale (**a**)

Expectations of Non-Invasive Brain Stimulation

The hypothesized model for the NIBS version of the EAS (EAS-NIBS) showed moderately good fit (RMSEA=0.07; M^2_{534}=1470.68, P=0.0001). Item fit characteristics demonstrate that all items fit well with the model (Table 5).

Table 5 Item fit characteristics of the EAS-NIBS

Cognitive domain	X^2	*d.f.*	Probability
General cognitive function	119.50	66	0.0001
Memory	121.87	62	0.0001
Distractibility	126.79	79	0.0005
Reasoning ability	145.33	67	0.0001
Multitasking ability	97.51	66	0.0071
Performance in everyday activities	106.66	61	0.0003

Table 6 Item characteristics of the EAS-NIBS. Parameter estimates and discrimination indices for the EAS-NIBS. Items demonstrate good model fit

Cognitive domain	a	*s.e.*	b_1	*s.e.*	b_2	*s.e.*	b_3	*s.e.*	b_4	*s.e.*	b_5	*s.e.*	b_6	*s.e.*
General cognitive function	[7]1.93	0.19	−2.99	0.27	−1.71	0.15	−0.91	0.09	0.05	0.07	1.30	0.12	2.87	0.28
Memory	[14]2.69	0.26	−2.21	0.16	−1.18	0.09	−0.52	0.06	0.28	0.06	1.33	0.11	2.36	0.21
Distractibility	[21]1.63	0.15	−2.56	0.22	−1.49	0.13	−0.67	0.09	0.28	0.08	1.55	0.15	2.82	0.28
Reasoning ability	[28]2.57	0.24	−1.72	0.12	−0.85	0.08	−0.28	0.06	0.51	0.07	1.43	0.12	2.40	0.22
Multitasking ability	[35]2.44	0.22	−1.66	0.12	−0.82	0.07	−0.30	0.06	0.45	0.07	1.32	0.11	2.40	0.21
Performance in everyday activities	[42]2.72	0.25	−1.95	0.14	−1.00	0.08	−0.54	0.06	0.19	0.06	1.11	0.09	2.34	0.20

IRT analysis yielded a reliability of 0.91 for responses on the EAS-NIBS. The item with the highest discrimination in expectations of NIBS was "performance in everyday activities" (2.72), although most items had high discriminations (Table 6). The item information curves show that each item is reliable at each level of the trait, with higher peaks representing higher discrimination on the item. (Figure 2). For example, the "performance in everyday activities" item (Figure 2f) discriminates best between respondents of high vs. lower expectancy trait, with particularly good reliability at the lower end of the expectation spectrum. This can be seen both in the table as well as in the height of the peaks in Figure 2. Figure 2f demonstrates that the "memory" item discriminates well across all levels of the expectancy trait, with particularly high reliability at lower levels of the trait. Conversely, the "distractibility" item demonstrates the lowest discrimination across all levels of expectancy (Figure 2c). Comparing all the item information curves shows that the items with lowest discrimination provide the same amount of information across all levels of expectancy. The total information curve shows that the EAS-NIBS is more reliable at lower levels of expectancy.

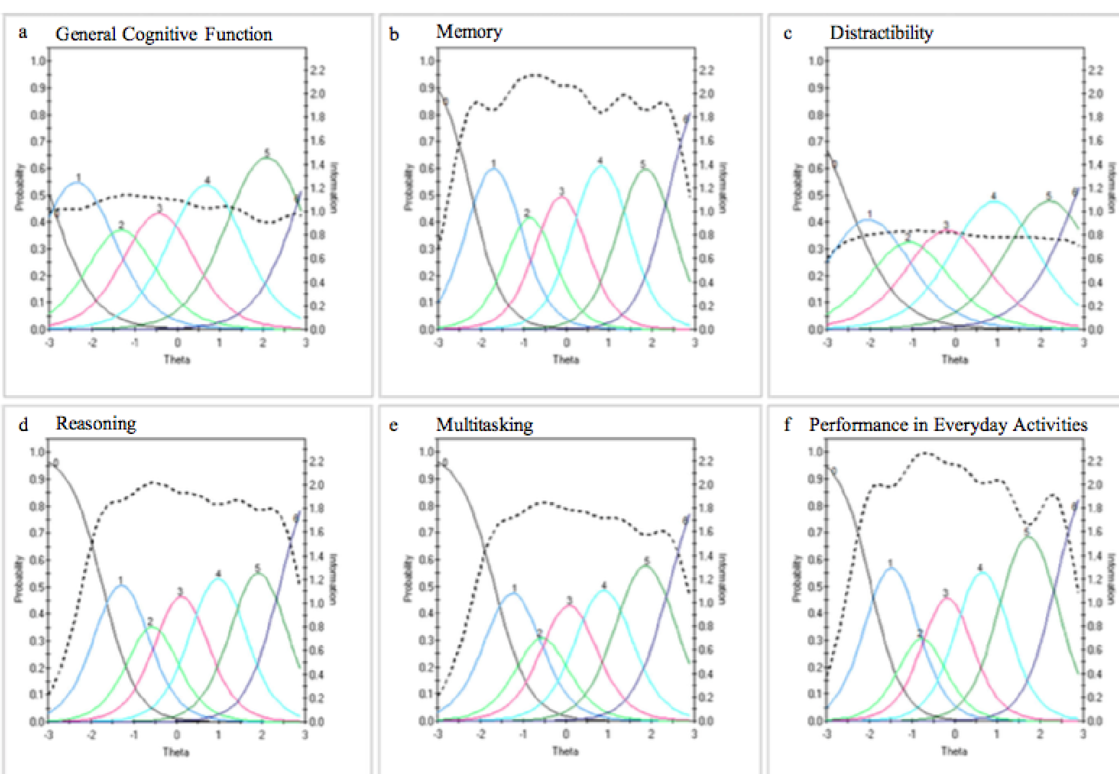


Fig. 2 Category characteristic curves and item information curves (dashed line) for the EAS-NIBS. Results suggest the NIBS version of the EAS discriminates responses well at all levels of the trait, for all included subscales (**a–f**). Category characteristic curves suggest the best discriminability in the "performance in everyday activities" subscale (**f**)

As predicted, we found substantial differences in the psychometric properties of both versions of the EAS under conditions of expectation priming. Specifically, despite good reliability under priming conditions, both versions of the EAS demonstrated poor fit with the hypothesized model under high (EAS-CCT: RMSEA=0.31;

M^2_{749}=45088.54, P=0.0001; EAS-NIBS: RMSEA=0.24; M^2_{534}=13051.28, P=0.0001) and low (EAS-CCT: RMSEA=0.26; M^2_{749}=32120.61, P=0.0001; EAS-NIBS: RMSEA=0.16; M^2_{534}=6397.45, P=0.0001) priming conditions.

Discussion

Expectations may influence the outcomes of cognitive enhancement interventions, but remain unaccounted for in the majority of trials. Here we demonstrate the reliability of a new tool, the EAS, designed specifically to measure expectations of outcomes in the context of cognitive enhancement interventions. Using IRT, we have found that the EAS has internal consistency and can serve as a reliable measure of participant expectations.

Our results further show good validity based on internal structure of the EAS across all subscales, for both CCT and NIBS. Response patterns are comparable across multiple samples of young and older adults, and suggest that older adults may have higher expectations of CCT compared to young (Rabipour et al., 2017a; Rabipour and Davidson, 2015). Moreover, although current analyses of the EAS cannot determine the extent to which responses are truly reflective of expectations, the EAS appears sensitive to changes in reported expectations, relative to baseline, in response to information indicating high or low intervention effectiveness. Because no distinct expectation scale currently exists, we cannot perform an analysis of external validation. However, we would argue that the EAS has high face validity.

Of course, the reliability of the EAS does not necessarily indicate how participants might have interpreted the purpose of the study or the reasoning behind their expectation ratings. Similarly, our results do not provide any insight into how participants interpreted each cognitive domain (i.e., item) in the EAS; notably, the different discriminability of the "concentration" and "distractibility" items, intended to be mirror opposites, suggest that participants may have perceived them as diverging. However, these potential considerations hardly undermine the utility of the tool. The EAS aims to capture how the average person – in particular, non-experts interested in cognitive enhancement interventions but naïve to the scientific context of CCT and NIBS – would respond when reading freely available information supporting or criticizing CCT or NIBS programs (e.g., through advertisements, consumer reviews, or personal anecdotes). Such information, which often fuels people's decision whether or not to pursue a particular program, formed the basis of our expectation priming messages (Rabipour and Davidson, 2015). Determining how people would respond in this type of hypothetical scenario represents an important first step to understanding people's motivations to pursue such interventions when presented with the opportunity.

Limitations

A potential limitation is our inclusion seven items in Study 1 and only six in Study 2. In addition, differential recruitment (i.e., lack of recruitment from FSU and from the Ottawa community for Study 2), as well as the inclusion of 50 OA recruited in the context of a brain training intervention in Study 1, could potentially explain result patterns across our studies.

Conclusion

The EAS can serve as a reliable and valid tool to assess the face validity of cognitive enhancement interventions, while accounting for expectations of outcomes. Using the EAS may help interpret the results of cognitive enhancement trials and determine the effectiveness and appropriateness of individual approaches in different populations. Our data may serve as a reference point to create a standardized expectation scale, with external validation and population norms.

Future studies may refine or customize the structure of the EAS as relevant, based on individual program structure, and use alternative approaches (e.g., involving factor analytic methods) for validating the tool. One useful next step would be to compare intervention outcomes in people who receive the EAS before beginning a study vs. those who do not, as suggested by our reviewers. Alternatively, allowing a certain period of time to pass between administration of the EAS and the intervention might be a good way to avoid having the EAS influence outcomes in an unexpected or artificial way. In addition, as suggested by a reviewer, future research could examine the psychometric properties of the EAS in situations where participants are given a basis for discriminating among the likely outcomes (e.g., providing information about the implicated brain regions and their associated functions).

Assessing expectations with the EAS before, during, and after cognitive enhancement interventions will likely prove useful for explaining intervention outcomes, identifying differences between responders and non-responders, and better tailoring interventions to target users.

Author Contributions

S.R. and P.S.R.D. developed the instrument and collected the data. S.R. and E.K. analyzed the data. S.R. and P.S.R.D. drafted the document, and finalized it based on edits from E.K. All authors approved the final version of the manuscript for submission.

Acknowledgements

We thank the Natural Sciences and Engineering Research Council of Canada for their support of this work.

3 Effects of Expectations on Cognitive Training in Healthy Older Adults and Non-Invasive Brain Stimulation in Healthy Young Adults

The following sections describe the first studies to examine the potential effect of participant expectations on cognitive enhancement interventions. The first study, unpublished pilot research describing a weeklong feasibility assessment, was carried out to determine the feasibility of priming expectations and using a combination of cognitive exercises – specifically, Sudoku puzzles and n-back tasks – in older adults. This pilot study helped form the basis for subsequently carrying out a complete, four-arm cognitive training trial using the pilot program (i.e., Sudoku puzzles and n-back tasks) as the active control condition. The two main studies, registered clinical trials of a CCT program and tDCS protocol, leverage the EAS we developed to measure and prime expectations either positively or negatively. In both trials, we found neither an effect of expectation priming or of experimental condition (i.e., assigned CCT program or tDCS protocol) on performance or subjective outcomes. We include in the Appendix supplemental figures demonstrating long term outcomes and data not presented in the manuscripts below. Despite our findings, future research should expound on this work, raising standards to include well-controlled conditions and an assessment of expectations, to determine whether – and under what conditions – expectations, CCT, and/or tDCS may influence objective and subjective measures of performance and wellbeing.

3.1 Unpublished Pilot Study: Testing the Feasibility of a "Placebo" Training Program in Older Adults

Determining the mechanism through which a CCT program influences cognition, behaviour, and affect requires an adequate comparison condition. This brief weeklong pilot experiment evaluated a "placebo" program involving common Sudoku puzzles and single N-back tasks. These tasks were selected for two main reasons: i) their popularity, which supported engagement and perceived challenge; and ii) their reported ineffectiveness in yielding improvements beyond practice effects (Thompson et al., 2013).

This pilot study sought to evaluate potential age-related differences in the feasibility and perceived enjoyment and challenge of using the EAS as well as the "placebo" program in a subset of participants, before commencing the full CCT trial.

In addition, we sought to compare potential differences in expectations and cognitive performance in YA and OA over a short timeframe.

Participants in this weeklong study included both young ($n = 18$; 10 women; 17-24 years of age) and older adults ($n = 24$; 20 women; 55-79 years of age). The weeklong pilot study involved five 40-minute sessions of training separated by a baseline and post-training assessment. The YA were recruited via the University of Ottawa Integrated System of Participation in Research and received course credits as compensation for their participation. Conversely, the OA were recruited from the Ottawa community via flyers, advertisements, and word-of-mouth, and were entered into a draw for a chance to win a gift card valued at 50$CAD as compensation for their participation.

Training Tasks

For the Sudoku puzzles, participants were able to select "easy", "medium", "hard", or "evil" levels at their discretion. However, to further deter the possibility that the "placebo" program would benefit participant performance on untrained tasks, the Sudoku puzzles included in all levels beyond "easy" were, in reality, randomized to generate an easy-level puzzle on 80% of trials. For the N-back tasks, participants were given the choice of single 2-, 3-, or 4-back tasks. In this study, the type of n-back was randomized to comprise: i) a randomly generated string of letters and numbers; ii) a randomly generated string of pictures; or iii) a spatial n-back task involving a cartoon brain image randomly moving across a 3x3 grid.

Expectation Priming

Participants were randomly assigned to receive a message implying that the 5-day intervention was either highly effective at improving cognitive function ($n = 21$), or not at all effective ($n = 21$). This expectation priming was delivered through the EAS described in the previous section and below.

Transfer Measures

The outcome measures in the present study include standardized neuropsychological tests and questionnaires commonly used in studies of CCT in OA.

California Verbal Learning Test, 2nd Edition (CVLT-II): The CVLT-II assesses short- and long-term verbal memory, learning, and interference tendency. The test consists of two 16-item word lists, which are composed of four semantic categories.

List A is verbally presented five times; the participant must immediately recall the words after each trial. List B is then presented a single time as an interference method, which participants are then asked to recall. Participants must subsequently recall as many words as they can from List A, followed by a semantic cue for each of the four categories. To assess long-term memory, participants are then asked to recall the words from the first list after a delay of 15-25 minutes, including free recall (no cues) and category recall (i.e., when given a category cue). Lastly, individuals are tested in their ability to discriminate between words that were or were not found on List A.

Trail Making Test (TMT): The TMT was administered as a distraction task in the 20-minute delay during the CVLT-II testing. The test involves two trails: Trail A includes numbers arbitrarily positioned on the page that must be connected in ascending order; Trail B contains a combination of numbers and letters randomly positioned on the page, requiring the participant to alternate between connecting numbers and letters (e.g., 1-A-2-B-3-C, etc.). For both trails, participants must connect the numbers (or numbers and letters) by drawing a straight line between them as quickly as possible, without lifting the writing utensil off the page.

Digit Span Task: This test was also completed as a distraction task during the 20-minute delay in the administration of the CVLT-II. Participants were asked to repeat a series of numbers in the forwards order (starting at two digits and going to nine digits). Participants were then asked to repeat a list of numbers in the backward order (starting with two digits and ending at eight digits). The task includes two trials for each increasing number of digits; the test is complete when a participant fails both trials in a series, or until the final trial is completed.

Expectation Assessment Scale (EAS): The EAS was administered to determine individual's beliefs and feelings about brain training. During the pre-assessment participants were asking if they thought cognitive training was effective at improving cognitive abilities and how much background information they had regarding intervention strategies. The survey is also the first-time participants were introduced to the message implying high or low effectiveness of the program. During the post-assessment, participants were again asked their beliefs regarding cognitive training effectiveness followed by if they thought the program they completed was an actual training program. These questions were asked to determine if the message implying high or low effectiveness influenced their understandings and beliefs regarding cognitive training.

Experimental Protocol

After obtaining consent, researchers carried out an initial assessment of baseline ability on the transfer measures. During this initial assessment, participants received a written message containing the high or low expectation priming information. The participants then returned home and completed the training program for fifteen minutes over five consecutive days. During this period, the researchers emailed participants to ensure the completion of the daily exercises. To reinforce the expectation priming during the program, the daily email also contained the expectation priming message.

Following the weeklong program, participants completed a follow-up assessment. We used an alternate version of the CVLT-II in this post-training assessment to minimize practice practice effects from the initial assessment. We also asked participants about their satisfaction with the program, and whether they believed they engaged in genuine cognitive training. Once the final assessment was complete, the participants were debriefed to understand the nature of the experiment and program.

Results

Participants found the "placebo" program to be believable as genuine cognitive training, and reported enjoying the program as well as finding it challenging (see Rabipour and Davidson, 2015). However, we did not find an effect of time (baseline vs. follow-up assessment), of expectation condition (high vs. low expectation priming), or of age group (YA vs. OA), or any interactions between these factors.

Discussion and Future Directions: Following-Up the Pilot Study

Preliminary results from this pilot study suggested that the program was feasible and that the EAS was easy to incorporate in the context of an intervention. Nevertheless, our training period of one week was insufficient to produce measurable effects on our transfer tasks.

In the following study, the authors followed up on these weeklong pilot experiments by directly examining the potential effects of expectations on a 5-week cognitive training intervention.

3.2 Few Effects of a 5-week Computerized Cognitive Training Program in Healthy Older Adults

Sheida Rabipour[1], Cassandra Morrison[1,2], Jessica Crompton[1], Marcelo Petrucelli[3], Murillo de Oliveira Gonçalves Germano[4], Anita Popescu[3], Patrick S. R. Davidson[1,2,5]

[1]School of Psychology, University of Ottawa, Ottawa, Canada

[2]Bruyère Research Institute, Bruyère Continuing Care, Ottawa, Canada

[3]Department of Computer Science, University of Ottawa, Ottawa, Canada

[4]Department of Mechanical Engineering, University of Ottawa, Ottawa, Canada

[5]Heart and Stroke Foundation of Ontario Canadian Partnership for Stroke Recovery, Ontario, Canada

Abstract

Computerized cognitive training programs are becoming increasingly popular and practical for cognitive aging. Nevertheless, basic questions remain about the benefits of such programs, and about the degree to which participant expectations might influence training and transfer. Here we examined a commercial cognitive training program (*Activate*) in a 5-week double blind, pseudo-randomized placebo-controlled trial. Based on *a priori* power analysis, we recruited 99 healthy older adults 59-91 years of age (M = 68.87, SD = 6.31; 69 women), assigning them to either the intervention or an active control program (Sudoku and n-back working memory exercises). We subdivided both groups into high and low expectation priming conditions, to probe for effects of participants' expectations on training and transfer. We assessed transfer using a battery of standard neuropsychological and psychosocial measures that had been agreed to by the training program developers. We planned and pre-registered our analyses (on osf.io). The majority (88%) of participants progressed through the training, and most provided positive feedback about it. Similarly, the majority (81%) of participants believed they were truly training their brains. Yet, transfer of training was minimal. Also minimal were any effects of expectations on training and transfer, although participants who received high expectation priming tended to engage more with their assigned program overall. Our findings suggest limited benefits of *Acti-*

vate training on cognition and psychosocial wellbeing in healthy older adults, at least under the conditions we used.

Keywords

Aging; Brain training; Computerized cognitive training; Executive function; Expectation; Placebo effect; Working memory.

Introduction

Subtle decline in several cognitive domains is typical even in healthy aging (Anderson and Craik, 2017; Davidson and Winocur, 2017; Drag and Bieliauskas, 2010; Toepper, 2017). To prevent or slow this cognitive decline, computerized interventions are increasingly becoming popular among researchers, clinicians, and older adults themselves. Such Computerized Cognitive Training (CCT) represents an attractive alternative to medication and other interventions that may be costly and have serious side effects (National Academies of Sciences et al., 2017). It is therefore unsurprising that older adults are prominent targets of – and subscribers to – commercialized CCT programs (e.g., *Lumosity, Cognifit, Brain Age*; Shah et al., 2017).

Nevertheless, basic questions remain about CCT. An obvious one is whether such programs actually work. When people ask this question, they are usually asking about *transfer* of training: That is, will training lead to improvement on tasks that were not trained, but that rely on the same underlying cognitive processes as those that underwent training? Answering this question has been difficult due to the poor methodological quality of previous research on CCT. For example, studies have often suffered from insufficient control conditions – notably, frequent lack of an active control group and inadequate consideration of potential placebo effects – and small sample sizes (Motter et al., 2016; National Academies of Sciences et al., 2017; Simons et al., 2016). Here we report a trial of the commercial CCT program *Activate* in older adults, in which we overcame many of these limitations and explicitly addressed the largely ignored potential confound of participant expectations.

Activate Program

Although many commercial CCT programs are available (for a partial list and review, see Simons et al., 2016), we selected the *Activate* web-based program because of its focus on training working memory (WM), sustained and divided attention, inhibition, and visuospatial perception. Many of these functions decline even in healthy aging (Davidson and Winocur, 2017; Reuter-Lorenz et al., 2015; Zanto and Gazzaley, 2014). Specifically, the *Activate* games are divided into four categories, targeting: i) spatial WM; ii) visual pursuit and category sorting; iii) visual pursuit and inhibition; and iv) pattern completion.

In our view, the *Activate* program had two advantages: First, the training is adaptive. In other words, the program adjusts for individual performance on each task, remaining at a certain level of difficulty as long as participant accuracy and response times continue to improve at a certain rate. The program only increases level of difficulty once performance has reached a plateau, rather than advancing to the next level after a predetermined number of correct trials. This approach allows participants to master each task at a given level of difficulty before moving on to subsequent levels. Researchers have argued that such adaptive training methods are particularly likely to produce transfer of training (Edwards et al., 2017; Morrison and Chein, 2011; Heinzel et al., 2014). Second, the *Activate* program had already shown promise of transfer in older adults with depression, with training reported to reduce depressive symptoms and measurably improve cognitive control (as indexed by the Trail-Making and Stroop tests; Morimoto et al., 2016, 2014). Despite these promising preliminary reports, no other evaluations of this program currently exist (Simons et al., 2016). Thus, we sought to replicate these previous reports by including the neuropsychological tasks from those studies (i.e., Trail-Making and Stroop tests), and came to a consensus with the *Activate* developers on other tasks that should show transfer in older adults.

Expectations and Placebo Effects

Much of the CCT literature has been criticized for having relatively low methodological quality (e.g., Motter et al., 2016; Simons et al., 2016). Perhaps the most serious problems revolve around insufficient control conditions, including lack of an appropriate active control group to distinguish intervention effects from those of placebo or other non-specific factors, and failure to account for participants' expectations of training outcomes. Previous surveys have suggested that older adults have optimistic expectations of CCT (Rabipour et al., 2017a; Rabipour and Davidson, 2015). Thus, what appear to be transfer effects following CCT could, instead, merely represent placebo effects. To our knowledge, expectations have rarely – if ever – been explicitly addressed in CCT trials. Perhaps the most powerful way to accomplish this is with a *balanced-placebo* design (Rohsenow and Marlatt, 1981), using a randomized double-blind placebo-controlled design and sub-dividing both the treatment and placebo control groups such that half of participants in each group are told they are in the treatment condition and the other half told they are in the placebo control group. Such a design helps one tease apart the true effects of the intervention from those of expectations.

The Present Study

Here we examined a 5-week CCT program in healthy older adults actively seeking preventative cognitive interventions. Using a balanced-placebo design, we aimed to elucidate the potential influence of such expectations on cognitive performance following participation in CCT. We took particular care in our study design and data collection to ensure: i) reasonable statistical power; ii) use of a dynamic CCT program adaptive to participant performance; iii) use of an active (rather than passive) control condition, comprised of a computerized program that would believably pass as cognitive training; iv) control of potential expectancy-mediated placebo effects; v) use of consensus transfer measures that the developers of the CCT program agreed should reflect the cognitive processes being trained by their exercises; vi) replication and extension of previous findings on *Activate* improving executive function in older adults (Morimoto et al., 2014), and of our own work on older adults having higher expectations of CCT (Rabipour and Davidson, 2015); and vii) double-blind design. These steps follow best practice recommendations (e.g., National Academies of Sciences et al., 2017).

Methods

Participants

We recruited 99 healthy older adults (M_{age}=68.88, SD=6.31 years; 69 women) with normal or corrected-to-normal vision and hearing from the Ottawa community via ads and flyers (Figure 1). We screened all participants based on the following exclusion criteria: i) diagnosis of memory impairment or cognitive decline; ii) diagnosis of neurological disorder; iii) experience of stroke or transcient ischemic attack; and iv) experience of injury or operation resulting in long-term changes in memory or cognitive function.

A-priori power analyses using G*Power version 3.1 determined that a minimal sample of 84 participants (i.e., 21 older adults per group) would be required for repeated-measures ANOVA with within-between subjects interactions, based on a moderate effect size of 0.3 and at 80% power with an adjusted alpha level of 0.01 to account for multiple measurements. This interaction between assigned group (see below) x time (pre vs. post training) would provide the strongest evidence of *Activate* having specific transfer effect(s).

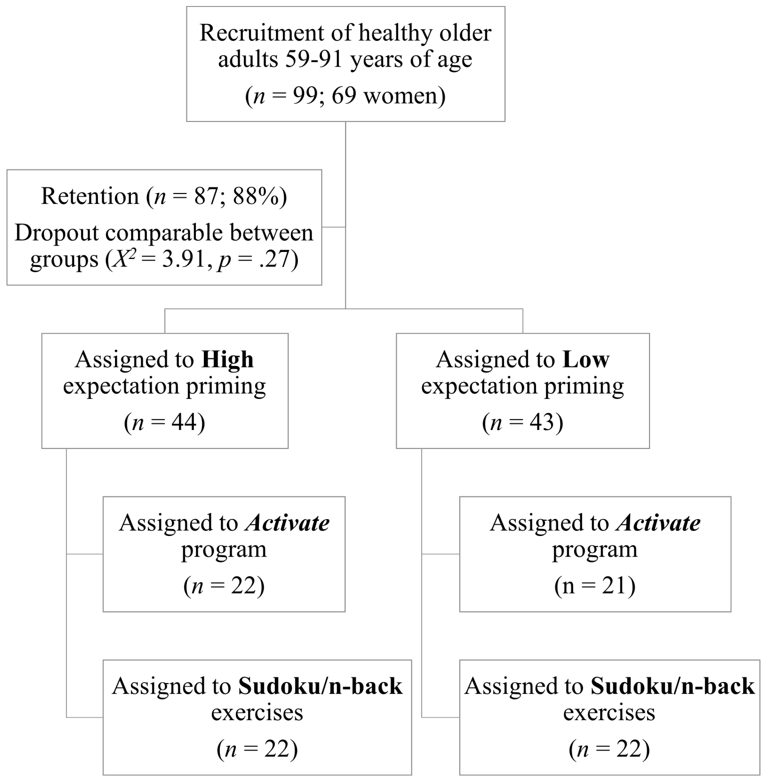


Figure 1. Participant recruitment and group assignment with final sample.

Experimental Design and Protocol

The study was a double-blind randomized controlled trial (registered at clinicaltrials.gov, ID: NCT0220571), crossing expectation priming (high vs. low) with CCT program (*Activate* vs. placebo-controlled Sudoku and n-back exercises). After providing consent, participants were assigned to one of two expectation priming conditions: i) High expectation priming, in which participants were told they would receive a type of CCT known to improve performance; and ii) Low expectation priming, in which participants were told they would receive a type of CCT with no known benefits. We then assigned participants to receive one of two programs: the commercialized *Activate* CCT intervention, or an active control (see below).

We followed a pseudo-randomization procedure, aiming to balance the age and sex of participants across groups as best as possible. Importantly, our expectation priming conditions and comparison of two separate CCT programs enabled blinding of participants with respect to their experimental condition. To avoid divulging the nature of the study and potentially skewing the results, participants who entered the study with a friend or family member, or who were referred to the study by a past participant, were assigned to the same group. To maintain blinding for researchers, we ensured that those examining participants would not be present during the training sessions and would have no contact with participants outside the pre- and post-training assessments.

Both CCT programs comprised five 40-minute training session per week, over five weeks. The 25 sessions each involved two 20-minute periods of training, separated by a brief break (i.e., several minutes) if desired. Each week, participants were instructed to complete a minimum of four home sessions in addition to one lab session, carried out in a small group setting at the University of Ottawa main campus (i.e., where several participants would complete their training together in the same room, on individual computers). The rationale for the weekly lab sessions was twofold: First, the supervised lab sessions helped us ensure that participants were adhering to the correct training protocol and were not experiencing any issues related to the program or understanding of the training tasks. Second, previous research has suggested that older adults may benefit from CCT to a greater extent when completing the program, at least in part, in supervised group sessions conducted at a center (Lampit et al., 2014; Wadley et al., 2006). Dividing the home and lab sessions in this manner permitted us to balance between convenience and quality control. Similarly, we selected the 5-week time frame to promote practicality and minimize participant attrition, while permitting a reasonable amount of training (i.e., 1000min or ±17h), comparable to other training studies and plausibly leading to transfer.

We administered behavioural assessments at baseline and following completion of the CCT program. We also performed a partial long-term follow-up assessment, wherein we asked participants to complete select questionnaires six months following the completion of the program. At the time of this long-term follow-up, participants were contacted via telephone to provide final comments on their experience and perspective on the effects of the program via an informal interview.

In order to maximize intrinsic motivation and avoid possible performance decrements associated with receipt of extrinsic rewards (Jaeggi et al., 2014), participants received no monetary or other compensation for participation in the CCT program. However, participants were able to retain free access to the program beyond their participation in the study. Moreover, to compensate for time spent in the research lab at the University of Ottawa, participants were offered free parking as well as a chance to enter a lottery to win a 50$CAD gift card. We received ethical approval to conduct this study from the Research Ethics Boards at the University of Ottawa and the Bruyère Research Institute.

Expectation Assessment and Priming

Participants rated their expectations of CCT effectiveness using the Expectation Assessment Scale (EAS), a validated questionnaire (Rabipour et al., 2018a) we have previously used to measure and prime expectations with written messages implying that the intervention is either highly effective or not expected to produce any meaningful change (see Rabipour et al., 2017a; Rabipour and Davidson, 2015). We administered the EAS on three occasions: i) at baseline; ii) after participants received the expectation priming messages (High or Low); and iii) after completing the 5-week CCT program. Participants rated their expectations of outcomes on a scale from 1-7 (1 = "completely unsuccessful," 2 = "fairly unsuccessful," 3 = "somewhat unsuccessful," 4 = neutral/"I have absolutely no expectations," 5 = "somewhat successful," 6 = "fairly successful," 7 = "completely successful"). We probed expectations on seven cognitive domains: i) general cognitive function; ii) memory; iii) concentration; iv) distractibility; v) reasoning ability; vi) multitasking ability; and vii) performance in everyday activities.

Training Programs

Activate training

The intervention, the pirate-themed *Activate* web program (C8 Sciences), comprised six adaptive computer games involving WM, sustained and divided attention, inhibition, and visuospatial perception. Specifically, the games are divided into four categories based on targeted cognitive functions: i) spatial WM (two games); ii) visual pursuit and category sorting (one game); iii) visual pursuit and inhibition (two games); and iv) pattern completion (one game).

The *Activate* intervention aims to account for individual differences in performance on each task: each task remains at a level of difficulty as long as participant accuracy and response times continue to improve, rather than advance after a predetermined number of correct trials. The program increases level of difficulty only once performance reaches a plateau. Originally created to enhance school performance in children with impulse-control impairments, the program has more recently been applied to older adults and appears to reduce depressive symptoms as well as executive dysfunction in patients with geriatric depression (Morimoto et al., 2014, 2016).

During each session, participants were presented with a choice of three possible games. The selected game was played for five minutes, after which the program terminated the game and presented participants with a new choice of three games. Once participants completed four 5-minute game blocks (i.e., 20 minutes of training), the program automatically logged participants out. We asked participants to complete two 20-minute training periods in immediate succession (with the possibility of a brief break in between), at least five different days per week, resulting in five weekly 40-minute sessions in total. Although participants were able to select which set of games to play throughout each session, the program limited choice if participants strongly favoured certain games over others, to ensure roughly equivalent amount of training with all games.

Sudoku and single n-back training

The active control program comprised non-adaptive computer games with no unifying theme. Participants had a choice of two game types: Sudoku or single n-back WM exercises. We selected these games based on popular conceptions that they improve cognitive functions (Boot et al., 2016), coupled with little empirical evidence supporting this notion (Souders et al., 2017). Unlike the intervention groups, participants assigned to the active control condition selected games entirely at their own discretion for each session. We nevertheless encouraged participants to split their sessions evenly between Sudoku puzzles and n-back games. Similar to the *Activate* training, participants were automatically logged out of the game portal after 20 minutes of task engagement, and were asked to complete two 20-minute training blocks in immediate succession (again, with possibility of a brief break), at least five different days per week.

For the Sudoku puzzles, participants had the option to select “easy”, “medium”, “hard”, or “evil” levels, as per traditional Sudoku. However, to further deter the possibility that the control program would enhance cognitive function or benefit participant performance on untrained tasks, the Sudoku puzzles included in all levels beyond “easy” were, in reality, randomized to generate an easy-level puzzle on 80% of trials, and a puzzle of the selected level on the remaining 20% of trials. Moreover, the “evil" level was, in reality, equivalent to “hard” (i.e., we did not actually include any “evil” level Sudoku puzzles in our program). Our analyses of these data reflect the level of Sudoku participants actually completed, rather than the level they selected.

For the n-back tasks, participants had the option of selecting 2-, 3-, or 4-back tasks. The type of n-back was randomized to comprise: i) a randomly generated string of letters and numbers; ii) a randomly generated string of pictures; or iii) a spatial n-back task involving a cartoon brain image randomly moving across a 3x3 grid. Due to technical issues with our database, we were unable to retain data regarding level of n-back for the majority of our participants; we analyzed these data based on n-back type.

Transfer Measures

We assessed performance on commonly used neuropsychological tests and subjective reports of cognition, quality of life (QOL), and affect. We included both objective and subjective measures to permit a more comprehensive analysis of potential training-related improvements on untrained tasks and general functioning. These measures were discussed and agreed upon by the lead authors (S.R. and P.S.R.D) and the creators of the *Activate* program at Yale University.

We included screening measures of global cognition and language function at baseline, as potential discriminating variables in our subsequent analyses. We assessed global cognition using the Montreal Cognitive Assessment (MoCA), a brief cognitive screening tool sensitive to mild declines in cognitive function (Nasreddine et al., 2004). Based on advice from our colleagues, we also used the 15-item Boston Naming Test (Lansing et al., 1999) as a screen for language function in our final 53 participants.

Neuropsychological Transfer Tasks

Previous studies have demonstrated decreases in scores on common neuropsychological tests – including the Wisconsin Card Sorting Test, Stroop Interference Task, Trail Making Test, and Controlled Oral Word Association Test – with increasing age (Lezak et al., 2012; Salthouse, 2010).

Wisconsin Card Sorting Task (WCST). The WCST, which requires participants to categorize cards by colour, shape, or number using only computer feedback, is a measure of executive function and cognitive flexibility (Rhodes, 2004). We evaluated number of categories completed, an index sensitive to age-related changes in executive function (Rhodes, 2004).

California Verbal Learning Test, second edition (CVLT-II. The CVLT assesses verbal memory by presenting the participant with two lists of 16 words, divided into four semantic categories, over several trials. The full version of the CVLT, used in the present study, involves a short- and long-delay component separated by 15-25 minutes. Scores are typically lower with increasing age and lower level of education, as well as in men compared to women (Lamar et al., 2003). We selected to evaluate the semantic clustering (Stricker et al., 2002) and long-delay cued recall sub-components of the CVLT, which index strategy use (i.e., organizational clustering) and recall ability. Whereas semantic clustering may correlate with frontal lobe function (Baldo et al., 2002) and predict memory impairment (Malek-Ahmadi et al., 2011), recall indices and may represent a stronger measure of executive function (Hill et al., 2012).

Digit Span Task. The digit span task, a subtest of the Wechsler Adult Intelligence Scale, is an index of WM capacity (and possibly also of effort; (Axelrod et al., 2006)). For the forward digit span (FDS) task, a measure of short-term recall, participants repeat a string of numbers that the examiner reads aloud; in the backward digit span (BDS) task, an index of WM capacity, participants recite the string of numbers in the reverse order. In the present study, participants completed both the FDS and BDS tasks, but only scores for the BDS were included in our analyses as a measure of executive function (Glisky et al., 1995).

Trail Making Test (TMT). The TMT requires participants to draw a straight line between numbers (Trail A) and alternating numbers and letters (Trail B) in sequential order, as quickly as possible. The time taken to complete each trail provides a measure of visuospatial capacity, executive control, and cognitive flexibility (Kortte et al., 2002). Here we administered both Trails A and B, but included only Trail B time for our final analyses, as per previous studies of *Activate* (Morimoto et al., 2014, 2016)

Controlled Oral Word Association Test (COWAT) and Animal Naming Test. The COWAT measures letter fluency (LF) with the generation of words that begin with a given letter within 60 seconds. Participants name as many words as possible that begin with the letter "F", then "A", and finally "S". The animal-naming test, administered immediately after the COWAT, is a measure of semantic fluency that requires participants to name as many animals as possible in 60 seconds. Scores represent the total number of admissible words reported and appear sensitive to age-related changes in verbal fluency (Long Lasting Memories Project, 2009). Although participants completed both the LF and animal naming tasks, only scores for the LF were included in our analyses as an index of executive function (Glisky et al., 1995; Mccabe et al., 2010).

Stroop Interference Task. One of the most commonly used measures in cognitive psychology, the Stroop task (Stroop, 1935) measures attention, processing speed, inhibition, and executive control. The test proceeds in three timed parts of 45 seconds each: In the first part, which measures reading speed, the participant is given a list of colour words and must read as many words as possible within the allotted time. In the second part, which measures colour-naming speed, the participant must name the ink color of printed “X”s as quickly as possible. In the final part – the interference condition – the participant must quickly name the color of the ink in which the colour words are written, without reading the words themselves (e.g., say "blue" when seeing the word "green" written in blue ink). The version used in the present study contains 120 words per part; scores in each part of the test are combined to create an interference score. Because it is brief, requires very little education, and is not culturally biased, this test is a useful screen for neuropsychological deficits. Older adults appear to have slower interference scores, which may reflect decreased efficiency of inhibitory processing (Spieler et al., 1996).

Letter-Number Sequencing. In a subset of our participants (n=69), we additionally explored performance on letter-number sequencing, a subtest of the Wechsler Adult Intelligence Scale. This brief, standardized measure of executive function indexes verbal and visuospatial WM performance, as well as processing speed (Crowe, 2000). During the task, examiners read a series of scrambled letters and numbers to participants, who must then recite the numbers in sequential order, followed by the letters in alphabetical order.

Psychosocial Indices

Multifactorial Memory Questionnaire (MMQ). The MMQ (Troyer and Rich, 2018) is a meta-memory questionnaire that includes scales of contentment or satisfaction (i.e., feelings regarding memory performance), ability (i.e., self-appraisal of memory capabilities), and strategy (i.e., reported frequency of memory strategy use). Self-report of memory may be an important predictor of cognitive decline (Reid and Maclullich, 2006). Nevertheless, both healthy older adults and those with memory disorders can report inaccurate beliefs about memory and aging – which may reflect negative cultural stereotypes – and poor evaluation of their own memory (Troyer and Rich, 2002). Such inaccuracies may lower expectations, reduce effort on everyday tasks involving memory, and lead to impaired memory performance.

Pittsburgh Sleep Quality Index (PSQI). The PSQI is a brief scale measuring sleep quality. Studies suggest that sleep quality may deteriorate in healthy older adults, independent of medication use or the presence of other physical or psychological conditions (Buysse et al., 1991; Nebes et al., 2009). Poor quality of sleep has been shown to associate with greater risk of cognitive decline and dementia (Spira et al., 2014).

Subjective Age Questionnaire. We included a measure of subjective age, adapted from (Hughes et al., 2013), which asks participants to rate their subjective age in years on four categories: i) general age; ii) age with respect to wellbeing; iii) physical age; and iv) cognitive age. Studies suggest that older adults feel older after immediately performing memory tests (Hughes et al., 2013), and that perceived age may correlate with cognitive function (Stephan et al., 2016). We sought to determine whether this pattern would persist in our sample or, conversely, whether perceived age would decrease after completing the cognitive intervention. We used a computerized version of the scale, asking participants to indicate their perceived age in each category by dragging the cursor to the appropriate location on a line denoted only by a "0" and "120" on either end. The relative location of the cursor determined subjective age.

Patient Health Questionnaire (PHQ-9). The PHQ-9 is a brief questionnaire that assesses the presence and severity of depression. PHQ-9 reports correlate with mental and general health, as well as social and physical functioning (Kroenke et al., 2001). We included the PHQ-9 in our final 71 participants based on advice from our colleagues, as a more sensitive substitute for the Center for Epidemiological Studies-Depression (CES-D) scale (Lewinsohn et al., 1997).

Social Engagement Questionnaire (SEQ). The SEQ measures indices of social engagement, including social activity, social network size, and social support (Krueger et al., 2009). We included this measure in our final 53 participants based on feedback from our colleagues, and slightly adapted the form under the guidance of Kristin Krueger, who initially developed the scale.

Short Form Health Survey (SF-36). The SF-36 is a 36-item measure of health-related QOL, found to be reliable in older adults (Hayes et al., 1995). The questionnaire categorizes the items into nine scales, including physical functioning, physical health problems, emotional problems, vitality, mental health, social functioning, bodily pain, general health, and health transition.

Feedback on Perceived Experience

At the post-training assessment, we asked participants to complete a satisfaction questionnaire for feedback regarding their perceived experience during the intervention. On a scale from 1-7 (1 = "very strongly disagree," 2 = "strongly disagree," 3 = "disagree," 4 = neutral/"neither agree nor disagree," 5 = "agree," 6 = "strongly agree," 7 = "very strongly agree"), participants rated the degree to which they found the experience: i) enjoyable; ii) challenging; iii) frustrating; iv) engaging; v) boring; vi) motivating; and vii) satisfying.

Statistical Analysis

We conducted repeated-measures multivariate analysis of variance (MANOVA) on each category of outcomes (i.e., expectation ratings, training tasks, and neuropsychological and psychosocial transfer measures), with expectation priming and CCT conditions as between-subjects factors, and time as a within-subjects factor. We followed up significant results with simple effects ANOVA and t-tests between the groups of interest. Where applicable, we used the Holm-Bonferroni correction for multiple comparisons and Greenhouse-Geisser correction for sphericity.

We performed analyses using IBM SPSS Statistics, Inc. version 23 and R version 3.1.1. We pre-registered our analysis plan on Open Science Framework, as part of the "OSF Pre-registration Challenge".

Results

MANOVA between assigned program (*Activate* vs. control) and expectation priming condition (high vs. low) indicated no significant group differences in age, years of education, cognitive function (MoCA and Boston Naming scores), or medication use (Wilk's $\lambda \geq .867$, $F_{(5,35)} \leq 1.08$, $p \geq .39$; Table 1). Chi-squared analysis similarly revealed no significant group differences in sex (X^2 = .389, p=.32). Self-reports of medication use indicated that the majority of participants (78/87=90%) did not take anticholinergic medication. Moreover, the distribution of Anticholinergic Cognitive Burden scores (Campbell et al., 2013) did not significantly differ between groups (X^2 = 2.31, p=.511).

Table 1. Participant demographics. Groups did not significantly differ with respect to distribution of sex, mean age, years of education, global cognition and memory, language function, and self-reported number of medications ingested.

Group	Program	Expectation Priming	n (women)	Age	Years of Education	MoCA Global Score	MoCA Memory Score	Boston Naming Test	Medication Number
1	*Activate*	High	22 (17)	67.59 *(6.89)*	16.55 *(2.48)*	27.5 *(2.69)*	3.23 *(1.82)*	14.55 *(.52)*	2.11 *(1.84)*
2	*Activate*	Low	22 (14)	69.59 *(6.91)*	17.64 *(3.53)*	26.86 *(2.77)*	2.45 *(2.02)*	13.82 *(.98)*	3.00 *(3.25)*
3	Sudoku /nback	High	21 (14)	68.95 *(4.44)*	15.86 *(2.97)*	27.29 *(2.45)*	3.24 *(1.79)*	14.45 *(.82)*	2.29 *(2.37)*
4	Sudoku /nback	Low	22 (15)	69.64 *(7.21)*	16.77 *(2.41)*	26.48 *(3.19)*	3.00 *(1.90)*	14.18 *(.98)*	2.41 *(2.50)*

Participant retention rate was high: after dropout due to scheduling conflicts (n=5), health issues (n=4), loss of interest (n=2), and other personal emergencies (n=1), 88% (87/99; 60 women) of our sample completed the study and were included in our final analyses.

Expectations of Outcomes

Participants in all groups were largely optimistic of CCT outcomes at baseline (Figure 2), with ratings in all cognitive domains significantly above neutral for participants in all groups ($t_{21} \geq 2.11$, $p \leq .047$, Cohen's $d \geq .45$), with the exception of ratings for "multitasking" in participants assigned to *Activate* training and low expectation priming (t_{21}=.84, p=.41). Mean expectation ratings did not significantly differ across groups at baseline.

We performed repeated measures MANOVA comparing expectation ratings across the seven cognitive domains between expectation priming condition and CCT program at three times: baseline, after receiving the expectation priming message, and after completing the CCT. This analysis revealed a significant main effect of time (Wilk's λ=.349, $F_{(14,70)}$=9.31, $p<.0001$, η_p^2=.65) as well as a significant interaction between time and expectation condition (Wilk's λ=.618, $F_{(14,70)}$=3.08, p=.003, η_p^2=.38; Figure 2). We did not find a main effect of program or of expectation condition on expectation ratings in any cognitive domain, after correcting for multiple comparisons.

Probing the results for each cognitive domain, we found a significant effect of time ($F_{(1.58,131.4)} \geq 17.67$, $p<.0001$, η_p^2=.104) and significant interaction between time and expectation condition ($F_{(1.49,123.38)} \geq 6.06$, $p \leq .044$, $\eta_p^2 \geq .04$) for all cognitive domains, except for "distractibility", where the effect of time ($F_{(1.58,130.7)}$=3.30, p=.051, η_p^2=.038) was marginal.

Follow up MANOVA comparing responses at each time showed that this interaction was significant immediately after participants first received the expectation priming message, before beginning the training program (Wilk's λ=.80, $F_{(7,77)}$=2.75, p=.013, η_p^2=.20). Specifically, after reading their respective expectation priming messages, participants in the high expectation condition significantly increased their expectations compared to baseline in all cognitive domains, whereas participants who received low expectation priming decreased their expectations ($F_{(1,83)} \geq 7.32$, $p \leq .008$, $\eta_p^2 \geq .081$). After correcting for multiple comparisons, we did not find group differences in ratings for any cognitive domain following completion of the program.

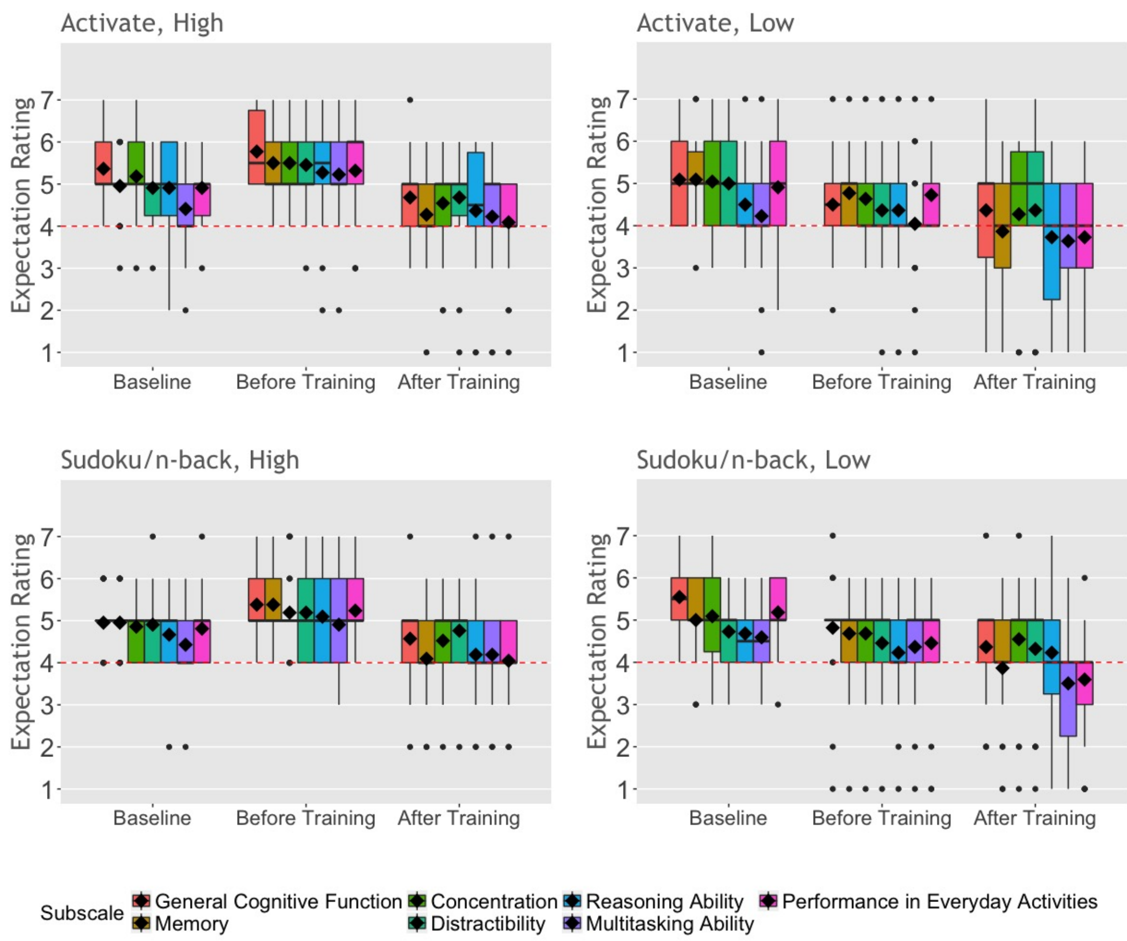


Figure 2. Participant EAS ratings at baseline, after receiving expectation priming (i.e., before training), and following completion of their assigned 5-week CCT program. Ratings of expected outcomes were on a scale of "1" ("completely unsuccessful") to "7" ("completely successful") for each subscale (i.e., cognitive domain). Red dashed lines represent a neutral rating of "4" ("no expectation"). Solid lines represent group medians; diamonds represent group means.

Training Performance

Engagement with Training Tasks

Using repeated measures MANOVA, we evaluated the amount of time participants in each expectation priming condition engaged in the *Activate* games over the five weeks (Figure 3a). We found a main effect of week (Wilk's λ=.309, $F_{(16,27)}$=3.77, p=.001, η_p^2=.69) and of expectation priming (Wilk's λ=.762, $F_{(4,39)}$=3.04, p=.028, η_p^2=.24), but no interaction between expectation and week ($F_{(16,27)}$=1.63, p=.128). Further examination revealed the effect of week to be significant for the "visual pursuit / category sorting" ($F_{(4,168)}$=2.93, p=.022, η_p^2=.065) and "visual pursuit / inhibition" ($F_{(4,168)}$=13.81, $p\leq$.0001, η_p^2=.25) categories, and the effect of expectation to be significant for the "visual pursuit / category sorting" games ($F_{(1,42)}$=5.76, p=.021, η_p^2=.12). Specifically, participants engaged in the "visual pursuit / category sorting" games significantly more during the fourth week of the program, compared to the first, second, and fifth weeks ($t_{(43)}$ $\geq$2.27, $p\leq$0.028, Cohen's $d\geq$.69); for the "visual pursuit / inhibition" category, participants engaged in the games significantly less in the fourth and fifth weeks ($t_{(43)} \geq 2.67$, $p \leq 0.011$, Cohen's $d \geq .81$), compared to the first three. Moreover, participants who received high expectation priming engaged significantly more with the "visual pursuit / category sorting" games, compared to those in the low expectation priming condition ($t_{(42)}=2.40$, $p=.021$, Cohen's $d=.74$). Based on these results, we included amount of time played per week as a covariate in analyses of performance outcomes (see below).

Figure 3. Amount of time (min) spent on the a) *Activate* games and b) Sudoku/n-back exercises each week, over the five weeks of the intervention. Error bars represent SEM.

Similarly, for participants in the control program, we used repeated measures MANOVA to examine amount of engagement in each level of Sudoku puzzle and type of n-back exercise over the five weeks (Figure 3b). We found no significant effect of time (Wilk's $\lambda=.332$, $F_{(24,18)}=1.51$, $p=.19$,), of expectation priming (Wilk's $\lambda=.909$, $F_{(6,36)}=.60$, $p=.73$,), or interaction between time and expectation priming (Wilk's $\lambda=.581$, $F_{(24,18)}=.54$, $p=.92$,).

Performance on Training Tasks

Because we found differences in amount of engagement with the program, we included total amount of time played (i.e., sum of played amount over the five weeks) as a covariate in our repeated measures multivariate analysis of performance on the *Activate* training tasks (Figure 5). We found a main effect of time on highest level achieved in the *Activate* games (Wilk's $\lambda=.371$, $F_{(16,25)}=2.64$, $p=.014$, $\eta_p^2=.63$), but no main effect of expectation priming ($F_{(4,37)}=1.90$, $p=.132$) or interaction between time and expectation priming ($F_{(16,25)}$=.91, p=.56). Follow-up univariate tests revealed this effect to be significant for the "“spatial WM" ($F_{(2.7,107.1)}$=4.25, p=.009, η_p^2=.096) and “visual pursuit / category sorting" categories ($F_{(1.5,107.1)}$=6.65, p=.005, η_p^2=.14). For the “spatial WM” games, where levels represent list length of items remembered, performance was significantly lower in the second week, compared to the first, fourth, and fifth weeks; for the “visual pursuit / category sorting” games, performance steadily and significantly improved over the five weeks ($t_{(42)}$ ≥11.5, p<.0001, Cohen’s d≥3.55).

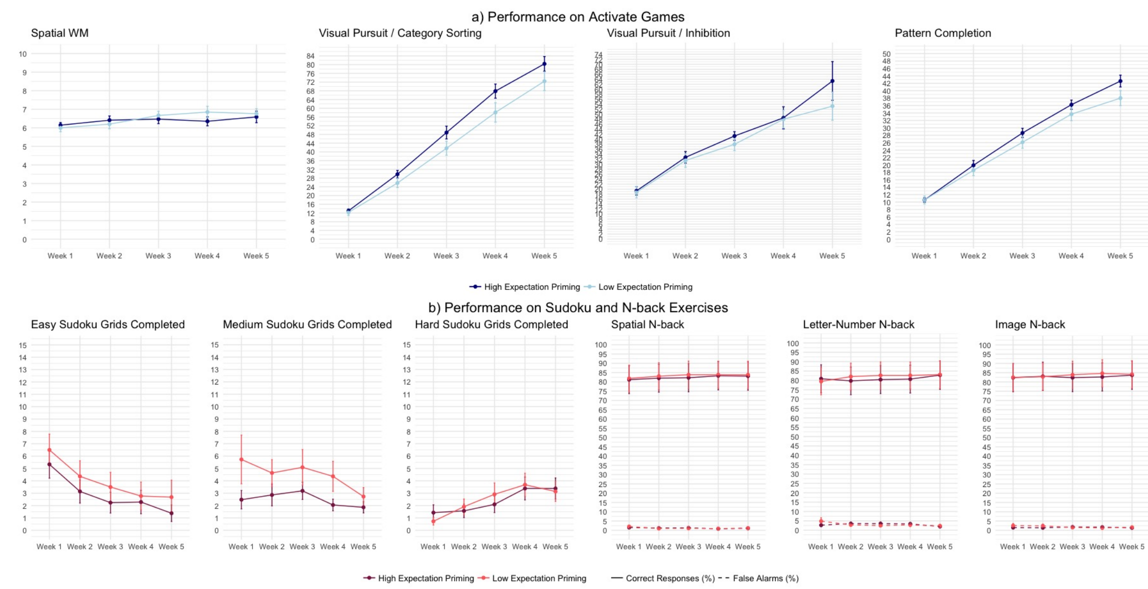


Figure 4. a) Highest level achieved on the *Activate* games over the five weeks of the intervention and b) performance on the Sudoku and n-back exercises, as measures by number of correctly completed Sudoku puzzles per level and percentage of correct trials and false alarms on the n-back tasks. Error bars represent SEM.

We performed the same analysis to evaluate performance on the control tasks (Figure 4b), again including total amount of time played as a covariate. For both the number of successfully completed Sudoku puzzles and performance on n-back games, we found no effect of time (Wilk’s λ=.688, $F_{(12,29)}$=1.10, p=.40; Wilk’s λ=.731, $F_{(24,17)}$=.26, p=1.0, respectively), of expectation priming (Wilk’s λ=.919, $F_{(3,38)}$=1.12, p=.36; Wilk’s λ=.891, $F_{(6,35)}$=.71, p=.64, respectively), or an interaction between the two (Wilk’s λ=.638, $F_{(12,29)}$=1.37, p=.23; Wilk’s λ=.512, $F_{(24,17)}$=.67, p=.82, respectively).

Neuropsychological Transfer Effects

Repeated measures MANOVA examining performance on neuropsychological transfer tests across expectation condition and program revealed a main effect of time (Wilk’s λ=.633, $F_{(7,75)}$=6.22, p<.0001, η_p^2=.37) and of expectation priming (Wilk’s λ=.761, $F_{(7,75)}$=3.36, p=.004, η_p^2=.24; Figure 5). Notably, we found no significant main effect of program or interactions between time, program, or expectation priming.

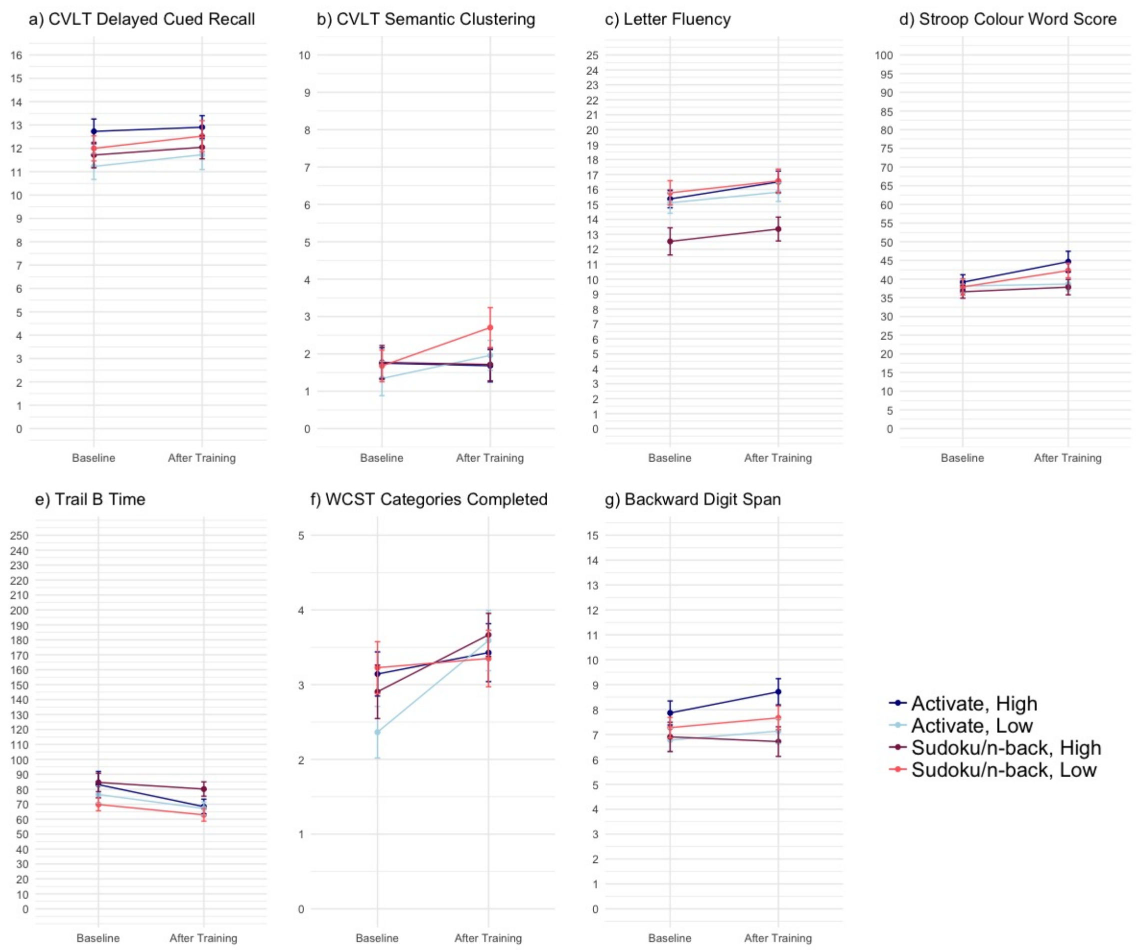


Figure 5. Performance on cognitive tasks analyzed, including: a) long-delay cued recall and b) semantic clustering on the CVLT; c) letter fluency, computed as the average number of words beginning with the letters F, A, and S; d) Stroop colour-word score; e) time (s) on Trail B of the TMT; f) categories completed on the WCST; and g) score on the BDS. Error bars represent SEM.

Follow-up analyses indicated a significant post-training improvement in Stroop colour-word score ($F_{(1,81)}$=11.35, p=.001, η_p^2=.12), time on TMT trail B ($F_{(1,81)}$=10.87, p=.001, η_p^2=.12), categories completed on the WCST ($F_{(1,81)}$=9.88, p=.002, η_p^2=.11), letter fluency ($F_{(1,81)}$=7.20, p=.009, η_p^2=.08), and CVLT semantic clustering ($F_{(1,81)}$=4.24, p=.043, η_p^2=.05). Moreover, we found that the effect of expectation was significant for time on TMT trail b ($F_{(1,81)}$=4.61, p=.035, η_p^2=.05), whereby participants assigned to low expectation priming had faster response times.

Psychosocial Transfer Effects

Repeated measures MANOVA examining subjective reports of psychosocial data across program and expectation condition revealed neither a main effect of time, nor any main effects or interactions on the basis of program or expectation priming (Figure 6).

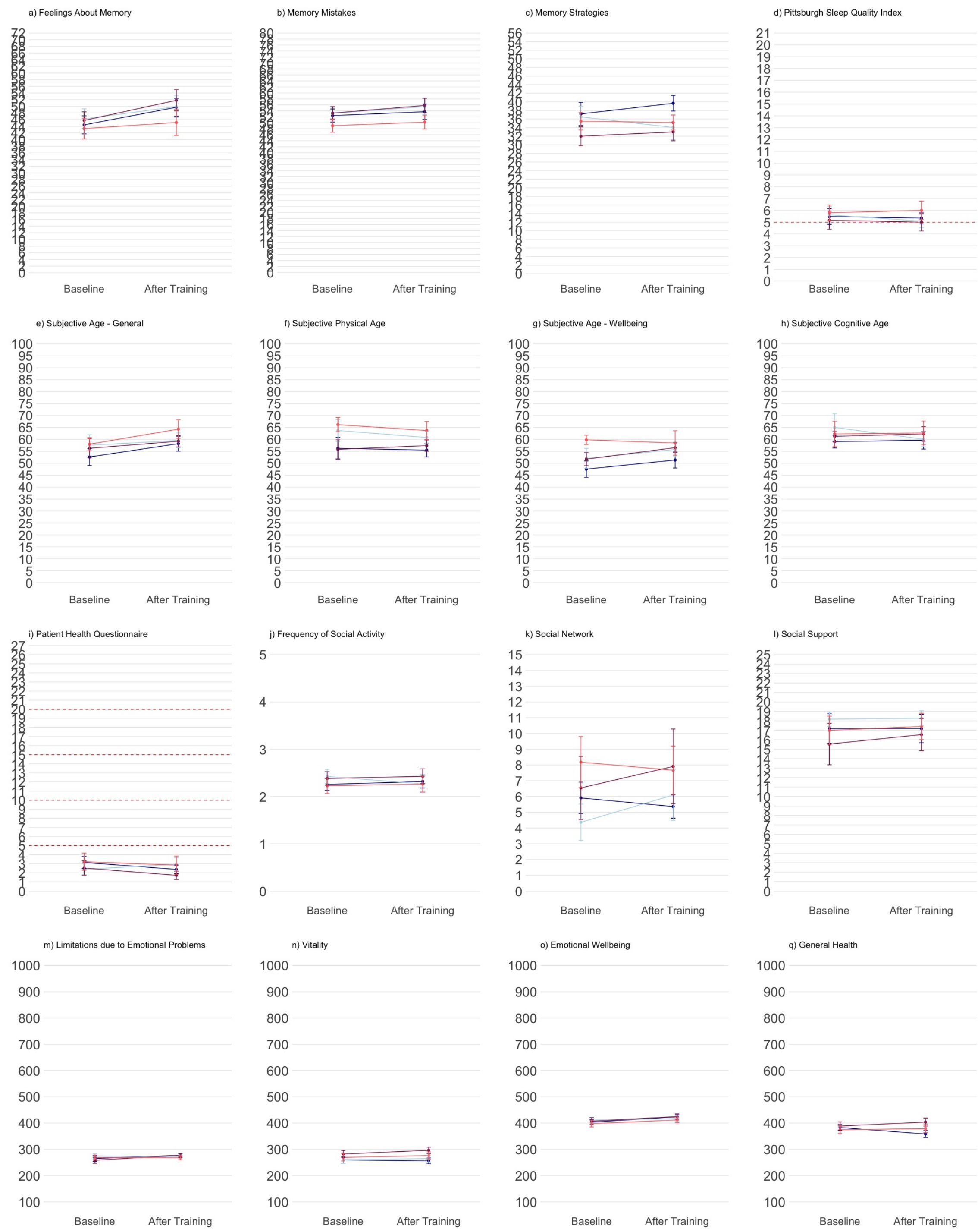


Figure 6. Subjective reports of (a-c) memory, (d) sleep quality, (e-h) perceived age, (i) mood, (j-l) social engagement, and (m-p) quality of life. Solid blue lines represent *Activate* groups; solid red lines represent control groups. Darker lines represent high expectation priming groups; lighter lines represent low expectation priming groups. Dashed red lines represent clinical threshold(s), where applicable. Error bars represent SEM.

Subjective Experience

The majority of participants (81%) believed their assigned program was genuinely training their brain. The proportion of participants with this belief was significantly larger in the active control condition (38/42=90%) compared to the *Activate* intervention (31/43=72%; X^2=4.7, p=.03).

Participants provided largely positive feedback and reported that they would recommend the program (Figure 7a), regardless of experimental condition (77/87=89%; X^2 = 2.45, ns). MANOVA of participant feedback across expectation priming and CCT program revealed a marginal effect of program (Wilk's λ=.838, $F_{(7,77)}$=2.12, p=.051, η_p^2=.162), but not of expectation priming, on subjective experience (Figure 9a). After correcting for multiple comparisons, we found that participants in the active control group (i.e., training on Sudoku and n-back tasks) reported significantly higher enjoyment ($F_{(1,83)}$=7.48, p=.008, η_p^2=.083) and lower boredom ($F_{(1,83)}$=9.42, p=.003, η_p^2=.102) of the program.

Perhaps more interestingly, MANOVA of feedback ratings revealed that believing the program genuinely trained the brain significantly influenced subjective experience (Wilk's λ=.751, $F_{(7,79)}$=3.75, p=.001, η_p^2=.249; Figure 7b). Specifically, after correcting for multiple comparisons, we found that people who perceived their assigned program as having genuinely trained their brain rated higher enjoyment ($F_{(1,85)}$=13.47, $p\leq$.0001, η_p^2=.137) and engagement ($F_{(1,85)}$=12.42, p=.001, η_p^2=.127) with their assigned program, and lower boredom ($F_{(1,85)}$=18.70, p<.0001, η_p^2=.180). Due to an unequal distribution of "believers" vs. "non-believers" and, in particular, low number of "non-believers", we collapsed "belief" (i.e., perception of training) across experimental conditions to perform these analyses.

Long Term Outcomes

About half of participants completed at least part of the 6-month follow-up assessment (n=53 responses on the psychosocial questionnaires; n=38 responses on the EAS, final feedback questionnaire, and informal follow-up interview). Due to low power, we elected not to analyze these outcomes.

Discussion

Here we sought to evaluate the effects of expectation priming and a 5-week CCT program on cognitive function and psychosocial wellbeing in healthy older adults.

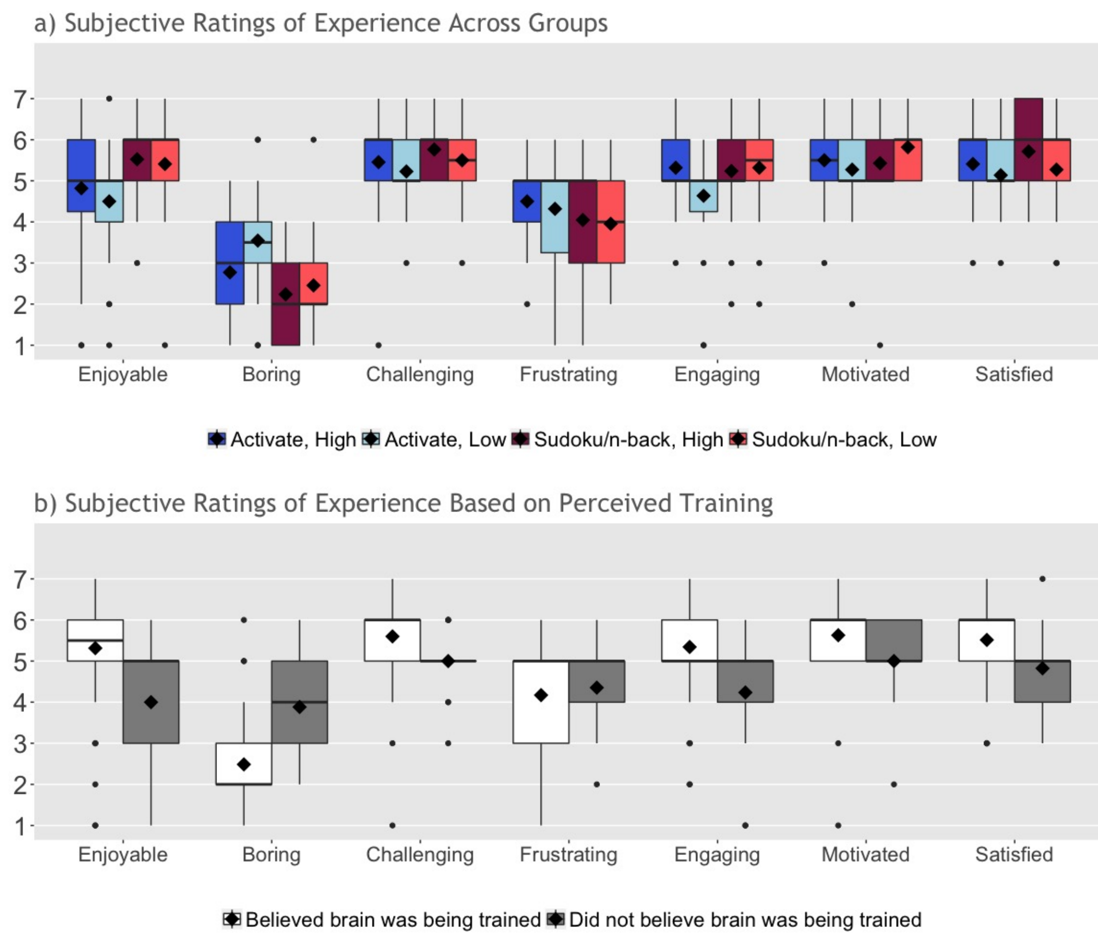


Figure 7. Subjective feedback on experience based on a) experimental group and b) belief that the assigned program genuinely trained the brain. Feedback ratings were on a scale of "1" ("completely disagree") to "7" ("completely agree") for each subscale. Solid lines represent group medians; diamonds represent group means.

We found that most participants adhered to their assigned program (88%), believed they were genuinely training their brains (81%) and had a positive experience overall. Nevertheless, while all participants improved on neuropsychological and psychosocial measures over time, we found no evidence for effects of the assigned program or expectation priming on training and transfer.

Participant Expectations

As in our previous work (Rabipour et al., 2017a; Rabipour and Davidson, 2015), here we found that older adults were largely optimistic about CCT outcomes before they began the study. Moreover, expectation ratings at the outset of the program suggested that our expectation priming (i.e., via the EAS) had successfully raised or lowered participant expectations. Following completion of the program, however, we found that participants were more uncertain about the effectiveness of the CCT in improving cognitive outcomes, with ratings closer to the "neutral" score in all experimental groups.

***Activate* and Control Training**

Participants assigned to the *Activate* CCT adhered to the program and improved in three out of four of the training domains, including "visual pursuit / category sorting", "visual pursuit / inhibition", and "pattern completion". Notably, the relative lack of improvement in the "spatial WM" exercises may reflect the restricted range of these game levels, which represented list length remembered, rather than a combination of correct responses and speed, as with the other categories. The number of days that participants engaged with the program did not differ between groups, although there was considerable variability within groups. Notably, some participants in each of the expectation conditions even continued with the *Activate* program long after they had completed the trial (we did not include data from sessions completed beyond the 5-week trial in our analyses).

Participants who completed the control tasks (i.e., Sudoku and n-back games) reported being highly engaged with the program, but did not improve on these exercises. Interestingly, participants assigned to complete the Sudoku and n-back exercises reported that they tended to select a larger number of "hard" Sudoku grids over time, indicating motivation to challenge themselves further. Unfortunately, due to issues with database design, we were unable to analyze performance of the n-back exercises on the basis of level (i.e., 2- vs. 3- vs. 4-back task) in this trial.

We examined amount of logged play time for both the *Activate* and control games (see Figure 3) because this was the closest comparison we could make between the two programs. Note, however, that we cannot be certain that the amount of time recorded for the control games consistently reflected engagement in the task, rather than the game remaining open in a web browser, due to reported glitches with the auto-logout. This may explain the relatively large variance for several of the control games (Figure 3b). This issue did not appear to exist for the *Activate* games.

Perhaps unsurprisingly, we found that participants assigned to the high expectation priming conditions logged on to their assigned program more frequently, on average, compared to their counterparts who received low expectation priming. In particular, participants in the active control condition trained for more days that those in the *Activate* intervention overall. Moreover, active control participants who received high expectation priming completed a significantly greater number of training days compared to those who received low expectation priming. These findings suggest that participants in the high expectation conditions may have been more motivated to participate in the program, and may have contributed greater effort throughout the training sessions, compared to those in the low expectation conditions. Nevertheless, differences in weekly amount of logged play time was not significant between the high and low expectation priming groups in either the *Activate* or control program. Furthermore, lack of significant differences on the training tasks suggests that any possible effects of motivation and effort were minimal, and did not meaningfully contribute to performance.

Subjective Perceptions

Participants enjoyed both the *Activate* and control (Sudoku/n-back) program. Interestingly, participants seemed to enjoy the Sudoku and n-back exercises more than the *Activate* games, and more participants assigned to those exercises believed the program was genuinely training the brain compared to participants who completed *Activate* training. Moreover, we found greater enjoyment and engagement, as well as lower boredom in participants who believed the program had genuinely trained their brain. This finding suggests that, similar to other contexts (e.g., in medicine; Gollub and Kong, 2011; Wampold and Imel, 2007), belief in the capacity of a CCT program to achieve its intended goal (i.e., train the brain) can significantly impact behavioural and other outcomes. Although we did not have a large enough sample of "believers" vs. "non-believers" across our experimental conditions to probe this effect further, future studies may wish to examine how such retrospective perceptions of a program's effectiveness may interact with other outcomes.

(Limited) Transfer Effects

Cognitive and Psychosocial Function

Although participants provided positive feedback, we did not find any effect of expectation priming or of CCT program on our transfer measures of cognitive or psychosocial function. Importantly, we did not detect any changes in self-reported measures of cognitive performance, psychosocial wellbeing, or health-related QOL. This finding may represent the – perhaps unrepresentative – nature of our participant sample, which may have comprised particularly high functioning older adults. Notably, the older adults we recruited were highly educated, independent, and motivated members of the Ottawa community. Many participants demonstrated considerable insight into their own behaviour as well as our study design and evaluation of the program.

MoCA scores suggest that our participants had high global cognition, with means in all experimental conditions above the clinical cutoff of “26/30”. Moreover, participants tended to have high subjective perceptions of cognition, wellbeing, and QOL at baseline. Variability in these measures, however, may moderate the effects of cognitive training (e.g., people with low ratings of affect or QOL may benefit from CCT to a greater extent; Morimoto et al., 2016). Although we did not find large changes in these outcomes, future studies with greater sample sizes may consider analyzing these variables as mediators or predictors rather than direct outcomes, as we did here.

Despite these potential caveats, we aimed to include a self-selected sample of older adults who were concerned about their cognitive health and likely to partake in cognitive training on their own. In this regard, our sample is likely representative of CCT subscribers. The possibility nevertheless remains that including low-functioning older adults, or populations with psychiatric conditions (e.g., as in Morimoto et al., 2016) would have led to positive improvements. The most promising research appears to be in people with Mild Cognitive Impairment (MCI), although even in that context the literature is inconsistent (e.g., Butler et al., 2018). One recent high-quality study reported improved memory and strategy use in people with amnesic MCI following eight weekly sessions of group-led cognitive training (Belleville et al., 2018). Nevertheless, there remains no conclusive evidence that cognitive training can prevent or delay the onset of MCI or other forms of dementia (National Academies of Sciences et al., 2017).

Although an assessment of strategy use was beyond the scope of this study, it is possible that some participants developed or obtained (e.g., from a friend or family member) more effective strategies on how to complete the games. For example, at post-assessment, a number of participants reported repeating items to be remembered out loud, assigning names to specific repeated stimuli, or placing the cursor in strategic locations in anticipation of a response. Similarly, because a large portion of the training was completed from home, we were unable to control for environment during home training sessions, or monitor the potential use of external aids (e.g., other computing software) to complete the Sudoku puzzles or n-back trials.

Expectation Priming

Regarding the *Activate* training, one possibility for the lack of an expectation or interaction effect is the subtlety of our priming messages. Although ratings on the EAS appear to consistently change in the predicted direction in hypothetical and anticipatory scenarios, the messages might be insufficient to alter perceptions when participants have actually undergone an intervention. We elected not to use a more overt or repeated priming strategy to avoid divulging the nature of our expectation manipulation. However, it is possible that using other forms of media (e.g., verbal messages or pre-recorded videos) would provide more potent expectation priming. Notably, our participants were relatively high-functioning, with active social lives and busy personal schedules. Many of our participants actively engaged in learning about cognitive aging in their leisure time and participated in research studies as a way to remain informed and involved. Consequently, many of our participants independently recognized – and stated in their follow-up interviews – that training effects can be nuanced, and that both achieving and measuring transfer can be difficult.

CCT Design

Although we found no significant expectation or training effects on cognition, we might have under other conditions. For example, it is possible that longer periods of training or participation in CCT as part of a regular lifestyle habit would lead to measurable effects. The scientific community has yet to agree on an optimal timeframe and intensity of training (i.e., "dose"; Rabipour et al., 2017b). Nevertheless, the creators of *Activate* agreed that our training schedule and timeline were reasonable, reaching the minimal 1000 minutes of training recommended to commercial subscribers to detect performance changes. Moreover, increasing either of these parameters (i.e., length and frequency of training) would also increase the risk of participant drop-out. Offering booster sessions at a pre-determined time interval (e.g., several months or a year following completion of the program) represents one possible compromise which may help maintain or even enhance training effects (Rebok et al., 2014). Nevertheless, this solution is unlikely to have altered outcomes in the present study given the lack of any immediate benefits. Moreover, although we conducted a 6-month follow-up, we were unable to analyze these data due to low response rate. In addition to prohibiting a measure of sustainability of the CCT or of possible delayed effects, such low response suggests that few participants would have been able or willing to return for booster sessions.

Our null findings may also have resulted from incorrect or sub-optimal measures. Although we carefully selected our transfer tasks based on evidence from the literature as well as consensus from the creators of the *Activate* program – researchers and medical professionals at Yale University – it is possible that the behavioural measures were not refined enough to detect small behavioural effects or changes at the neurological level. For this reason, we have begun a follow-up trial of the *Activate* program using identical training and control conditions, but with different behavioural tasks as well as electrophysiological outcome measures shown to change following training (Anguera et al., 2013; Küper et al., 2017). In addition, as with all subjective measures, it is possible that responses on our self-reports of expectations, subjective memory, and wellbeing were unrepresentative (e.g., if participants simply told us what they believed we wanted to hear; i.e., "demand characteristics"). However, reported expectation ratings replicated our previous findings, and the subjective questionnaires we administered are commonly used in studies of cognition, aging, and CCT.

Finally, although we conducted a power analysis *a priori* to determine the minimal required sample size, it is possible that the effects are smaller than anticipated and therefore would be discernible with a larger sample size. Increasing the number of participants would further enable exploratory analyses, examining the potential influence of individual factors (e.g., differences in baseline performance, mood, subjective perceptions of performance and function, etc.) in mediating training outcomes.

Conclusions

The present study is the first, to our knowledge, to directly examine expectations of CCT outcomes in the lab setting. By priming participants to have either high or low expectations of training at the outset, we sought to tease apart effects of training from those of expectations of CCT in older adults.

Moreover, we incorporated many of the best practices recommended for high quality intervention research. Crucially, studies rarely account for psychological influences such as expectations of outcomes – a factor we directly evaluated and manipulated experimentally. Examining such factors is particularly imperative for clinical populations, where placebo effects are known to affect outcomes (Benedetti et al., 2011) and where participants may have more to lose compared to healthy populations. Interestingly, evidence suggests that the placebo effect is weaker, and potentially nonexistent, in people with certain forms of dementia (e.g., Alzheimer's; Benedetti et al., 2006). Expectancy-related placebo effects may therefore represent less of a confound in cognitive training trials in this population.

Our findings replicate previous reports that older adults have high expectations of CCT outcomes (Rabipour and Davidson, 2015). Feedback from our participants further supports the importance of believability on subjective experience, including engagement with the program. Nevertheless, our 5-week trial of a commercially-available CCT program indicated no effect of training program, or of expectations, on cognitive performance or subjective perceptions of cognition and wellbeing.

Lack of any program or expectation effect calls into question the effectiveness of such short-term computerized programs on behavioural outcomes. Follow-up studies should examine possible subtle effects of expectations and/or CCT using more refined measures, including brain imaging. Our findings may nevertheless reflect the specific parameters of this study, and do not imply that all CCT programs – even other versions of *Activate* – are ineffective.

Given the widespread appeal of CCT as an affordable and accessible form of cognitive enhancement in both healthy and clinical populations, understanding the potential impact of expectations and of program design is imperative to assessing the practical value of such interventions. In addition, optimizing CCT design and harnessing the potential positive effects of expectations can generalize to other types of behavioural interventions in the home, clinic, or other specialized settings. Eventually, this understanding may inform the development of more effective approaches towards enhancing cognitive function as well as optimizing clinical interventions for people diagnosed with, or at risk for, conditions resulting in cognitive impairment.

Author Contributions

S.R. and P.S.R.D. designed the study with help from M.P. S.R., C.M., and J.C. collected the data. S.R. and P.S.R.D. analyzed the data with help from C.M., J.C., M.O.G.G., and A.P. S.R. and P.S.R.D. wrote the manuscript. All authors reviewed and approved the final version of the manuscript.

Acknowledgements

We thank Bruce Wexler and Sean O'Leary for granting us free access to and support for the *Activate* program. We also thank Bruce Wexler, Sarah Morimoto, and Morris Bell for providing feedback on our experimental protocol and analysis plan, as well as Veronika Huta for guidance on our statistical analyses. We thank Bruce Wexler for helpful comments on an earlier draft of this manuscript. We thank Zachary Ball, Lara Geinoz, Victoria Hall, Alix Hill, Katia Giguère Marshal, Awais Rahman, Raphaëlle Robidoux, Zak Sanaye, Jonathan Tran, and Allison Walsh for help with data collection and verification. We also acknowledge the Natural Sciences and Engineering Research Council (NSERC, Discovery Grant), Ontario Graduate Scholarships, and Fonds de Recherche Québec – Santé for their support of this work.

3.3 Expectations and tDCS: Can they influence motor and cognitive performance?

Non-invasive brain stimulation (NIBS) using magnetic fields or electrical currents is increasingly used in health and disease. In particular, transcranial direct current stimulation (tDCS) has gained increasing interest among researchers, clinicians, and individual consumers as a portable, cheap, user-friendly, and generally safe approach. However, similar to cognitive training, the literature on tDCS effects is inconclusive due to a lack of reproducible findings and uncertainty surrounding its mechanism(s) of action.

In an initial study, we assessed expectations of NIBS and examined the effects of expectation priming on cognitive performance following tDCS in healthy young adults (Rabipour et al., 2018b). This study – the first of its kind, to our knowledge – presented evidence for a potential effect of expectations on cognitive performance following a single-session tDCS intervention in this population.Findings form this study demonstrated the importance of assessing participant expectations as a possible influence on the outcomes of cognitive interventions, and examining potential interactions between expectations and NIBS or related approaches to cognitive enhancement.

In the following study, the authors followed up on their initial research by examining the potential effects of expectations on motor and cognitive performance during a tDCS intervention.

3.4 Examining the Interactions between Expectations and tDCS Effects on Motor and Cognitive Performance

Sheida Rabipour[1], Petar Sefik Vidjen[1], Anthony Remaud[2], Patrick S. R. Davidson[1,2,3], François Tremblay[2]

[1]School of Psychology, University of Ottawa, Ottawa, Canada

[2]Bruyère Research Institute, Bruyère Continuing Care, Ottawa, Canada

[3]Heart and Stroke Foundation of Ontario Canadian Partnership for Stroke Recovery, Ontario, Canada

Abstract

Background: Transcranial direct current stimulation (tDCS), increasingly promoted for motor and cognitive enhancement, remains shrouded in controversy. Despite a growing literature and commercial market, tDCS effectiveness remains questionable. Notably, studies rarely examine factors such as expectations of outcomes, which may influence tDCS response through placebo-like effects. We sought to determine whether expectations could influence responses to a tDCS intervention. **Methods**: We recruited 121 naïve young adults 18-34 years of age (M=21.14, SD=3.58; 88 women). We evaluated expectations of tDCS as well as motor and cognitive performance at three times: i) at baseline; ii) after being primed to have High or Low expectations of outcomes; and iii) after a single session of sham-controlled anodal tDCS over the left or right motor cortex. Before and after stimulation, participants performed tasks measuring motor dexterity, response time, and response inhibition. **Results**: Repeated measures ANOVA revealed that participants had varying, largely uncertain, expectations regarding tDCS effectiveness at baseline. Expectation ratings significantly increased or decreased in response to High or Low priming, respectively, and decreased following the intervention. Response times and accuracy on motor and cognitive measures were largely unaffected by expectation or stimulation conditions. Overall, our analysis revealed no effect attributable to baseline expectations, belief of group assignment, or experimental condition on behavioral outcomes. Subjective experience did not differ based on expectation or stimulation condition. **Conclusions**: Our results question the efficacy of tDCS as a performance enhancer, supporting re-

cent criticisms of this technique and highlighting the need for further investigations regarding tDCS effects. Researchers and clinicians should consider the potential effects of expectations when designing tDCS interventions and interpreting outcomes to determine whether such methods are truly effective.

Keywords

Cognitive enhancement; Expectation; Non-invasive brain stimulation; Placebo effect; Transcranial direct current stimulation

Introduction

Stimulating the brain non-invasively to enhance performance using methods such as transcranial direct current stimulation (tDCS) represents an enticing, albeit controversial prospect. Relatively inexpensive and safe (Matsumoto and Ugawa, 2017; Bikson et al., 2016), tDCS is increasingly promoted for motor and cognitive enhancement in healthy and clinical populations (e.g., Coffman et al., 2014; Zhao et al., 2017). Such perceptions regarding tDCS-induced performance have fueled an explosion of consumer interest in these approaches (Brühl and Sahakian, 2016), including a burgeoning Do-It-Yourself community of non-expert tDCS enthusiasts (201, 2015).

Despite a growing scientific literature, tDCS effectiveness remains controversial (Bestmann et al., 2015), raising concerns over potential commercial applications in the general public (Wurzman et al., 2016; Carter and Forte, 2016; Farah, 2015; Jwa, 2015). Whereas some studies have reported improvements in functions such as memory (Katz et al., 2017; Sandrini et al., 2014), motor and cognitive skill (Hashemirad et al., 2016; Kang et al., 2016; Kincses et al., 2004), and executive function (Au et al., 2016; Dockery et al., 2009), others suggest no reliable effect of different stimulation protocols on motor (Horvath et al., 2016; López-Higes et al., 2018), cognitive (Medina and Cason, 2017; Nilsson et al., 2017), or even basic neurophysiological (Dyke et al., 2016; Parkin et al., 2018) outcomes. Such inconsistencies have blurred interpretations of tDCS outcomes as a whole. For example, a systematic review of neurophysiological outcomes concluded that tDCS had no reliable effect beyond change in motor evoked potentials, a marker of corticospinal excitability (Hallett, 2007), outlining high variability and flawed methodology as limiting factors in comparing and pooling results across existing research (Horvath et al., 2015, 2016). These conclusions have been further criticized on the ground that the authors attempted to prematurely - and, at times, erroneously - aggregate results of tDCS studies regardless of key differences in protocol and using an inappropriate statistical approach (Antal et al., 2015; Price and Hamilton, 2015).

In addition to the variability in study parameters, researchers have raised concerns over the quality of the increasing body of work surrounding tDCS. Specifically, studies have typically included small samples, heterogeneous populations, insufficiently challenging tasks, poorly motivated participants, and failed to account for other important factors – such as individual differences in performance, biological characteristics, or psychological composure – that may influence responsiveness to tDCS interventions (Horvath et al., 2014; Berryhill et al., 2014). Examinations of technical factors such as electrode placement (Parkin et al., 2018; Penolazzi et al., 2013), intensities (Underwood, 2016; Vöröslakos et al., 2018), and stimulation schedule (Au et al., 2016) have not adequately resolved the inconsistencies in reported tDCS effects or the large intra- and inter-individual variability of response to tDCS (Li et al., 2015; López-Alonso et al., 2015; Wiethoff et al., 2014). Overcoming these limitations is imperative to determine whether tDCS protocols truly are effective and, even if genuine positive effects are possible, to identifying the boundary conditions based on individual contexts.

Notably, studies have rarely examined factors such as expectations of outcomes, which may influence tDCS response through placebo-like effects (e.g., Benedetti, 2014; Boot et al., 2013b; Schwarz et al., 2016). Incentive-based motivation may increase the cognitive benefits of tDCS (Jones et al., 2015). Expectations, moreover, have been show to modulate the effects of deep brain stimulation in clinical populations, such as patients with Parkinson's disease (Keitel et al., 2013). Mixed findings in the literature have generated polarized claims in popular science magazines and media, which may influence expectations of outcomes at the outset of an intervention (Rabipour et al., 2017a).

Previously, we found that high expectations of outcomes could enhance the effects of anodal tDCS on executive functions in young adults (YA), whereas low expectations seemed to have opposite effects (Rabipour et al., 2018b). Here we sought to extend this finding by further examining the potential interactions between expectations of outcomes and tDCS effects on tasks that rely both on motor and cognitive function. Although reports of improvement in motor performance have been more consistent than those regarding cognitive performance (e.g., improvements in motor dexterity after single tDCS administration in healthy YA (Christova et al., 2015) and older adults (Greenwood et al., 2018; Parikh and Cole, 2014)), the real impact of tDCS effects with respect to improvements in motor and cognitive functions remains highly controversial (Fagerlund et al., 2015). We therefore aimed to directly address such inconsistencies in the literature using a double-blind balanced-placebo design with sham control, reasonable statistical power, and commonly reported tDCS parameters.

Methods

In a series of studies, we examined the effects of tDCS, applied over the primary motor cortex, and of expectation priming on tasks in which people generally have stable performance. In Study 1, participants performed tasks with their preferred (dominant) hand. Study 2 was a replication and extension in which participants performed tasks with their non-preferred (non-dominant) hand, to examine the potential effects of tDCS and expectation priming under conditions supporting greater room for improvement.

Participants

We recruited 121 healthy young adults (YA; 88 women, age=21.1±3.6 years) through the Integrated System of Participation in Research at the University of Ottawa and from the Ottawa community via ads and flyers. For our initial experiment (*Study 1*), we collected data from 58 YA (42 women; age=21.6±3.6), with no handedness specifications. We then recruited 63 right-handed YA (46 women; age=20.6±3.5) for a follow-up replication and extension of our initial protocol (*Study 2*).

In both studies, we screened participants for health issues that could potentially interfere with performance outcomes (e.g., neurological conditions) and for contraindications to brain stimulation (e.g., history of epilepsy, presence of metal in head, pregnancy etc.) using a questionnaire (adapted from Keel et al., 2011). Participants reported handedness using a web-based version of the Edinburgh Handedness Inventory (adapted from Oldfield, 1971, see results for handedness distributions). Participants were told about possible side effects before providing consent. We received ethical approval to conduct this study from the Research Ethics Boards at the University of Ottawa and the Elizabeth Bruyère Research Institute. We registered the trial at clinicaltrials.gov (ID: NCT02498574).

Study Design

After providing consent, participants in each study were assigned to one of two expectation priming conditions: i) High expectation priming, in which participants were told they would receive a type of brain stimulation known to improve performance; and ii) Low expectation priming, in which participants were told they would receive a type of brain stimulation with no known benefits. We then randomized participants to receive one of two stimulation conditions: active anodal or sham tDCS.

All participants proceeded to complete the baseline transfer measures in counterbalanced order, followed by expectation assessment and priming, the tDCS session, and, finally, the post-stimulation assessment of expectations and performance on the transfer tasks.

Expectation Assessment and Priming

In both Study 1 and 2, participants rated their expectations of tDCS effectiveness using the Expectation Assessment Scale (EAS), a questionnaire we described in our previous work (Rabipour et al., 2017a; Rabipour and Davidson, 2015) and validated for use in this context (Rabipour et al., 2018a), on three occasions: i) at baseline; ii) after receiving High or Low expectation priming; and iii) after the tDCS session. Briefly, participants rated their expectations of outcomes on a scale from 1-7 (Table 1). We probed expectations on nine outcomes: i) general cognitive function; ii) memory; iii) concentration; iv) distractibility; v) reasoning ability; vi) multitasking ability; vii) performance in everyday activities; viii) motor dexterity; and ix) response time.

Study 1: Stimulation over M1 Representing the Preferred Hand

Stimulation Procedure

To determine the location of the hand-motor representation (ie, primary motor cortex: M1) for each participant, we delivered transcranial magnetic stimulation using a Magstim 200 stimulator (MagStim Corp., Dyfed U.K.) connected to a focal figure-eight coil (70 mm inner loop). TMS-induced motor evoked potentials (MEPs) were recorded in hand muscles using small surface electrodes (Delsys 2.1, Bagnoli EMG, Delsys, Inc) placed over the first dorsal interosseus (FDI) muscle. Usning a suprathreshold intensity (1.1 x motor threshold), the area over the scalp was explored with the coil in 1cm steps until reliable MEPs (>50 microVolts) could be elicited in FDI. We then marked this site with a felt pen on the scalp.

We delivered tDCS with a a programmable battery-driven direct current (DC) stimulator (HDCStim, Newronika, Milano, Italy) using a pair of electrodes encased in 5 x 7 cm synthetic sponges and soaked in 0.9% saline. The montage corresponded to the "classical motor learning montage" (Nitsche et al., 2008) with the anode placed over the M1 region (i.e., area representing the motor cortex as defined with TMS) and the cathode located on the supraorbital region on the opposite side. The electrodes were held against the head with elastic bandages. These parameters are in-line with

Table 1. Rating scale used in the Expectation Assessment Scale

(a) Items included in the questionnaire. Participants rated the degree to which they predicted the stimulation would be successful (before stimulation) or felt the stimulation was successful (after stimulation) at improving each ability. Definitions and formatting shown as provided in the survey.

Item
Cognitive function.
Memory.
Concentration.
Distractibility (i.e., *lowering* how much you lose focus on a task).
Reasoning ability.
Multi-tasking ability (i.e., managing multiple tasks at the same time).
Performance in everyday tasks (e.g., driving, remembering important dates, managing finances, etc.)
Motor dexterity (i.e., how *well* you manipulate objects with your fingers).
Motor reaction time (i.e., how *fast* you respond with your fingers).

(b) Rating scale and accompanying definitions. Participants were shown the definition only for the first item; for efficiency, subsequent items displayed only the options for degree of expected success

Rating	Degree of expected success	Definition
1	Completely unsuccessful	No change in brain activity or noticeable behaviour. Such a procedure would be a waste of time and resources.
2	Fairly unsuccessful	Possible changes in specific brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life. Such a procedure would be a waste of time and resources.
3	Somewhat unsuccessful	Possible changes in general brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life.
4	I have absolutely no expectations	*Neutral rating; additional definition not provided.*
5	Somewhat successful	Possible changes in specific brain activity and behaviour. Such a procedure would NOT be a waste of time or resources.
6	Fairly successful	Possible changes in general brain activity as well as noticeable behavioural changes.
7	Completely successful	Changes in general brain activity as well as noticeable changes in overall thought and behaviour that positively impact daily life. Such a procedure would be a good investment of time and resources.

those reported to yield relatively consistent outcomes (Ho et al., 2016).

For tDCS applications, the stimulator was programmed to deliver a constant current of 2mA (density of 0.054 mA/cm^2) for a duration of 20min with a ramp-up and ramp-down of 30s. In the active condition, the DC stimulation was maintained for the whole duration, whereas for the sham, the DC current was delivered only during the ramp-up and ramp-down phases. This allowed participants in each group to experience the same initial and terminal sensations (i.e., mild tingling). These stimulation parameters have been previously validated for safety and potential cognitive effects in healthy participants (Bikson et al., 2016; Iyer et al., 2005), as well as for consistency in motor outcomes (Ammann et al., 2017; Jamil et al., 2017). Both participants and experimenters were blind to the stimulation condition.

Stimulation Task

During the 20-minute tDCS application (active or sham), participants performed the *Finger Fitness* task (Motrix ©; available via iTunes and www.motrix.me), a game-based reaction time (RT) task, on a touch-screen electronic tablet (iPad). The task involved tapping fingers as fast as possible on the tablet according to a pre-defined sequence, indicated by a change in color of the target location. We used this task as a means to ensure that participants remained vigilant and focused on their dexterity performance during the stimulation period, rather than an outcome measure *per se*.

Outcome Measures

Grooved Pegboard Test (GPT): The GPT is a standardized, commonly used test requiring participants to place pegs (n=25) into the grooves of a board placed directly in front of them, as quickly as possible. The test requires complex visuo-sensori-motor integration to rotate pegs to the correct orientation before placing them in the hole. The GPT, although primarily used as an index of manual dexterity, can also provide an index of cognitive function in older adults (Ashendorf et al., 2009; Bezdicek et al., 2014; Vasylenko et al., 2018). Thus, the GPT can be considered a sensitive measure of potential changes in both motor learning and cognitive function following brain stimulation. We allotted participants one practice trial at baseline and then assessed their performance (ie, time to complete the board) on a test trial with both the preferred and non-preferred hand, before and after the stimulation procedure.

Feedback on Perceived Experience

Following the stimulation procedure, we asked participants to complete a satisfaction questionnaire for feedback regarding their perceived experience. On a scale of 1-7 (Table 2), participants rated the degree to which they found the experience: i) enjoyable; ii) challenging; iii) frustrating; iv) engaging; v) boring; vi) motivating; and vii) satisfying.

Study 2: Stimulation over M1 Representing the Non-Preferred Hand

Stimulation Procedure

We used the same TMS protocol to locate the hand motor area (M1) representing the non-preferred hand in Study 2. The tDCS protocol was also similar, using the same montage as Study 1, except that the anodal stimulation was directed at the M1 of the non-preferred hand. The stimulation conditions and task were identical to those in Study 1.

Table 2. Questions and rating scales included in the subjective feedback questionnaire.

(a) Feedback questions (i.e., items). Participants rated the extent to which they agreed with each statement, and finally the degree to which they were satisfied with the overall experience.

Item
I found the program to be enjoyable.
I found the program to be challenging.
I found the program to be frustrating.
I found the program to be engaging.
I found the program to be boring.
I was motivated to do the brain stimulation program.
How satisfied were you with this program?

(b) Rating scales.

Rating	Agreement scale	Satisfaction scale
1	Very strongly disagree	Extremely dissatisfied
2	Strongly disagree	Fairly dissatisfied
3	Disagree	Somewhat dissatisfied
4	Neither agree nor disagree	Neither satisfied nor dissatisfied
5	Agree	Somewhat satisfied
6	Strongly agree	Fairly satisfied
7	Very strongly agree	Extremely satisfied

Outcome Measures

GPT: In Study 2, participants were also tested on the GPT, but only with the non-preferred hand. The testing protocol with the GPT was otherwise identical.

Additional outcomes: In addition to the GPT, we assessed participants on: 1) the Finger Tapping test and 2) the Choice Reaction Time (CRT) test, both performed with the non-preferred hand. We administered the two tests using a MoART panel (Lafayette Instruments) with the accompanying software (PsymSoft II™). For the finger tapping test, participants were asked to repeatedly tap their index finger on a target location on the board as quickly as possible in response to a "go" cue (green light), for the duration of the cue (30s). For the CRT test, participants were asked to release their index finger from the target location on the board in response to the "go" cue (green light), but not in response to one of two possible "no-go" cues: i) red light; or ii) green light paired with a tone. RT on the CRT test were measured in milliseconds from stimulus onset to response, averaged over five blocks of 20 trials.

Feedback on Perceived Experience

In addition to the satisfaction questionnaire administered in Study 1, we probed participants' expectations and experience of side effects commonly reported in tDCS interventions (Brunoni et al., 2011; Kessler et al., 2012), including itchiness, warmth/heat, pinching, pain, iron taste, fatigue, or other.

Statistical Analysis

In both studies we analyzed primary outcomes using repeated-measures analysis of variance (ANOVA), as well as univariate ANOVA and multivariate ANOVA (MANOVA), with within-between factors interactions to evaluate the outcome measures described, at an alpha level of 0.05. Where applicable, we used the Holm-Bonferroni correction for multiple comparisons and Greenhouse-Geisser correction for sphericity.

We performed analyses using IBM SPSS Statistics, Inc. version 24 and R version 3.1.1. For both experiments, we determined sample sizes a priori using G*Power version 3.1, based on a moderate effect size, alpha level of .05, and 80% power.

Results

We excluded from our analyses four women and two men who did not complete the study protocol in Study 1 due to hair thickness preventing proper application of tDCS (n=5) and anxiety regarding the protocol (n=1).

Participants in both studies were matched across experimental conditions, with no significant group differences in age, sex, prior knowledge of NIBS methods, prior experience with NIBS, concern over declining cognitive function, or use of medications for emotional or mood-related issues within the past five years (Table 3). These proportions did not significantly differ based on stimulation site (i.e., between our initial and follow-up experiments).

The handedness questionnaire revealed four left-handed women and one ambidextrous woman in Study 1. Results did not differ qualitatively on the basis of handedness; we therefore elected to retain these participants in our analyses.

Expectation Effects

Patterns of expectation ratings did not significantly differ between Study 1 and 2; we therefore combined data from the two studies in our analyses of these results.

Participants were largely optimistic of NIBS outcomes at baseline: ratings in most domains were significantly above neutral ($t_{114} \geq 3.3$, $p \leq 0.001$, Cohen's $d \geq .63$), with the exception of "reasoning" ($t_{114}=1.93$, $p=.056$), "multitasking" ($t_{114}=.27$, $p=.787$), and "performance in everyday activities" ($t_{114}=1.08$, $p=.283$). Mean expectation ratings did not significantly differ across groups at baseline. Because of missing responses (n=16) in the "motor dexterity" and "response time" domains, we dropped those from further analyses.

Table 3. Sample composition in Study 1 and 2. Groups were balanced with respect to distribution of sex, mean age, prior knowledge of and experience with NIBS, concern over declining cognitive function, and use of medications for emotional or mood-related issues. Notably, although the majority of participants had at least some prior knowledge of NIBS, few had any experience with such techniques.

(a) Study 1 participant demographics

Group	Stimulation	Expectation Priming	n (women)	Age *(SD)*	Prior Knowledge	Prior Experience	Concern	Medication Use
1	Active	High	13 (9)	22.15 *(3.53)*	75%	23%	15%	33%
2	Active	Low	12 (10)	21.75 *(3.60)*	75%	15%	33%	25%
3	Sham	High	13 (11)	20.62 *(2.40)*	75%	23%	38%	27%
4	Sham	Low	14 (8)	22.00 *(4.62)*	54%	7%	21%	15%

(b) Study 2 participant demographics

Group	Stimulation	Expectation Priming	n (women)	Age *(SD)*	Prior Knowledge	Prior Experience	Concern	Medication Use
1	Active	High	18 (12)	20.44 *(3.79)*	67%	22%	19%	17%
2	Active	Low	14 (9)	21.00 *(3.68)*	57%	14%	23%	35%
3	Sham	High	18 (14)	19.78 *(2.51)*	56%	44%	42%	28%
4	Sham	Low	13 (11)	21.38 *(4.07)*	69%	15%	38%	46%

Repeated measures MANOVA comparing expectation ratings across the remaining seven domains between stimulation and expectation condition at baseline, after receiving the expectation priming message, and after stimulation revealed a significant main effect of time (Wilk's λ=.736, $F_{(14,432)}$=5.10, p<.0001, η_p^2=.14) and of expectation condition (Wilk's λ=.669, $F_{(14,105)}$=7.42, p<.0001, η_p^2=.33), as well as a significant interaction between time and expectation condition (Wilk's λ=.648, $F_{(14,432)}$=7.49, p<.0001, η_p^2=.20; Figure 1). We did not find a main effect of stimulation condition on expectation ratings in any of the domains.

Further examination of the ratings for each cognitive domain demonstrated a significant effect of time for general cognitive function($F_{(1.8,199.7)}$=11.52, p<.0001, η_p^2=.09), memory ($F_{(2,222)}$=12.85, p<.0001, η_p^2=.10), and performance in everyday activities ($F_{(1.9,209.7)}$=12.22, p<.0001, η_p^2=.10), as well as a significant effect of expectation condition ($F_{(1,111)}$ $\geq$23.68, p<.0001, η_p^2=.18) and a significant interaction between time and expectation condition ($F_{(1.7,338.2)}$ $\geq$8.76, $p\leq$.001, η_p^2=.07) for all domains. Specifically, after reading their respective expectation messages, participants who received high expectation priming rated higher expectations of outcomes on all domains ($t_{61}\geq$3.49, $p\leq$0.001, Cohen's $d\geq$.89), whereas those in the low expectation conditions rated lower expectations on all domains ($t_{52}\geq$2.92, $p\leq$0.005, Cohen's

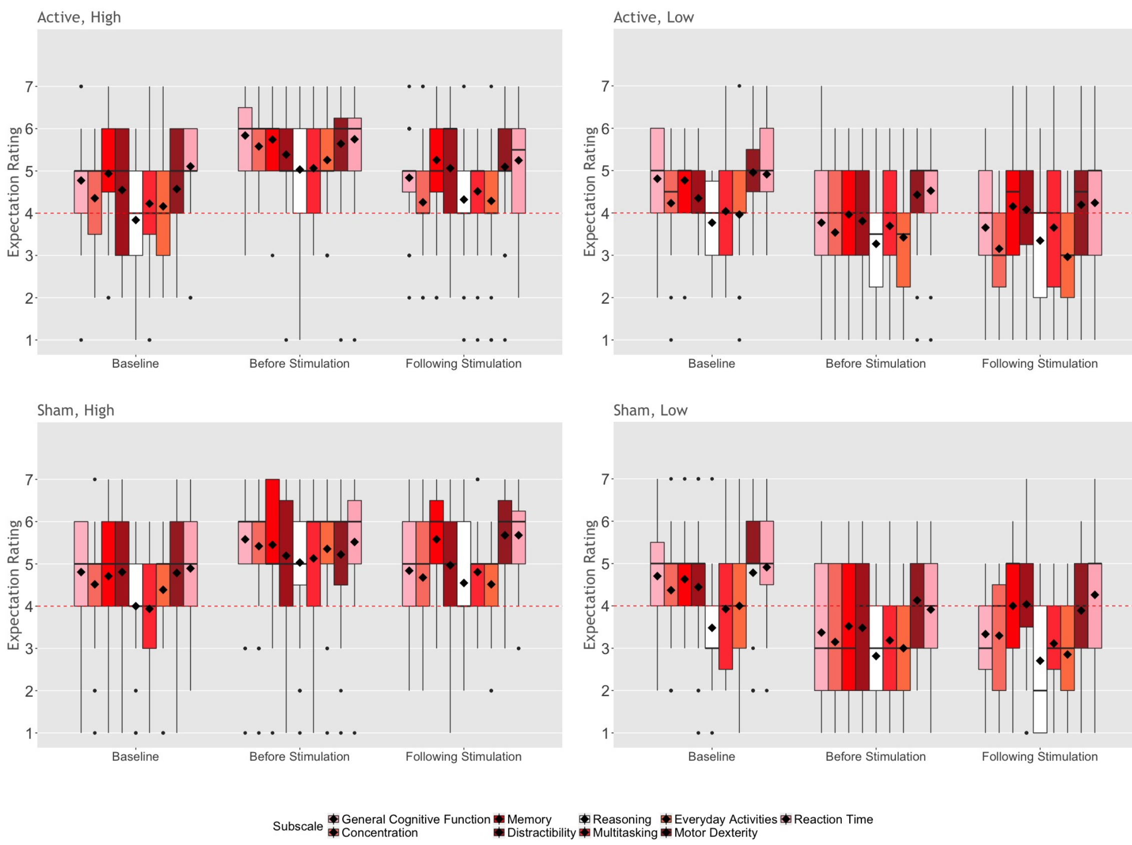


Figure 1. Expectation ratings of NIBS outcomes across time, based on experimental condition, collapsed across Study 1 and 2. Lines represent group medians. Diamonds represent group means. Dots represent outliers. Dashed lines represent "neutral" rating.

$d \geq .81$), compared to baseline. Following stimulation, participants assigned to the high expectation condition rated significantly lower expectations of improvement in general cognitive function ($t_{61}=5.23$, $p<.0001$, Cohen's $d=1.34$), memory ($t_{61}=6.69$, $p<.0001$, Cohen's $d=1.71$), reasoning ability ($t_{61}=3.94$, $p<.0001$, Cohen's $d=1.00$), and performance in everyday activities ($t_{61}=5.31$, $p<.0001$, Cohen's $d=1.36$). Conversely, ratings of participants in the low expectation priming condition did not significantly differ following stimulation, compared to their ratings after first receiving the expectation priming message. Finally, we found that participants who received high expectation priming maintained higher expectations of outcomes following stimulation, compared to those who received low expectation priming ($t_{113} \geq 3.30$, $p \leq .001$, Cohen's $d \geq .62$).

We also probed whether participants believed the priming they received was convincing enough to change their initial expectations, as well as the extent to which participants thought the priming messages were persuasive before and after the stimulation protocol. We found that participants who received high expectation priming were more likely to be convinced by the priming message (45/62=73%), compared to those who were primed to have low expectation (26/53=49%; $X^2=6.69$, $p=.01$).

These ratings did not differ based on stimulated hemisphere.

Repeated measures ANOVA examining participant reports of persuasiveness based on experimental condition and stimulated hemisphere showed a main effect of time ($F_{(1,111)}$=13.86, p<.0001, η_p^2=.11), of stimulation ($F_{(1,107)}$=6.11, p=.015, η_p^2=.05) and of expectation condition ($F_{(1,107)}$=13.90, p<.0001, η_p^2=.12), as well as an interaction between stimulation condition and stimulated hemisphere ($F_{(1,107)}$=11.94, p=.001, η_p^2=.10). Specifically, participants who received active anodal stimulation to the preferred hemisphere reported being significantly less convinced by the priming message following stimulation, compared to participants who received sham stimulation to the preferred hemisphere ($F_{(1,50)}$=11.46, p=.001, η_p^2=.19). Moreover, participants assigned to receive high expectation priming were significantly less convinced by the priming message following stimulation, compared to those who received low expectation priming (t_{61}=4.11, p<.0001, Cohen's d=1.05).

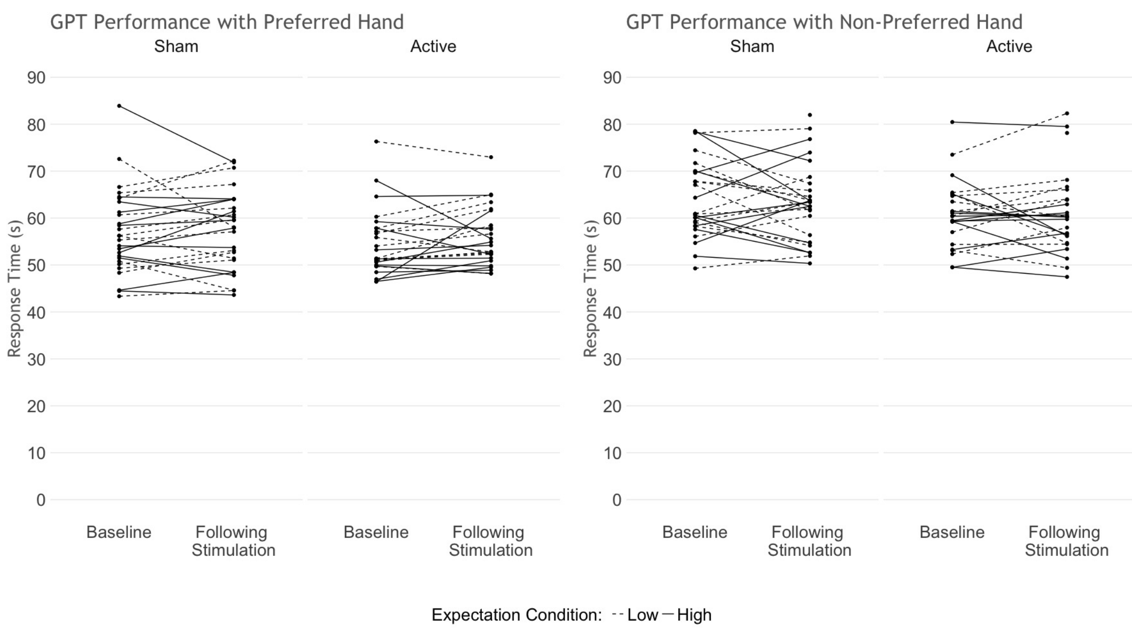
Performance Effects

Study 1: Stimulation Over Primary Motor Cortex Representing the Preferred Hand

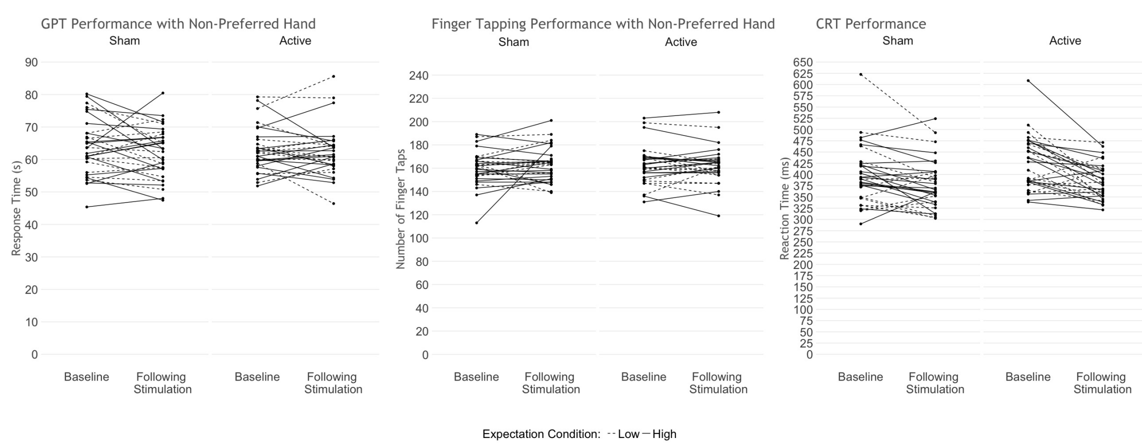
We performed repeated measures ANOVA examining GPT performance with the preferred and non-preferred hand, before and after stimulation. We found no significant differences on the basis of time (baseline vs. following stimulation; $F_{(2,47)}$=2.14, p=.13), stimulation (active vs. sham; $F_{(2,47)}$=.577, p=.57) or expectation priming condition (high vs. low; $F_{(2,47)}$=.332, p=.72), and no interaction effect (Figure 2a).

Study 2: Stimulation Over Primary Motor Cortex Representing the Non-Preferred Hand

Repeated measures MANOVA examining GPT and finger-tapping performance with the non-preferred hand before and after stimulation revealed no difference in either outcome on the basis of time ($F_{(2,58)}$=1.107, p=.34), stimulation ($F_{(2,58)}$=.117, p=.89), or expectation condition ($F_{(2,58)}$=.09, p=.91), and no interaction effect (Figure 2b). Examining CRT accuracy and RT revealed no group differences at baseline. Because of a ceiling effect causing little variance in hit rate, we examined only RT in further analyses. Repeated measures MANOVA examining RT over the five trials between groups, across time revealed a significant effect of time (Wilk's λ=.709, $F_{(1,59)}$=24.24, p<.0001, η_p^2=.29), wherein all participants responded faster in all trials following



(a) GPT performance before and after stimulating over the hemisphere representing the preferred hand (Study 1)



(b) GPT and finger tapping performance before and after stimulating over the hemisphere representing the non-preferred hand (Study 2)

Figure 2. Performance on the motor transfer tasks before and after stimulation in a) Study 1 and b) Study 2. We found no significant differences based on stimulation or expectation condition on the transfer measures in either study. Solid lines represent group medians. Diamonds represent group means. Dots represent outliers.

stimulation, compared to baseline (t_{62}=4.96, p<.0001, Cohen's d=1.26). However, we found no significant effect of trial, expectation, or stimulation condition, and no interaction between any of the variables on RT.

Subjective Experience

Overall Experience

Participants' feedback on their overall experience did not significantly differ between our two studies. We therefore combined analyses of these ratings across both Study 1 and 2.

The majority of participants in all groups (≥81%) reported believing they received active stimulation; these proportions did not significantly differ based on experimental group (X^2=2.52, *ns*). Moreover, participants largely reported having a positive experience, with ratings of enjoyment (t_{25} ≥3.17, p≤.004, Cohen's d≥1.27), engagement (t_{25} ≥5.20, p<.0001, Cohen's d≥2.08), motivation (t_{25} ≥4.17, p<.0001, Cohen's d≥1.67), and satisfaction (t_{25} ≥6.93, p<.0001, Cohen's d≥2.77), significantly above neutral, and ratings of boredom (t_{25} ≥4.60, p<.0001, Cohen's d≥1.84) significantly below neutral, in all groups (Figure 3). Interestingly, after correcting for multiple comparisons, only participants assigned to the high expectation priming conditions reported feeling challenged by the stimulation task (t_{29} ≥2.53, p≤.017, Cohen's d≥.94).

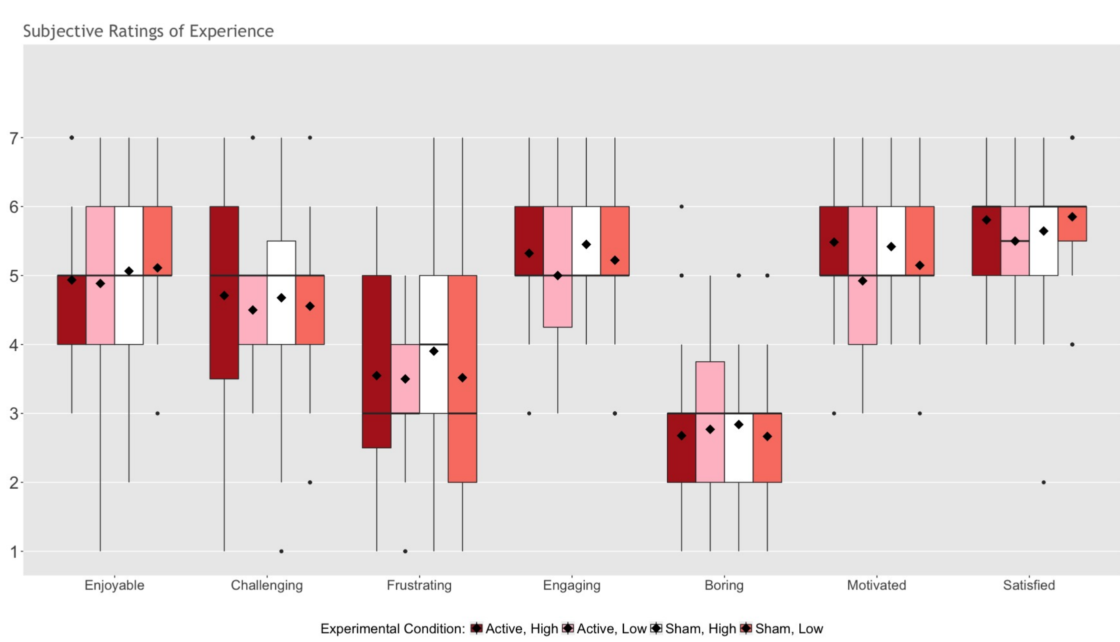


Figure 3. Participant feedback on experience, collapsed across Study 1 and 2. On a scale of "1" (lowest) to "7" (highest), participants rated the degree to which they found the program to be enjoyable, challenging, frustrating, engaging, boring, motivating, and satisfying (see Table 2). Dashed line represents "neutral" rating. Solid lines represent group medians. Diamonds represent group means. Dots represent outliers.

Study 2: Experience of Side Effects

Although participants in both studies were notified of possible side effects at the outset of the experiment, we examined reports of anticipated and experienced side effects in Study 2. Before stimulation, the majority of participants in all groups ($\geq$58%) reported having no expectation of experiencing any side effects (X^2=2.41, *ns*). Nevertheless, following stimulation, the majority of participants in all groups ($\geq$75%) reported experiencing at least one side effect. The proportion of reported side effects did not significantly differ between groups (Table 4), or based on belief of stimulation received.

Table 4. Proportion of participants who reported experiencing side effects following stimulation. Reports of side effects did not differ based on stimulation or expectation condition; data missing from 23 participants who did not respond to these questions.

Group	Stimulation	Expectation Priming	Itchiness	Warmth / heat	Pinching	Pain	Iron taste	Fatigue
1	Active	High	1/8 (13%)	4/8 (50%)	2/8 (25%)	0/8 (0%)	0/8 (0%)	1/8 (13%)
2	Active	Low	8/11 (73%)	7/11 (64%)	2/11 (18%)	1/11 (9%)	1/11 (9%)	2/11 (18%)
3	Sham	High	5/13 (38%)	10/13 (77%)	6/13 (46%)	1/13 (8%)	2/13 (15%)	0/13 (0%)
4	Sham	Low	3/8 (38%)	2/8 (25%)	3/8 (38%)	0/8 (0%)	0/8 (0%)	1/8 (13%)

Exploring Individual Factors

We explored whether any factors related to participant demographics or performance might influence baseline expectations or performance outcomes. We found a significant effect of baseline performance on the GPT with the non-preferred hand in Study 1 ($t_{37.05}$=2.97, p=.003, Cohen's d=.98), and the CRT (RT) in Study 2 (t_{61}=4.91, p<.0001, Cohen's d=1.26). After correcting for multiple comparisons, we found no significant effect of baseline expectations, sex, prior knowledge of or experience with brain stimulation, media exposure, programming experience, gaming, medication use, or concern over declining cognitive function on performance changes in either Study 1 or 2.

Based on findings from previous research (Wong et al., 2018), we analyzed changes in performance outcomes based on the time of day in which the testing session occurred. Repeated measures MANOVA revealed no effect of session time (i.e., morning vs. afternoon) on GPT performance in Study 1 ($F_{(2,49)}$=.407, p=.67), and only a marginal effect on performance outcomes in Study 2 ($F_{(7,55)}$=2.092, p=.06).

We found no interaction between time (i.e., baseline vs. following stimulation) and session time in either Study 1 ($F_{(2,49)}$=.449, p=.64) or Study 2 ($F_{(7,55)}$=1.544, p=.17).

Discussion

Here we sought to address a major limitation in the tDCS literature by directly examining potential expectancy-related placebo effects in a self-replication series of double-blind, sham-controlled, well-powered tDCS trials using a balanced-placebo design. We used parameters shown to have relatively good consistency in reported effects (i.e., current intensity (Jamil et al., 2017), electrode size and montage (Ho et al., 2016)), as well as comparable outcome measures.

Expectations of outcomes

As previously reported (Rabipour et al., 2018b, 2017a), we found that participant expectations of outcomes were variable at the outset, with mean ratings suggesting relatively neutral or mildly optimistic expectations of improvement on the probed domains. Also as expected, we found that our expectation priming manipulation was effective: participants who were primed to have high expectations of outcomes significantly increased their expectation ratings compared to baseline, whereas those who received low expectation priming significantly decreased their ratings. However, following the stimulation procedure, we found that participants who were primed to have high expectations significantly decreased their ratings on a number of the probed domains, whereas participants who were primed to have low expectations maintained similar ratings. Perhaps unsurprisingly, these ratings suggest a stronger effect of personal experience over our expectation priming manipulation.

Interestingly, participants who received high expectation priming maintained higher expectations of outcomes compared to those who received low expectation priming, regardless of stimulation condition. Similarly, participants who received high expectation priming were more likely to report being convinced by the information they received. These findings suggest that positive information about intervention outcomes may me more readily accepted and that receiving positive information may help raise subsequent expectations of outcomes and credulity, at least in self-reports by non-experts.

In contrast, we found that receiving active stimulation to the hemisphere representing the preferred hand (i.e., in Study 1) or high expectation priming correlated with lower self-reported persuasiveness of the priming messages. Taken together with the aforementioned findings on expectation ratings, particularly following stimulation, our results suggest that participants might not have been aware of the malleability of their expectation ratings.

Performance Outcomes

We found no effect of expectation or stimulation condition on any of our performance outcomes in either Study 1 or 2, including the GPT (preferred and non-preferred hand), finger tapping, or CRT performance. These null findings support the emerging criticisms of tDCS effects on motor performance, and further suggest that expected outcomes might not explain variability in reported findings. Notably, the absence of an effect of time, coupled with the low variance on CRT hit rate, suggest a possible ceiling effect in our participants. Although we selected these tasks for comparability across studies of motor dexterity and RT, these may have been inappropriate for the current sample and protocol. In this regard, it is possible that tasks involving more of a learning component (e.g., learning a motor sequence) may be more suitable, as well as more susceptible to priming and stimulation effects (de Xivry and Shadmehr, 2014; Savic and Meier, 2016) – although even reported motor learning effects are often small and variable (Lopez-Alonso et al., 2018). In addition, more refined measures such as GPT sub-tasks (e.g., peg selection, transport, insertion, removal) may be more sensitive to interference linked with hand preference, age, or presence of disease (Almuklass et al., 2017, 2018; Bryden and Roy, 2005).

Subjective Experience Following tDCS Protocol

Feedback reports suggest that participants had a positive experience, and were engaged with the tasks as well as motivated to perform well, regardless of experimental condition. Perhaps most importantly, we found that the majority of participants believed they received active stimulation, confirming the effectiveness of our blinding. Similarly, we found that most participants experienced at least one side effect, regardless of experimental condition or belief that they received active stimulation. Together, these findings suggest that our protocol was tolerable and believable, and that our performance outcomes are unlikely to be explained by differences in subjective experience.

Limitations and future considerations

Although we found no effects of either stimulation or expectation priming in our protocol, studies suggest that long-term application of tDCS over multiple sessions yields more consistent effects on cognitive functions such as working memory (Berryhill, 2017). Multi-session interventions further enable the possibility to study learning, which may interact differently with tDCS and expectancy effects. The possibility therefore remains that a multi-session protocol would exert a measurable effect on motor and cognitive performance, and that expectations would interact with stimulation in a more pronounced manner over such long-term interventions (e.g., through indirect factors such as participant motivation and engagement in the intervention; Boot et al., 2013b). Similarly, the effects of tDCS administration may have been more pronounced after longer delay (Fujiyama et al., 2014); nevertheless, the majority of studies suggests greatest effects immediately following application of tDCS (Christova et al., 2015; Rumpf et al., 2017). Moreover, although we employed a conventional tDCS montage using two electrodes encased in 35cm^2 sponges, different electrode configurations (e.g., high-density montages) may have yielded more potent outcomes (Pixa et al., 2017).

Conclusion

The results of our initial study and self-replication suggest no effect of or interaction between expectations and anodal tDCS on motor dexterity or cognitive performance. Our findings question the efficacy of tDCS as a performance enhancer, supporting recent criticisms of this technique and highlighting the need for further investigations regarding tDCS effects. Researchers and clinicians should consider the potential effects of expectations when designing tDCS interventions and interpreting outcomes to determine whether such methods are truly effective.

Acknowledgements

We thank Anita Popescu and Vilma Bezerra Alves for help with data processing, as well as members of the Neuropsychology Lab at the University of Ottawa for help with data collection. We also acknowledge the Natural Sciences and Engineering Research Council (NSERC, Discovery Grant), Ontario Graduate Scholarships, and Fonds de Recherche Québec – Santé for their support of this work.

4 General Discussion

4.1 Summary of Findings

The body of work presented in this thesis has several strengths. In each study, we paid particular attention to design, including: i) reasonable statistical power; ii) appropriate control conditions; iii) evidence-based intervention protocols; iv) consensus transfer measures and analyses; v) a-priori analysis plan, pre-registered where possible; vi) replication and/or extension of previous study parameters; vii) accounting for psychological factors (e.g., expectations of outcomes); and viii) blinding of both participants and researchers to the experimental conditions.

Our studies revealed a number of novel findings important to the literature on cognitive enhancement techniques. First, our research has consistently demonstrated that people – particularly older adults – are relatively optimistic about "brain training" with computerized programs. Conversely, expectations are more varied and neutral for lesser-known methods such as non-invasive brain stimulation.

Moreover, using the EAS, a tool we developed to assess and prime expectations, we showed that expectation ratings are malleable to information suggesting an intervention is either effective at improving certain outcomes or unlikely to produce any meaningful change. We further found that self-rated expectations, at least under the conditions we studied, do not necessarily influence cognitive performance or subjective perceptions of cognition and wellbeing.

Perhaps most importantly, we did not find an effect of either baseline expectations or expectation priming on cognitive or motor performance, in young or older adults. In our CCT trial, although participants generally improved on neuropsychological and cognitive tasks of memory and executive function after the five weeks of training, changes were not specific to the assigned program or priming condition. Furthermore, we found no significant group differences in subjective measures of performance and wellbeing after training. In our tDCS trial, participants showed comparable performance at baseline and after the 20-minute stimulation procedure on indices of motor and cognitive performance, regardless of experimental or priming condition.

In both the CCT and tDCS interventions, participants largely believed they were assigned to the intervention (rather than control condition) and reported being engaged and motivated throughout the study. Coupled with the self-selected nature of our sample, such positive subjective experience suggests that our findings are unlikely to result from lack of interest or effort.

Despite our largely null findings regarding the influence of expectations on intervention outcomes, the literature on cognitive enhancement is replete with mixed results and failures to replicate previous findings. Furthermore, the mechanisms through which CCT and tDCS may exert their purported effects are poorly understood. These caveats suggest that reported CCT and tDCS effects may result from non-specific or extraneous factors. Because people's beliefs and perceptions can greatly influence behaviour and intervention outcomes (e.g., in contexts such as medicine), expectations should be evaluated – and, ideally, controlled for – in all intervention studies.

4.2 Limitations and Future Directions

The studies included in the present thesis focused on carrying out research with balanced experimental design and overcame many of the caveats in previous research. Nevertheless, a number of considerations and potential limitations could help explain our findings.

Sample composition: The sample composition represents one limitation of this research. In developing the EAS, our samples were relatively imbalanced with respect to age and recruitment site – two factors that may have influenced our findings. Participants who completed the intervention studies were relatively healthy, well-educated, and highly motivated to comply. The literature on the benefits of CCT and NIBS interventions is mixed, with reports of a "Matthew Effect" (i.e., greater improvements in people with higher baseline performance) as well as indications that lower performers (including patient populations) benefit more. Our work suggests, however, that our participants had little room for improvement on many of our outcome measures – either due to high baseline performance (i.e., ceiling effect where performance was high at baseline) or excessive challenge (i.e., floor effect where performance remained low over time). Moreover, the relative uniformity of our sample provided little opportunity to examine performance based on individual differences. Although our inclusion of self-selected participants was intentional, to better represent people who are more likely to invest in commercial training approaches, future work should focus on recruiting participants beyond convenience samples, and include participants with perceived or diagnosed cognitive declines.

Expectation priming: The timing and nature of our expectation priming may have been suboptimal. Although we validated the priming messages through initial studies of the EAS, and attempted to mimic realistic exposure without being overbearing, the current method (i.e., brief, infrequent exposure to a written message) might not have been sufficiently potent. This may be particularly true of participants who began the studies with a stronger expectation of outcomes – the brief exposure to our relatively subtle priming may have been insufficient to reverse predisposed and potentially long-held preconceptions of the intervention. Future work could examine the influence of other expectation priming methods, including more frequent exposure to the expectation messages as well as different delivery modalities (i.e., through images, with verbal communication, or via audiovisual recordings). Although we adopted a more conservative approach to priming to avoid suspicion among our participants regarding the nature of our research, these changes in expectation priming may increase the potency of the priming messages, and are worth investigating in extensions of this work.

External validity: We paid particular attention to study design in all the work described (i.e., survey and intervention design). However, due to the novelty of the driving research question (i.e., effects of expectations on cognitive interventions) as well as the inconsistency in methods and findings in both the CCT and tDCS literatures, it is possible that our selected approaches were inadequate. For example, for our tDCS intervention, using a high-density rather than conventional montage may have yielded more potent outcomes, particularly in our relatively high-performing sample (Gozenman and Berryhill, 2016). With respect to the EAS, although we based our tool on the survey used in the initial study that identified the lack of control for expectations in cognitive intervention studies (Boot et al., 2013b), using established tools probing related characteristics in conjunction with the EAS would provide validation beyond internal consistency. Finally, although we explored survey responses under conditions where participants were asked to provide ratings they believed would comply with what the experimenters would want or expect (see Appendix B), a more extensive examination of demand characteristics may help improve interpretations and future developments of the EAS.

Training dose: For both the CCT and NIBS intervention trials, the selected duration and intensity of training are potential caveats. Although no consensus exists regarding the right "dose" of training, particularly for CCT. For tDCS, recent research suggests that multiple applications of tDCS may facilitate more consistent improvements in cognitive performance (Berryhill, 2017). Conversely, recent reviews of the literature have suggested that training more than three days per week may be too frequent ("over-training") and undermine the potential for training-related gains (Lampit et al., 2014). In addition, including booster sessions, merging core training programs with strategy guidance (e.g., Rebok et al., 2014), and instructing participants to vary their prioritization of tasks in multitasking contexts (e.g., Lussier et al., 2017) may bolster training effects.

Outcome evaluations: More refined outcome measures such as neuroimaging methods and computerized tasks that are better able to parse performance related to different cognitive functions vs. response time may provide greater insights into the influence of training on cognition, Similarly, the effects of training might be delayed. Neither of our intervention studies included an extensive long-term analysis of outcomes. This might have been particularly interesting for tDCS, where effects have sometimes been reported at a delayed interval. To this end, we have recently completed a new CCT trial with the *Activate* program, with more refined outcome measures including electroencephalography (EEG) markers of attention and executive function shown to change following CCT (Anguera et al., 2013; Küper et al., 2017; Maclin et al., 2011; Tusch et al., 2016).

A number of CCT programs, including *Activate*, incorporate physical exercises into the intervention. Although this combination was beyond the scope of the current work, evidence suggests that the combination of CCT and physical exercise may be beneficial in both YA (Ward et al., 2017) and OA ((e.g., Styliadis et al., 2015) although effects might stem largely from the cognitive training (Shatil, 2013); for a review see (Rabipour et al., 2017b)). Incorporating physical activity to CCT as well as in daily life appears particularly important, with research suggesting a negative impact of sedentary living – in particular, amount of time spent sitting – on brain structure (Siddarth et al., 2018), and a vast literature suggesting both physical and cognitive benefits of physical exercise across the lifespan (e.g., for a brief review, see Erickson et al., 2015).

Extensions of this work are already underway. For example, a multi-session tDCS trial in older adults with cognitive decline has received funding for study at the post-doctoral level. This trial will employ a similar balanced-placebo design as the trials presented in this thesis, crossing active and sham tDCS within subjects and positive vs. neutral expectation priming between subjects. Moreover, neuroimaging outcomes will be assessed at baseline, mid-trial, and following the completion of the trial.

References

2015. Hacking your brain. *The Economist*.

Almuklass, A. M., D. F. Feeney, D. Mani, L. D. Hamilton, and R. M. Enoka
2017. Peg-manipulation capabilities during a test of manual dexterity differ for persons with multiple sclerosis and healthy individuals. *Experimental Brain Research*.

Almuklass, A. M., D. F. Feeney, D. Mani, L. D. Hamilton, and R. M. Enoka
2018. Peg-manipulation capabilities of middle-aged adults have a greater influence on pegboard times than those of young and old adults. *Experimental Brain Research*.

Alzheimer Society
2012. A new way of looking at the impact of dementia in Canada. Technical report.

Amanzio, M. and F. Benedetti
1999. Neuropharmacological dissection of placebo analgesia: Expectation-activated opioid systems versus conditioning-activated specific subsystems. *Journal of Neuroscience*, 19(1):484–494.

Ammann, C., M. A. Lindquist, and P. A. Celnik
2017. Response variability of different anodal transcranial direct current stimulation intensities across multiple sessions. *Brain Stimulation*.

Anderson, N. D. and F. I. Craik
2017. 50 years of cognitive aging theory. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*.

Angelakis, E., S. Stathopoulou, J. L. Frymiare, D. L. Green, J. F. Lubar, and J. Kounios
2007. EEG neurofeedback: A brief overview and an example of peak alpha frequency training for cognitive enhancement in the elderly. *Clinical Neuropsychologist*, 21(1):110–129.

Anguera, J. A., J. Boccanfuso, J. L. Rintoul, O. Al-Hashimi, F. Faraji, J. Janowich, E. Kong, Y. Larraburo, C. Rolle, E. Johnston, and A. Gazzaley
2013. Video game training enhances cognitive control in older adults. *Nature*, 501(7465):97.

Antal, A., D. Keeser, A. Priori, F. Padberg, and M. A. Nitsche
2015. Conceptual and Procedural Shortcomings of the Systematic Review " Evidence That Transcranial Direct Current Stimulation (tDCS) Generates Little-to-no Reliable Neurophysiologic Effect Beyond MEP Amplitude Modulation in Healthy Human Subjects: A Systematic Review" by Horvath and Co-workers. *Brain Stimulation*, 8(4):846–849.

Ashendorf, L., J. L. Vanderslice-Barr, and R. J. McCaffrey
2009. Motor tests and cognition in healthy older adults. *Applied Neuropsychology*.

Astell, A., N. Alm, R. Dye, G. Gowans, P. Vaughan, and M. Ellis
2014. Digital Video Games for Older Adults with Cognitive Impairment. In *Computers Helping People with Special Needs*, number 8547, Pp. 264–271. Springer International Publishing.

Au, J., M. Buschkuehl, G. J. Duncan, and S. M. Jaeggi
2016. There is no convincing evidence that working memory training is NOT effective: A reply to Melby-Lervag and Hulme (2015). *Psychonomic Bulletin & Review*, 23(1):331–337.

Axelrod, B. N., N. L. Fichtenberg, S. R. Millis, and J. C. Wertheimer
2006. Detecting incomplete effort with digit span from the Wechsler Adult Intelligence Scale - Third edition. *Clinical Neuropsychologist*, 20(3):513–523.

Bahar-Fuchs, A., L. Clare, and B. Woods
2013. Cognitive training and cognitive rehabilitation for mild to moderate Alzheimer's disease and vascular dementia. *Cochrane Database of Systematic Reviews*, (6).

Baldo, J. V., D. Delis, J. Kramer, and A. P. Shimamura
2002. Memory performance on the California Verbal Learning Test–II: Findings from patients with focal frontal lesions. *Journal of the International Neuropsychological Society*, 8:539–546.

Ball, K., D. B. Berch, K. F. Helmers, J. B. Jobe, M. D. Leveck, M. Marsiske, J. N. Morris, G. W. Rebok, D. M. Smith, S. L. Tennstedt, F. W. Unverzagt, S. L. Willis, and f. t. A. S. Group
2002. Effects of Cognitive Training Interventions With Older Adults. *JAMA: The Journal of the American Medical Association*, 288(18):2271–2281.

Ballesteros, S., J. Mayas, A. Prieto, P. Toril, C. Pita, L. P. de Leon, J. M. Reales, and J. A. Waterworth
2015. A randomized controlled trial of brain training with non-action video games in older adults: results of the 3-month follow-up. *Frontiers in Aging Neuroscience*, 7.

Barber, S. J. and M. Mather
2013. *Stereotype Threat in Older Adults.*

Barnett, W. S., K. Jung, D. J. Yarosz, J. Thomas, A. Hornbeck, R. Stechuk, and S. Burns
2008. Educational effects of the Tools of the Mind curriculum: A randomized trial. *Early Childhood Research Quarterly.*

Basak, C., W. R. Boot, M. W. Voss, and A. F. Kramer
2008. Can Training in a Real-Time Strategy Video Game Attenuate Cognitive Decline in Older Adults? *Psychology and aging*, 23(4):765–777.

Belleville, S., C. Hudon, N. Bier, C. Brodeur, B. Gilbert, S. Grenier, M.-C. Ouellet, C. Viscogliosi, and S. Gauthier
2018. MEMO+: Efficacy, Durability and Effect of Cognitive Training and Psychosocial Intervention in Individuals with Mild Cognitive Impairment. *Journal of the American Geriatrics Society.*

Benedetti, F.
2014. Placebo effects: From the neurobiological paradigm to translational implications.

Benedetti, F., C. Arduino, S. Costa, S. Vighetti, L. Tarenzi, I. Rainero, and G. Asteggiano
2006. Loss of expectation-related mechanisms in Alzheimer's disease makes analgesic therapies less effective. *Pain*, 121(1-2):133–144.

Benedetti, F., E. Carlino, and A. Pollo
2011. How Placebos Change the Patient's Brain. *Neuropsychopharmacology Reviews*, 3681:339–354.

Bentham, P., R. Gray, J. Raftery, R. Hills, E. Sellwood, C. Courtney, D. Farrell, W. Hardyman, P. Crome, S. Edwards, C. Lendon, L. Lynch, and A. C. Grp
2004. Long-term donepezil treatment in 565 patients with Alzheimer's disease (AD2000): randomised double-blind trial. *Lancet*, 363(9427):2105–2115.

Berman, M. G., J. Jonides, and S. Kaplan
2008. The Cognitive Benefits of Interacting With Nature. *Psychological Science*, 19(12):1207–1212.

Berry, A. S., T. P. Zanto, W. C. Clapp, J. L. Hardy, P. B. Delahunt, H. W. Mahncke, and A. Gazzaley
2010. The influence of perceptual training on working memory in older adults. *Plos One*, 5(7):e11537.

Berryhill, M. E.
2017. Longitudinal tDCS: Consistency across Working Memory Training Studies. *AIMS Neuroscience*, 4(2):71–86.

Berryhill, M. E., D. J. Peterson, K. T. Jones, and J. A. Stephens
2014. Hits and misses: leveraging tDCS to advance cognitive research. *Frontiers in Psychology*.

Bestmann, S., A. O. de Berker, and J. Bonaiuto
2015. Understanding the behavioural consequences of noninvasive brain stimulation.

Bezdicek, O., T. Nikolai, M. Hoskovcová, J. Štochl, H. Brožová, P. Dušek, K. Zárubová, R. Jech, and E. Růžička
2014. Grooved Pegboard Predicates More of Cognitive Than Motor Involvement in Parkinson's Disease. *Assessment*.

Bherer, L.
2015. Cognitive plasticity in older adults: Effects of cognitive training and physical exercise. *Annals of the New York Academy of Sciences*.

Bialystok, E. and A. M. DePape
2009. Musical Expertise, Bilingualism, and Executive Functioning. *Journal of Experimental Psychology-Human Perception and Performance*, 35(2):565–574.

Bikson, M., P. Grossman, C. Thomas, A. L. Zannou, J. Jiang, T. Adnan, A. P. Mourdoukoutas, G. Kronberg, D. Truong, P. Boggio, A. R. Brunoni, L. Charvet, F. Fregni, B. Fritsch, B. Gillick, R. H. Hamilton, B. M. Hampstead, R. Jankord, A. Kirton, H. Knotkova, D. Liebetanz, A. Liu, C. Loo, M. A. Nitsche, J. Reis, J. D. Richardson, A. Rotenberg, P. E. Turkeltaub, and A. J. Woods
2016. Safety of Transcranial Direct Current Stimulation: Evidence Based Update 2016.

Boot, W. R., M. Champion, D. P. Blakely, T. Wright, D. J. Souders, and N. Charness
2013a. Video games as a means to reduce age-related cognitive decline: attitudes, compliance, and effectiveness. *Frontiers in Psychology*, 4.

Boot, W. R. and A. F. Kramer
2014. The Brain-Games Conundrum: Does Cognitive Training Really Sharpen the Mind? .

Boot, W. R., D. J. Simons, C. Stothart, and C. Stutts
2013b. The Pervasive Problem With Placebos in Psychology: Why Active Control Groups Are Not Sufficient to Rule Out Placebo Effects. *Perspectives on Psychological Science*.

Boot, W. R., D. Souders, N. Charness, K. Blocker, N. Roque, and T. Vitale
2016. The Gamification of Cognitive Training: Older Adults' Perceptions of and Attitudes Toward Digital Game-Based Interventions. *LNCS*, 9754:290–300.

Bossaer, J. B., J. A. Gray, S. E. Miller, G. Enck, V. C. Gaddipati, and R. E. Enck
2013. The Use and Misuse of Prescription Stimulants as "Cognitive Enhancers" by Students at One Academic Health Sciences Center. *Academic Medicine*, 88(7):967–971.

Brouillette, R. M., H. Foil, S. Fontenot, A. Correro, R. Allen, C. K. Martin, A. J. Bruce-Keller, and J. N. Keller
2013. Feasibility, Reliability, and Validity of a Smartphone Based Application for the Assessment of Cognitive Function in the Elderly. *Plos One*, 8(6).

Brühl, A. B. and B. J. Sahakian
2016. Drugs, games, and devices for enhancing cognition: Implications for work and society. *Annals of the New York Academy of Sciences*.

Brunoni, A. R., J. Amadera, B. Berbel, M. S. Volz, B. G. Rizzerio, and F. Fregni
2011. A systematic review on reporting and assessment of adverse effects associated with transcranial direct current stimulation.

Bryden, P. J. and E. A. Roy
2005. A new method of administering the Grooved Pegboard Test: Performance as a function of handedness and sex. *Brain and Cognition*.

Butler, M., E. McCreedy, V. A. Nelson, P. Desai, E. Ratner, H. A. Fink, L. S. Hemmy, J. R. McCarten, T. R. Barclay, M. Brasure, H. Davila, and R. L. Kane
2018. Does cognitive training prevent cognitive decline?

Buysse, D. J., C. F. Reynolds, T. H. Monk, C. C. Hoch, A. L. Yeager, and D. J. Kupfer
1991. Quantification of Subjective Sleep Quality in Healthy Elderly Men and Women Using the Pittsburgh Sleep Quality Index (Psqi). *Sleep*, 14(4):331–338.

Cabeza, R., N. D. Anderson, J. K. Locantore, and A. R. McIntosh
2002. Aging gracefully: compensatory brain activity in high-performing older adults. *Neuroimage*, 17(3):1394–1402.

Cai, L., D. Thissen, and S. H. C. du Toit
2011. IRTPRO for Windows [Computer software].

Campbell, A. and T. Choudhury
2012. From Smart to Cognitive Phones. *Ieee Pervasive Computing*, 11(3):7–11.

Campbell, N. L., I. Maidment, C. Fox, B. Khan, and M. Boustani
2013. The 2012 update to the anticholinergic cognitive burden scale. *Journal of the American Geriatrics Society*, 61(S1):S142–S143.

Cancelli, I., M. Beltrame, G. L. Gigli, and M. Valente
2009. Drugs with anticholinergic properties: cognitive and neuropsychiatric side-effects in elderly patients. *Neurol Sci*, 30(2):87–92.

Carr, N. G.
2010. *The shallows: What the Internet is doing to our brains*, 1st edition. New York: W.W. Norton.

Carter, O. and J. Forte
2016. Medical risks: Regulate devices for brain stimulation. *Nature*, 533(7602):179.

Cellan-Jones, R.
2014. Stephen Hawking warns artificial intelligence could end mankind.

Cespón, J., C. Miniussi, and M. C. Pellicciari
2018. Interventional programmes to improve cognition during healthy and pathological ageing: Cortical modulations and evidence for brain plasticity.

Chadick, J. Z., T. P. Zanto, and A. Gazzaley
2014. Structural and functional differences in medial prefrontal cortex underlie distractibility and suppression deficits in ageing. *Nature Communications*, 5.

Chan, M. Y., S. Haber, L. M. Drew, and D. C. Park
2014. Training Older Adults to Use Tablet Computers: Does It Enhance Cognitive Function? *Gerontologist*, Pp. 1–11.

Chapman, S. B., S. Aslan, J. S. Spence, J. J. Hart Jr., E. K. Bartz, N. Didehbani, M. W. Keebler, C. M. Gardner, J. F. Strain, L. F. Defina, and H. Lu
2013. Neural Mechanisms of Brain Plasticity with Complex Cognitive Training in Healthy Seniors. *Cerebral Cortex*.

Charles, S. T. and L. L. Carstensen
2010. Social and Emotional Aging. *Annual Review of Psychology*, 61:383–409.

Charness, N. and W. R. Boot
2009. Aging and Information Technology Use: Potential and Barriers. *Current Directions in Psychological Science*, 18(5):253–258.

Cheng, Y., W. Wu, W. Feng, J. Wang, Y. Chen, Y. Shen, Q. Li, X. Zhang, and C. Li
2012. The effects of multi-domain versus single-domain cognitive training in non-demented older people: a randomized controlled trial. *BMC Med*, 10:30.

Chowdhury, R., T. Sharot, T. Wolfe, E. Duzel, and R. J. Dolan
2014. Optimistic update bias increases in older age. *Psychological Medicine*, 44(9):2003–2012.

Christova, M., D. Rafolt, and E. Gallasch
2015. Cumulative effects of anodal and priming cathodal tDCS on pegboard test performance and motor cortical excitability. *Behavioural Brain Research*.

Clare, L. and R. T. Woods
2004. Cognitive training and cognitive rehabilitation for people with early-stage Alzheimer's disease: A review. *Neuropsychological Rehabilitation*, 14(4):385–401.

Clark, J. E., A. K. Lanphear, and C. C. Riddick
1987. The Effects of Videogame Playing on the Response Selection Processing of Elderly Adults. *Journals of Gerontology*, 42(1):82–85.

Coffman, B. A., V. P. Clark, and R. Parasuraman
2014. Battery powered thought: Enhancement of attention, learning, and memory in healthy adults using transcranial direct current stimulation.

CogniFit Inc.
2014. CogniFit.

CognitiveTrainingData.org
2014. Cognitive Training Data: An Open Letter.

Colloca, L. and F. G. Miller
2011. How placebo responses are formed: a learning perspective. *Philosophical Transactions of the Royal Society B-Biological Sciences*, 366(1572):1859–1869.

Cotten, S. R., G. Ford, S. Ford, and T. M. Hale
2014. Internet Use and Depression Among Retired Older Adults in the United States: A Longitudinal Analysis. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences*, 69(5):763–771.

CREATE
2012. Center for Research and Education on Aging and Technology Enhancement.

Crowe, S. F.
2000. Does the letter number sequencing task measure anything more than digit span? *Assessment*, 7(2):113–117.

Cruz, V. T., J. Pais, V. Bento, C. Mateus, M. Colunas, I. Alves, P. Coutinho, and N. P. Rocha
2013. A rehabilitation tool designed for intensive web-based cognitive training: description and usability study. *JMIR Res Protoc*, 2(2):e59.

Csikszentmihalyi, M.
1990. *Flow : the psychology of optimal experience*, 1st edition. New York: Harper & Row.

Dafnis, J.
2014. This Neuroscientist Wants To Use Video Games Like Medicine. *Game Informer*.

Davidson, P. S. R. and G. Winocur
2017. Aging and Cognition. *Reference Module in Neuroscience and Biobehavioral Psychology*, Pp. 1–7.

Daviglus, M. L., C. C. Bell, W. Berrettini, P. E. Bowen, E. S. Connolly Jr, N. J. Cox, J. M. Dunbar-Jacob, E. C. Granieri, G. Hunt, K. McGarry, D. Patel, A. L. Potosky, E. Sanders-Bush, D. Silberberg, and M. Trevisan
2010. National Institutes of Health state-of-the-science conference statement: Preventing Alzheimer disease and cognitive decline. *Annals of Internal Medicine*, 153(3):176–181.

Davis, N. J.
2014. Transcranial stimulation of the developing brain: a plea for extreme caution. *Frontiers in Human Neuroscience*, 8.

Davis, S. W., N. A. Dennis, S. M. Daselaar, M. S. Fleck, and R. Cabeza
2008. Que PASA? The posterior-anterior shift in aging. *Cerebral Cortex*, 18(5):1201–1209.

Dawadi, P. N., D. J. Cook, and M. Schmitter-Edgecombe
2013. Automated Cognitive Health Assessment Using Smart Home Monitoring of Complex Tasks. *Ieee Transactions on Systems Man Cybernetics-Systems*, 43(6):1302–1313.

de Xivry, J. J. O. and R. Shadmehr
2014. Electrifying the motor engram: effects of tDCS on motor learning and control. *Experimental Brain Research*, 232(11):3379–3395.

deCharms, R. C.
2008. Applications of real-time fMRI. *Nature Reviews Neuroscience*, 9(9):720–729.

Dennis, N. A.
2008. Neuroimaging of healthy cognitive aging. In *The Handbook of Aging and Cognition*, F. I. M. Craik, ed., chapter 1, Pp. 1–54. New York, NY: Psychology Press.

Diamond, A.
2012. Activities and Programs That Improve Children's Executive Functions. *Current Directions in Psychological Science*, 21(5):335–341.

Ditye, T., L. Jacobson, V. Walsh, and M. Lavidor
2012. Modulating behavioral inhibition by tDCS combined with cognitive training. *Experimental Brain Research*, 219(3):363–368.

Dockery, C. A., R. Hueckel-Weng, N. Birbaumer, and C. Plewnia
2009. Enhancement of Planning Ability by Transcranial Direct Current Stimulation. *Journal of Neuroscience*, 29(22):7271–7277.

Drag, L. L. and L. A. Bieliauskas
2010. Contemporary review 2009: cognitive aging. *J Geriatr Psychiatry Neurol*, 23(2):75–93.

Drobics, M. and S. Smith
2014. Game-Based IT Solutions for Active and Healthy Aging. *Games for Training, Education, Health and Sports*, 8395:8–11.

Dye, M. W. G., C. S. Green, and D. Bavelier
2009. Increasing Speed of Processing With Action Video Games. *Current Directions in Psychological Science*, 18(6):321–326.

Dyke, K., S. Kim, G. M. Jackson, and S. R. Jackson
2016. Intra-Subject Consistency and Reliability of Response Following 2mA Transcranial Direct Current Stimulation. *Brain Stimulation*, 9:819–825.

Edwards, J. D., B. A. Fausto, A. M. Tetlow, R. T. Corona, and E. G. Valdés
2017. Systematic review and meta-analyses of useful field of view cognitive training. *Neuroscience and Biobehavioral Reviews*, 84:72–91.

Emanuel, R. M., S. L. Frellsen, K. J. Kashima, S. M. Sanguino, F. S. Sierles, and C. J. Lazarus
2013. Cognitive Enhancement Drug Use Among Future Physicians: Findings from a Multi-Institutional Census of Medical Students. *Journal of General Internal Medicine*, 28(8):1028–1034.

Embretson, S. E. and S. P. Reise
2000. *Item Response Theory for Psychologists*. Psychology Press.

Erdö, F., L. Denes, and E. De Lange
2017. Age-associated physiological and pathological changes at the blood-brain barrier: A review.

Erickson, K. I., C. H. Hillman, and A. F. Kramer
2015. Physical activity, brain, and cognition. *Behavioral Sciences*, 4:27–32.

Fagerlund, A. J., J. L. Freili, T. L. Danielsen, and P. M. Aslaksen
2015. No Effect of 2 mA Anodal tDCS Over the M1 on Performance and Practice Effect on Grooved Pegboard Test and Trail Making Test B 1,2,3. 2(4):72–14.

Fan, J., B. D. McCandliss, T. Sommer, A. Raz, and M. I. Posner
2001. Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*.

Farah, M. J.
2015. The unknowns of cognitive enhancement. *Science*, 350(6259):379–380.

Fazli, S., J. Mehnert, J. Steinbrink, G. Curio, A. Villringer, K. R. Muller, and B. Blankertz
2012. Enhanced performance by a hybrid NIRS-EEG brain computer interface. *Neuroimage*, 59(1):519–529.

Federal Trade Commission
2015. Makers of Jungle Rangers Computer Game for Kids Settle FTC Charges that They Deceived Consumers with Baseless "Brain Training" Claims.

Federal Trade Commission
2016. Lumosity to Pay $2 Million to Settle FTC Deceptive Advertising Charges for Its "Brain Training" Program.

Finniss, D. G., T. J. Kaptchuk, F. Miller, and F. Benedetti
2010. Biological, clinical, and ethical advances of placebo effects. *Lancet*, 375(9715):686–695.

foc.us
2017. foc.us.

Foroughi, C. K., S. S. Monfort, M. Paczynski, P. E. McKnight, and P. M. Greenwood
2016. Placebo effects in cognitive training. *Proc Natl Acad Sci U S A*, 113(27):7470–7474.

Foster, G. C., H. Min, and M. J. Zickar
2017. Review of Item Response Theory Practices in Organizational Research : Lessons Learned and Paths Forward. 20(3):465–486.

Fox, C., K. Richardson, I. D. Maidment, G. M. Savva, F. E. Matthews, D. Smithard, S. Coulton, C. Katona, M. A. Boustani, and C. Brayne
2011. Anticholinergic Medication Use and Cognitive Impairment in the Older Population: The Medical Research Council Cognitive Function and Ageing Study. *Journal of the American Geriatrics Society*, 59(8):1477–1483.

Franke AG, Bagusat C, Rust S, Engel A, and Lieb K
2014. Substances used and prevalence rates of pharmacological cognitive enhancement among healthy subjects. *European Archives of Psychiatry and Clinical Neuroscience*, 264(Supplement 1):83–90.

Fujiyama, H., J. Hyde, M. R. Hinder, S. J. Kim, G. H. McCormack, J. C. Vickers, and J. J. Summers
2014. Delayed plastic responses to anodal tDCS in older adults. *Frontiers in Aging Neuroscience*.

Gamberini, L., F. Martino, B. Seraglia, A. Spagnolli, M. Fabregat, F. Ibanez, M. Alcaniz, and J. M. Andres
2009. Eldergames Project: An innovative Mixed Reality Table-top Solution to Preserve Cognitive Functions in Elderly People. *Hsi: 2009 2nd Conference on Human System Interactions*, Pp. 161–166.

García-Betances, R. I., M. F. Cabrera-Umpiérrez, and M. T. Arredondo
2017. Computerized neurocognitive interventions in the context of the brain training controversy. *Reviews in the Neurosciences*.

Gard, T., B. K. Hölzel, and S. W. Lazar
2014. The potential effects of meditation on age-related cognitive decline: A systematic review. *Annals of the New York Academy of Sciences*.

Gindrat, A.-D., M. Chytiris, M. Balerna, E. M. Rouiller, and A. Ghosh
2015. Use-Dependent Cortical Processing from Fingertips in Touchscreen Phone Users. *Current Biology*.

Glickstein, M.
2006. Golgi and Cajal: The neuron doctrine and the 100th anniversary of the 1906 Nobel Prize. *Current Biology*, 16(5):R147–R151.

Glisky, E. L.
2007. Changes in Cognitive Function in Human Aging. In *Brain Aging: Models, Methods, and Mechanisms*, D. R. Riddle, ed. Boca Raton (FL): [publisher unknown].

Glisky, E. L., M. R. Polster, and B. C. Routhieaux
1995. Double Dissociation Between Item and Source Memory. *Neuropsychology*.

Gollub, R. L. and J. Kong
2011. For Placebo Effects in Medicine, Seeing is Believing. *Pain*, 3(70).

Google
2014. The Glass Explorer Program.

Gozenman, F. and M. E. Berryhill
2016. Working memory capacity differentially influences responses to tDCS and HD-tDCS in a retro-cue task. *Neuroscience Letters*, 629:105–109.

Graham, J. E., K. Rockwood, B. L. Beattie, R. Eastwood, S. Gauthier, H. Tuokko, and I. McDowell
1997. Prevalence and severity of cognitive impairment with and without dementia in an elderly population. *Lancet*, 349(9068):1793–1796.

Green, C. S. and D. Bavelier
2008. Exercising your brain: a review of human brain plasticity and training-induced learning. *Psychology and aging*, 23(4):692–701.

Green, C. S., T. Strobach, and T. Schubert
2014. On methodological standards in training and transfer experiments. *Psychological Research-Psychologische Forschung*, 78(6):756–772.

Greenwood, P. M., E. J. Blumberg, and M. R. Scheldrup
2018. Hypothesis for cognitive effects of transcranial direct current stimulation_ Externally- and internally-directed cognition.

Gross, L.
2017. Putting placebos to the test. *PLoS Biol*, 15(2):e2001998.

Gruzelier, J. H.
2014a. EEG-neurofeedback for optimising performance. I: A review of cognitive and affective outcome in healthy participants. *Neuroscience and Biobehavioral Reviews*, 44:124–141.

Gruzelier, J. H.
2014b. EEG-neurofeedback for optimising performance. II: Creativity, the performing arts and ecological validity. *Neuroscience and Biobehavioral Reviews*, 44:142–158.

Gur, R. C., J. Richard, P. Hughett, M. E. Calkins, L. Macy, W. B. Bilker, C. Brensinger, and R. E. Gur
2010. A cognitive neuroscience-based computerized battery for efficient measurement of individual differences: standardization and initial construct validation. *J Neurosci Methods*, 187(2):254–262.

Hallett, M.
2007. Transcranial Magnetic Stimulation: A Primer.

Halo Neuroscience
2017. Halo.

Hambrick, D. Z., T. A. Salthouse, and E. J. Meinz
1999. Predictors of crossword puzzle proficiency and moderators of age-cognition relations. *Journal of Experimental Psychology-General*, 128(2):131–164.

Hampshire, A., R. R. Highfield, B. L. Parkin, and A. M. Owen
2012. Fractionating Human Intelligence. *Neuron*, 76(6):1225–1237.

Harada, C. N., M. C. N. Love, and K. L. Triebel
2013. Normal Cognitive Aging. *Clinics in Geriatric Medicine*, 29(4):737–+.

Hashemirad, F., M. Zoghi, P. B. Fitzgerald, and S. Jaberzadeh
2016. The effect of anodal transcranial direct current stimulation on motor sequence learning in healthy individuals: A systematic review and meta-analysis. *Brain and Cognition*.

Hassan, T. A., R. M. Klein, and G. C. Wilson
2015. The AttentionTrip: A Game-Like Task for Assessment of Attention Networks. *Canadian Journal of Experimental Psychology-Revue Canadienne De Psychologie Experimentale*, 69(4):374.

Hayduk, L., G. Cummings, K. Boadu, H. Pazderka-Robinson, and S. Boulianne
2007. Testing! testing! one, two, three - Testing the theory in structural equation models! *Personality and Individual Differences*, 42(5):841–850.

Hayes, V., J. Morris, C. Wolfe, and M. Morgan
1995. The Sf-36 Health Survey Questionnaire - Is It Suitable for Use with Older Adults. *Age and Ageing*, 24(2):120–125.

Heaton, R. K., N. Akshoomoff, D. Tulsky, D. Mungas, S. Weintraub, S. Dikmen, J. Beaumont, K. B. Casaletto, K. Conway, J. Slotkin, and R. Gershon
2014. Reliability and validity of composite scores from the NIH Toolbox Cognition Battery in adults. *J Int Neuropsychol Soc*, 20(6):588–598.

Hedden, T. and J. D. E. Gabrieli
2004. Insights into the ageing mind: A view from cognitive neuroscience. *Nature Reviews Neuroscience*, 5(2):87–U12.

Heinzel, S., S. Schulte, J. Onken, Q.-L. Duong, T. G. Riemer, A. Heinz, N. Kathmann, and M. A. Rapp
2014. Working memory training improvements and gains in non-trained cognitive tasks in young and older adults. *Aging, Neuropsychology, and Cognition*, 21(2):146–173.

Henrich, J., S. J. Heine, and A. Norenzayan
2010. The weirdest people in the world? *Behavioral and Brain Sciences*.

Hertzog, C., A. F. Kramer, R. S. Wilson, and U. Lindenberger
2008. Enrichment Effects on Adult Cognitive Development: Can the Functional Capacity of Older Adults Be Preserved and Enhanced? *Psychological Science in the Public Interest*, 9:1–65.

Hill, B. D., M. Alosco, L. Bauer, and G. Tremont
2012. The Relation of Executive Functioning to CVLT II Learning Memory and Process Indexes. *Applied Neuropsychology: Adult*, 19(3):198–206.

Hindin, S. B. and E. M. Zelinski
2012. Extended Practice and Aerobic Exercise Interventions Benefit Untrained Cognitive Outcomes in Older Adults: A Meta-Analysis. *Journal of the American Geriatrics Society*, 60(1):136–141.

Ho, K. A., J. L. Taylor, T. Chew, V. Gálvez, A. Alonzo, S. Bai, S. Dokos, and C. K. Loo
2016. The Effect of Transcranial Direct Current Stimulation (tDCS) Electrode Size and Current Intensity on Motor Cortical Excitability: Evidence from Single and Repeated Sessions. *Brain Stimulation*.

Hooper, D., J. Coughlan, and M. Mullen
2008. Structural Equation Modelling: Guidelines for Determining Model Fit. *Electronic Journal of Business Research Methods*, 6(1):53–60.

Horvath, J. C., O. Carter, and J. D. Forte
2014. Transcranial direct current stimulation: five important issues we aren't discussing (but probably should be). *Frontiers in Systems Neuroscience.*

Horvath, J. C., O. Carter, and J. D. Forte
2016. No significant effect of transcranial direct current stimulation (tDCS) found on simple motor reaction time comparing 15 different simulation protocols. *Neuropsychologia.*

Horvath, J. C., J. D. Forte, and O. Carter
2015. Evidence that transcranial direct current stimulation (tDCS) generates little-to-no reliable neurophysiologic effect beyond MEP amplitude modulation in healthy human subjects: A systematic review.

Howick, J., C. Friedemann, M. Tsakok, R. Watson, T. Tsakok, J. Thomas, R. Perera, S. Fleming, and C. Heneghan
2013. Are Treatments More Effective than Placebos? A Systematic Review and Meta-Analysis. *Plos One*, 8(5).

Howren, M. B., M. W. Vander Weg, and F. D. Wolinsky
2014. Computerized cognitive training interventions to improve neuropsychological outcomes: evidence and future directions. *Journal of Comparative Effectiveness Research*, 3(2):145–154.

Hughes, M. L., L. Geraci, and R. L. De Forrest
2013. Aging 5 years in 5 minutes: the effect of taking a memory test on older adults' subjective age. *Psychological Science*, 24(12):2481–2488.

Ihl, R., L. Frolich, B. Winblad, L. Schneider, A. Burns, H. J. Moller, and W. T. F. T. Guideli
2011. World Federation of Societies of Biological Psychiatry (WFSBP) Guidelines for the Biological Treatment of Alzheimer's disease and other dementias. *World Journal of Biological Psychiatry*, 12(1):2–32.

Iyer, M. B., U. Mattu, J. Grafman, M. Lomarev, S. Sato, and E. M. Wassermann
2005. Safety and cognitive effect of frontal DC brain polarization in healthy individuals. *Neurology*, 64(5):872–875.

Jackson, J. J., P. L. Hill, B. R. Payne, B. W. Roberts, and E. A. L. Stine-Morrow
2012. Can An Old Dog Learn (and Want To Experience) New Tricks? Cognitive Training Increases Openness to Experience in Older Adults. *Psychology and aging*, 27(2):286–292.

Jacobson, L., M. Koslowsky, and M. Lavidor
2012. tDCS polarity effects in motor and cognitive domains: a meta-analytical review. *Experimental Brain Research*, 216(1):1–10.

Jaeggi, S. M., M. Buschkuehl, P. Shah, and J. Jonides
2014. The role of individual differences in cognitive training and transfer. *Mem Cognit*, 42(3):464–480.

Jamil, A., G. Batsikadze, H.-I. Kuo, L. Labruna, A. Hasan, W. Paulus, and M. A. Nitsche
2017. Systematic evaluation of the impact of stimulation intensity on neuroplastic after-effects induced by transcranial direct current stimulation TMS SI 1mV (stimulus intensity for 1 mV MEP amplitude) sensitivity correlated negatively with 1.0 mA anodal tDCS effects on excitability. Our study thus provides further insights on the extent of non-linear intensity-dependent neuroplastic after-effects of anodal and cathodal tDCS. *J Physiol The Journal of Physiology C The Physiological Society J Physiol*, 5954(5954):1273–1288.

Jiang, Y., R. Abiri, and X. Zhao
2017. Tuning up the old brain with new tricks: Attention training via neurofeedback.

Jobe, J. B., D. M. Smith, K. Ball, S. L. Tennstedt, M. Marsiske, S. L. Willis, G. W. Rebok, J. N. Morris, K. F. Helmers, M. D. Leveck, and K. Kleinman
2001. Active: A cognitive intervention trial to promote independence in older adults. *Controlled Clinical Trials*, 22(4):453–479.

Jones, K. T., F. Gözenman, and M. E. Berryhill
2015. The strategy and motivational influences on the beneficial effect of neurostimulation: A tDCS and fNIRS study. *NeuroImage*.

Jwa, A.
2015. Early adopters of the magical thinking cap: a study on do-it-yourself (DIY) transcranial direct current stimulation (tDCS) user community. *Journal of Law and the Biosciences*, 2(2):292–335.

Kadosh, R. C., N. Levy, J. O'Shea, N. Shea, and J. Savulescu
2012. The neuroethics of non-invasive brain stimulation. *Current Biology*, 22(4):R108–R111.

Kang, N., J. J. Summers, and J. H. Cauraugh
2016. Transcranial direct current stimulation facilitates motor learning post-stroke: A systematic review and meta-analysis.

Kapur, N., E. L. Glisky, and B. A. Wilson
2002. External memory aids and computers in memory rehabilitation. In *Handbook of memory disorders*, A. D. Baddeley, M. D. Kopelman, and B. A. Wilson, eds., Pp. 757–783. Chichester, West Sussex, England ; Hoboken, NJ, USA: J. Wiley.

Karbach, J. and P. Verhaeghen
2014. Making Working Memory Work: A Meta-Analysis of Executive-Control and Working Memory Training in Older Adults. *Psychological Science*, 25(11):2027–2037.

Katz, B., J. Au, M. Buschkuehl, T. Abagis, C. Zabel, S. M. Jaeggi, and J. Jonides
2017. Individual Differences and Long-term Consequences of tDCS-augmented Cognitive Training. *Journal of Cognitive Neuroscience*, 29(9):1498–1508.

Katz, H. H. and M. T. Nesbitt
2014. Patient monitoring and drug delivery system and method of use.

Kaufman, D., L. Sauve, L. Renaud, and E. Duplaa
2014. Cognitive Benefits of Digital Games for Older Adults.

Keel, J. C., M. J. Smith, and E. M. Wassermann
2011. A safety screening questionnaire for transcranial magnetic stimulation. *Clinical Neurophysiology*.

Keitel, A., S. Ferrea, M. Sudmeyer, A. Schnitzler, and L. Wojtecki
2013. Expectation modulates the effect of deep brain stimulation on motor and cognitive function in tremor-dominant Parkinson's disease. *Plos One*, 8(12):e81878.

Kelly, M. E., D. Loughrey, B. A. Lawlor, I. H. Robertson, C. Walsh, and S. Brennan
2014. The impact of cognitive training and mental stimulation on cognitive and everyday functioning of healthy older adults: a systematic review and meta-analysis. *Ageing Res Rev*, 15:28–43.

Kessler, S. K., P. E. Turkeltaub, J. G. Benson, and R. H. Hamilton
2012. Differences in the experience of active and sham transcranial direct current stimulation. *Brain Stimulation*.

Kim, S. and L. S. Feldt
2010. The estimation of the IRT reliability coefficient and its lower and upper bounds, with comparisons to CTT reliability statistics. *Asia Pacific Education Review*.

Kincses, T. Z., A. Antal, M. A. Nitsche, O. Bartfai, and W. Paulus
2004. Facilitation of probabilistic classification learning by transcranial direct current stimulation of the prefrontal cortex in the human. *Neuropsychologia*, 42(1):113–117.

Klingberg, T.
2010. Training and plasticity of working memory. *Trends in Cognitive Sciences*, 14(7):317–324.

Klingberg, T., E. Fernell, P. J. Olesen, M. Johnson, P. Gustafsson, K. Dahlstrom, C. G. Gillberg, H. Forssberg, and H. Westerberg
2005. Computerized training of working memory in children with ADHD - A randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry*, 44(2):177–186.

Klingberg, T., H. Forssberg, and H. Westerberg
2002. Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology*, 24(6):781–791.

Kochhar, R.
2014. 10 projections for the global population in 2050.

Koroshetz, W. J.
2015. Noninvasive Brain Stimulation: Applications and Implications.

Kortte, K. B., M. D. Horner, and W. K. Windham
2002. The trail making test, part B: cognitive flexibility or ability to maintain set? *Applied Neuropsychology*, 9(2):106–109.

Kramer, A. F., K. I. Erickson, and S. J. Colcombe
2006. Exercise, cognition, and the aging brain. *J Appl Physiol*, 101:1237–1242.

Kroenke, K., R. L. Spitzer, and J. B. W. Williams
2001. The PHQ-9 - Validity of a brief depression severity measure. *Journal of General Internal Medicine*, 16(9):606–613.

Krueger, K. R., R. S. Wilson, J. M. Kamenetsky, L. L. Barnes, J. L. Bienias, and D. A. Bennett
2009. Social engagement and cognitive function in old age. *Experimental Aging Research*.

Kueider, A. M., J. M. Parisi, A. L. Gross, and G. W. Rebok
2012. Computerized cognitive training with older adults: a systematic review. *Plos One*, 7(7):e40588.

Küper, K., P. D. Gajewski, C. Frieg, M. Falkenstein, L. Bherer, T. Strobach, and B. Kopp
2017. A Randomized Controlled ERP Study on the Effects of Multi-Domain Cognitive Training and Task Difficulty on Task Switching Performance in Older Adults.

Kvedar, J., M. J. Coye, and W. Everett
2014. Connected health: A review of technologies and strategies to improve patient care with telemedicine and telehealth. *Health Affairs*.

Lamar, M., S. M. Resnick, and A. B. Zonderman
2003. Longitudinal changes in verbal memory in older adults - Distinguishing the effects of age from repeat testing. *Neurology*, 60(1):82–86.

Lampit, A., H. Hallock, and M. Valenzuela
2014. Computerized cognitive training in cognitively healthy older adults: a systematic review and meta-analysis of effect modifiers. *Plos Medicine*, 11(11):e1001756.

Lansing, A. E., R. J. Ivnik, M. Clinic, C. M. Cullum, and C. Randolph
1999. An Empirically Derived Short Form of the Boston Naming Test. *Archives of Clinical Neuropsychology*, 14(6):481–487.

Legault, I. and J. Faubert
2012. Perceptual-cognitive training improves biological motion perception: evidence for transferability of training in healthy aging. *Neuroreport*, 23(8):469–473.

Levine, B., A. Bacopulos, N. D. Anderson, S. E. Black, P. S. Davidson, S. A. Fitneva, M. McAndrews, J. Spaniol, N. Jeyakumar, H. Abdi, D. Beaton, A. M. Owen, and A. Hampshire
2013. Validation of a Novel Computerized Test Battery for Automated Testing. *Stroke*, 44(12):E196–E196.

Lewinsohn, P. M., J. R. Seeley, R. E. Roberts, and N. B. Allen
1997. Center for epidemiologic studies depression scale (CES-D) as a screening instrument for depression among community-residing older adults. *Psychology and aging*, 12(2):277–287.

Lezak, M. D., D. B. Howieson, E. D. Bigler, and D. Tranel
2012. *Neuropsychological Assessment*, 5 edition. Oxford University Press.

Li, B., X. Y. Zhu, J. H. Hou, T. J. Chen, P. Y. Wang, and J. Li
2016. Combined Cognitive Training vs. Memory Strategy Training in Healthy Older Adults. *Frontiers in Psychology*, 7.

Li, L. M., K. Uehara, and T. Hanakawa
2015. The contribution of interindividual factors to variability of response in transcranial direct current stimulation studies. *Frontiers in Cellular Neuroscience*, 9.

Long Lasting Memories Project
2009. Long Lastin Memories: Mind and Body Fitness for Life.

López-Alonso, V., M. Fernández-del Olmo, A. Costantini, J. J. Gonzalez-Henriquez, and B. Cheeran
2015. Intra-individual variability in the response to anodal transcranial direct current stimulation. *Clinical Neurophysiology*.

Lopez-Alonso, V., S. L. Liew, M. F. del Olmo, B. Cheeran, M. Sandrini, M. Abe, and L. G. Cohen
2018. A preliminary comparison of motor learning across different non-invasive brain stimulation paradigms shows no consistent modulations. *Frontiers in Neuroscience*.

López-Higes, R., M. T. Martín-Aragoneses, S. Rubio-Valdehita, M. L. Delgado-Losada, P. Montejo, M. Montenegro, J. M. Prados, J. de Frutos-Lucas, and D. López-Sanz
2018. Efficacy of cognitive training in older adults with and without subjective cognitive decline is associated with inhibition efficiency and working memory span, not with cognitive reserve. *Frontiers in Aging Neuroscience*.

Lumos Labs Inc.
2013. Lumosity Grows 150 Percent in the Past Year Reaching Over 35 Million Members Worldwide: Mobile and International Expansion Planned in 2013.

Lumos Labs Inc.
2017. Lumosity.

Lussier, M., A. Bugaiska, and L. Bherer
2017. Specific transfer effects following variable priority dual-task training in older adults. *Restorative Neurology and Neuroscience*.

Maclin, E. L., K. E. Mathewson, K. A. Low, W. R. Boot, A. F. Kramer, M. Fabiani, and G. Gratton
2011. Learning to multitask: Effects of video game practice on electrophysiological indices of attention and resource allocation. *Psychophysiology*, 48(9):1173–1183.

Maher, B.
2008. Poll results: look who's doping. *Nature*, 452(7188):674–675.

Malek-Ahmadi, M., A. Raj, and B. J. Small
2011. Semantic clustering as a neuropsychological predictor for amnestic-MCI. *Aging, Neuropsychology, and Cognition*.

Marcum, Z. A. and E. P. Peron
2012. Medication Use in Older Adults . In *The Epidemiology of Aging*, A. B. Newman and H. A. Cauley, eds., Pp. 317–326. Springer.

Martin, D. M., R. Liu, A. Alonzo, M. Green, and C. K. Loo
2014. Use of transcranial direct current stimulation (tDCS) to enhance cognitive training: effect of timing of stimulation. *Experimental Brain Research*.

Martin M, Clare L, A. Am, C. Mh, and F. Zehnder
2011. Cognition-based interventions for healthy older people and people with mild cognitive impairment (Review). *Cochrane Database of Systematic Reviews*, (1).

Matsumoto, H. and Y. Ugawa
2017. Adverse events of tDCS and tACS: A review. *Clinical Neurophysiology Practice*.

Mayas, J., F. B. R. Parmentier, P. Andres, and S. Ballesteros
2014. Plasticity of Attentional Functions in Older Adults after Non-Action Video Game Training: A Randomized Controlled Trial. *Plos One*, 9(3).

Mccabe, D. P., H. L. Roediger Iii, M. A. Mcdaniel, D. A. Balota, and D. Z. Hambrick
2010. The Relationship Between Working Memory Capacity and Executive Functioning: Evidence for a Common Executive Attention Construct. *Neuropsychology*, 24(2):222–243.

McCabe, J. A., T. S. Redick, and R. W. Engle
2016. Brain-Training Pessimism, but Applied-Memory Optimism. *Psychol Sci Public Interest*, 17(3):187–191.

McCambridge, J., J. Witton, and D. R. Elbourne
2014. Systematic review of the Hawthorne effect: New concepts are needed to study research participation effects. *Journal of Clinical Epidemiology*, 67(3):267–277.

Meade, A. W. and G. J. Lautenschlager
2004. A comparison of item response theory and confirmatory factor analytic methodologies for establishing measurement equivalence/invariance. *Organizational Research Methods*, 7(4):361–388.

Medina, J. and S. Cason
2017. No evidential value in samples of transcranial direct current stimulation (tDCS) studies of cognition and working memory in healthy populations. *Cortex*, 94:131–141.

Melby-Lervag, M., T. S. Redick, and C. Hulme
2016. Working Memory Training Does Not Improve Performance on Measures of Intelligence or Other Measures of "Far Transfer": Evidence From a Meta-Analytic Review. *Perspectives on Psychological Science*, 11(4):512–534.

Mercado, R., C. Constantoyannis, T. Mandat, A. Kumar, M. Schulzer, A. J. Stoessl, and C. R. Honey
2006. Expectation and the placebo effect in Parkinson's disease patients with subthalamic nucleus deep brain stimulation. *Movement Disorders*, 21(9):1457–1461.

Merriam, S. B. and Y. Kee
2014. Promoting Community Wellbeing: The Case for Lifelong Learning for Older Adults. *Adult Education Quarterly*, 64(2):128–144.

Merzenich, M. M., W. M. Jenkins, P. Johnston, C. Schreiner, S. L. Miller, and P. Tallal
1996. Temporal processing deficits of language-learning impaired children ameliorated by training. *Science*, 271(5245):77–81.

Microsoft Corporation
2013. SenseCam.

Miller, G.
2014. Is This Mind-Controlled Exoskeleton Science or Spectacle? *Wired*.

Miniussi, C., J. A. Harris, and M. Ruzzoli
2013. Modelling non-invasive brain stimulation in cognitive neuroscience. *Neuroscience and Biobehavioral Reviews*, 37(8):1702–1712.

Mitroff, S. R., A. T. Biggs, S. H. Adamo, E. W. Dowd, J. Winkle, and K. Clark
2014. What Can 1 Billion Trials Tell Us About Visual Search? *Journal of Experimental Psychology: Human Perception and Performance*, Advance on.

Moreau, D., I. J. Kirk, and K. E. Waldie
2016. Seven Pervasive Statistical Flaws in Cognitive Training Interventions. *Frontiers in Human Neuroscience*, 10:153.

Morimoto, S. S., F. M. Gunning, B. E. Wexler, W. Hu, I. Ilieva, J. Liu, J. Nitis, and G. S. Alexopoulos
2016. Executive Dysfunction Predicts Treatment Response to Neuroplasticity-Based Computerized Cognitive Remediation (nCCR-GD) in Elderly Patients with Major Depression. *The American Journal of Geriatric Psychiatry*, 24:816–820.

Morimoto, S. S., B. E. Wexler, J. C. Liu, W. L. Hu, J. Seirup, and G. S. Alexopoulos
2014. Neuroplasticity-based computerized cognitive remediation for treatment-resistant geriatric depression. *Nature Communications*, 5.

Morrison, A. B. and J. M. Chein
2011. Does working memory training work? The promise and challenges of enhancing cognition by training working memory. *Psychonomic Bulletin & Review*, 18(1):46–60.

Motter, J. N., D. P. Devanand, P. M. Doraiswamy, and J. R. Sneed
2016. Clinical Trials to Gain FDA Approval for Computerized Cognitive Training: What Is the Ideal Control Condition? *Frontiers in Aging Neuroscience*, 8.

Mowszowski, L., A. Lampit, C. C. Walton, and S. L. Naismith
2016. Strategy-Based Cognitive Training for Improving Executive Functions in Older Adults: a Systematic Review. *Neuropsychol Rev*, 26(3):252–270.

Murray, M. D. and C. M. Callahan
2003. Improving medication use for older adults: An integrated research agenda. *Annals of Internal Medicine*, 139(5):425–429.

Myhre, J. W. and E. L. Glisky
2013. *Effects of online social networking on the cognitive, social, and emotional health of older adults*. PhD thesis.

Myhre, J. W., M. R. Mehl, and E. L. Glisky
2016. Cognitive Benefits of Online Social Networking for Healthy Older Adults. *J Gerontol B Psychol Sci Soc Sci*.

Mynatt, E. D.
2001. Developing Technology to Support the Functional Independence of Older Adults . *Ageing International*, 27(1):24–41.

Nasreddine, Z. S., H. Chertkow, N. Phillips, V. Whitehead, I. Collin, and J. L. Cummings
2004. The Montreal Cognitive Assessment (MoCA): a brief cognitive screening tool for detection of Mild Cognitive Impairment. *Neurology*, 62(7):A132–A132.

National Academies of Sciences, E., Medicine, Health and Medicine Division, Board on Health Sciences Policy, and Committee on Preventing Dementia and Cognitive Impairment
2017. *Preventing Cognitive Decline and Dementia: A Way Forward*. Washington, DC: The National Academies Press.

Nebes, R. D., D. J. Buysse, E. M. Halligan, P. R. Houck, and T. H. Monk
2009. Self-Reported Sleep Quality Predicts Poor Cognitive Performance in Healthy Older Adults. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences*, 64(2):180–187.

Nilsson, J., A. V. Lebedev, A. Rydström, and M. Lövdén
2017. Direct-Current Stimulation Does Little to Improve the Outcome of Working Memory Training in Older Adults. *Psychological Science*.

Nintendo DS
2017. Brain Age: Concentration Training.

Nitsche, M. A., L. G. Cohen, E. M. Wassermann, A. Priori, N. Lang, A. Antal, W. Paulus, F. Hummel, P. S. Boggio, F. Fregni, and A. Pascual-Leone
2008. Transcranial direct current stimulation: State of the art 2008. *Brain Stimulation*, 1(3):206–223.

Northey, J. M., N. Cherbuin, K. L. Pumpa, D. J. Smee, and B. Rattray
2018. Exercise interventions for cognitive function in adults older than 50: a systematic review with meta-analysis. *British journal of sports medicine*.

Nosek, B. A., M. R. Banaji, and A. G. Greenwald
2002. E-research: Ethics, security, design, and control in psychological research on the Internet. *Journal of Social Issues*, 58(1):161–176.

Nyberg, L., M. Lovden, K. Riklund, U. Lindenberger, and L. Backman
2012. Memory aging and brain maintenance. *Trends in Cognitive Sciences*, 16(5):292–305.

Nyhan, B., J. Reifler, S. Richey, and G. L. Freed
2014. Effective messages in vaccine promotion: a randomized trial. *Pediatrics*, 133(4):835–42.

Office for National Statistics
2014. Internet Access – Households and Individuals 2014. Technical report, Newport, Wales.

Oldfield, R. C.
1971. The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*.

Owen, A. M., A. Hampshire, J. A. Grahn, R. Stenton, S. Dajani, A. S. Burns, R. J. Howard, and C. G. Ballard
2010. Putting brain training to the test. *Nature*, 465(7299):775–U6.

Owsley, C.
2011. Aging and vision. *Vision Research*, 51(13):1610–1622.

Parikh, P. J. and K. J. Cole
2014. Effects of transcranial direct current stimulation in combination with motor practice on dexterous grasping and manipulation in healthy older adults. *Physiological Reports*.

Park, D. and A. Gutchess
2006. The Cognitive Neuroscience of Aging and Culture. *Current Directions in Psychological Science*, 15(3):105–108.

Parkin, B. L., M. Bhandari, J. C. Glen, and V. Walsh
2018. The Physiological Effects of Transcranial Electrical Stimulation in Studies of Cognitive Neuromodulation. *Neuropsychologia*.

Parsey, C. M. and M. Schmitter-Edgecombe
2013. Applications of Technology in Neuropsychological Assessment. *Clinical Neuropsychologist*, 27(8):1328–1361.

Partridge, B. J., S. K. Bell, J. C. Lucke, S. Yeates, and W. D. Hall
2011. Smart Drugs "As Common As Coffee": Media Hype about Neuroenhancement. *Plos One*, 6(11).

Payesko, J.
2017. Akili Achieves Primary Efficacy Endpoint in ADHD Trial. *MD Magazine*.

Peira, N., G. Pourtois, and M. Fredrikson
2013. Learned cardiac control with heart rate biofeedback transfers to emotional reactions. *Plos One*, 8(7):e70004.

Penolazzi, B., M. Pastore, and S. Mondini
2013. Electrode montage dependent effects of transcranial direct current stimulation on semantic fluency. *Behavioural Brain Research*, 248:129–135.

Pew, R. W. and S. B. V. Hemel
2004. Technology for Adaptive Aging.

Pixa, N. H., F. Steinberg, and M. Doppelmayr
2017. High-definition transcranial direct current stimulation to both primary motor cortices improves unimanual and bimanual dexterity. *Neuroscience Letters*.

Portugal, A. M., D. S. Ferreira, J. S. Reis, F. Pinho, and N. S. Dias
2013. Cognitive Intervention Protocol for Age-Related Memory Impairments. *2013 Ieee 2nd International Conference on Serious Games and Applications for Health (Segah)*.

Posit Science
2015. InSight.

Price, A. R. and R. H. Hamilton
2015. A re-evaluation of the cognitive effects from single-session transcranial direct current stimulation. *Brain Stimulation*, 8(4):655–683.

Prince, M., M. Guerchet, G.-C. Ali, Y.-T. Wu, and M. Prina
2015. World Alzheimer Report 2015: The Global Economic Impact of Dementia. Technical report.

Prinsloo, G. E., H. G. L. Rauch, and W. E. Derman
2014. A Brief Review and Clinical Application of Heart Rate Variability Biofeedback in Sports, Exercise, and Rehabilitation Medicine. *Physician and Sportsmedicine*, 42(2):88–99.

Rabbitt, P. M. A.
1993. Crystal quest: A search for the maintenance of practised skills into old age. In *Attention, Selection Awareness and Control. A tribute to Donald Broadbent.*, A. D. Baddeley and L. Weiskrantz, eds., Pp. 188–230. Oxford: Clarendon Press, OUP.

Rabipour, S., R. Andringa, W. R. Boot, and P. S. R. Davidson
2017a. What Do People Expect of Cognitive Enhancement? *Journal of Cognitive Enhancement*, 2(1):70–77.

Rabipour, S. and P. S. Davidson
2015. Do you believe in brain training? A questionnaire about expectations of computerised cognitive training. *Behavioural Brain Research*, 295:64–70.

Rabipour, S., P. S. R. Davidson, and E. Kristjansson
2018a. Measuring Expectations of Cognitive Enhancement: Item Response Analysis of the Expectation Assessment Scale. *Journal of Cognitive Enhancement*.

Rabipour, S., D. Miller, V. Taler, C. Messier, and P. Davidson
2017b. Physical and Cognitive Exercise in Ageing. In *Handbook of Gerontology Research Methods: Understanding successful aging*.

Rabipour, S. and A. Raz
2012. Training the brain: Fact and fad in cognitive and behavioral remediation. *Brain and Cognition*, 79(2):159–179.

Rabipour, S., A. D. Wu, P. S. R. Davidson, M. Iacoboni, S. R. Vanier, H. #3040, and J.-J. Lussier
2018b. Expectations May Influence the Effects of Transcranial Direct Current Stimulation.

Reardon, S.
2015. Memory-boosting devices tested in humans. *Nature*, 527:15–16.

Rebok, G. W., K. Ball, L. T. Guey, R. N. Jones, H. Y. Kim, J. W. King, M. Marsiske, J. N. Morris, S. L. Tennstedt, F. W. Unverzagt, and S. L. Willis
2014. Ten-year effects of the advanced cognitive training for independent and vital elderly cognitive training trial on cognition and everyday functioning in older adults. *Journal of the American Geriatrics Society*.

Reid, L. M. and A. M. J. Maclullich
2006. Subjective Memory Complaints and Cognitive Impairment in Older People. *Dementia and Geriatric Cognitive Disorders*, 22(5-6):471–85.

Reijnders, J., C. van Heugten, and M. van Boxtel
2013. Cognitive interventions in healthy older adults and people with mild cognitive impairment: A systematic review. *Ageing Res Rev*, 12(1):263–275.

Reuter-Lorenz, P. A., S. B. Festini, and T. K. Jantz
2015. Executive Functions and Neurocognitive Aging. In *Handbook of the Psychology of Aging*, chapter 13, Pp. 245–262.

Rhodes, M. G.
2004. Age-Related Differences in Performance on the Wisconsin Card Sorting Test: A Meta-Analytic Review. *Psychology and Aging*, 19(3):482–494.

Rief, W., Y. Nestoriuc, S. Weiss, E. Welzel, A. J. Barsky, and S. G. Hofmann
2009. Meta-analysis of the placebo response in antidepressant trials. *Journal of Affective Disorders*, 118(1-3):1–8.

Rohsenow, D. J. and G. A. Marlatt
1981. The Balanced Placebo Design - Methodological Considerations. *Addictive Behaviors*, 6(2):107–122.

Ross, L. A., S. A. Freed, J. D. Edwards, C. B. Phillips, and K. Ball
2017. The Impact of Three Cognitive Training Programs on Driving Cessation Across 10 Years: A Randomized Controlled Trial. *Gerontologist*.

Rueda, M. R., M. K. Rothbart, B. D. McCandliss, L. Saccomanno, and M. I. Posner
2005. Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences of the United States of America*, 102(41):14931–14936.

Rumpf, J. J., M. Wegscheider, K. Hinselmann, C. Fricke, B. R. King, D. Weise, J. Klann, F. Binkofski, G. Buccino, A. Karni, J. Doyon, and J. Classen
2017. Enhancement of motor consolidation by post-training transcranial direct current stimulation in older people. *Neurobiology of Aging*.

Rutherford, B. R., T. D. Wager, and S. P. Roose
2010. Expectancy and the Treatment of Depression: A Review of Experimental Methodology and Effects on Patient Outcome. *Curr Psychiatry Rev*, 6(1):1–10.

Ruths, D. and J. Pfeffer
2014. Social sciences. Social media for large studies of behavior. *Science*, 346(6213):1063–1064.

Sahakian, B. and S. Morein-Zamir
2007. Professor's little helper. *Nature*, 450(7173):1157–1159.

Salthouse, T. A.
2010. Selective review of cognitive aging. *Journal of the International Neuropsychological Society*, 16(5):754–760.

Salthouse, T. A.
2014. Correlates of Cognitive Change. *Journal of Experimental Psychology-General*, 143(3):1026–1048.

Samejima, F.
1997. Graded Response Model. In *Handbook of Modern Item Response Theory*, W. J. v. d. Linden and R. K. Hambleton, eds., Pp. 85–100. Springer International Publishing AG.

Sandrini, M., M. Brambilla, R. Manenti, S. Rosini, L. G. Cohen, and M. Cotelli
2014. Noninvasive stimulation of prefrontal cortex strengthens existing episodic memories and reduces forgetting in the elderly. *Frontiers in Aging Neuroscience*.

Savic, B. and B. Meier
2016. How Transcranial Direct Current Stimulation Can Modulate Implicit Motor Sequence Learning and Consolidation: A Brief Review. *Frontiers in Human Neuroscience*.

Schambra, H. M., M. Bikson, T. D. Wager, M. F. Dossantos, and A. F. Dasilva
2014. It's all in your head: Reinforcing the placebo response with tDCS.

Schmiedek, F., M. Lovden, and U. Lindenberger
2010. Hundred Days of Cognitive Training Enhance Broad Cognitive Abilities in Adulthood: Findings from the COGITO Study. *Front Aging Neurosci*, 2.

Schneider, L. S., P. N. Tariot, K. S. Dagerman, S. M. Davis, J. K. Hsiao, M. S. Ismail, B. D. Lebowitz, C. G. Lyketsos, J. M. Ryan, T. S. Stroup, D. L. Sultzer, D. Weintraub, and J. A. Lieberman
2006. Effectiveness of atypical antipsychotic drugs in patients with Alzheimer's disease. *New England Journal of Medicine*, 355(15):1525–1538.

Schulke, D. F.
2013. The Regulatory Arms Race: Mobile-Health Applications and Agency Posturing. *Boston University Law Review*, 93(5):1699–1752.

Schwarz, K. A., R. Pfister, and C. Buchel
2016. Rethinking Explicit Expectations: Connecting Placebos, Social Cognition, and Contextual Perception. *Trends in Cognitive Sciences*, 20(6):469–480.

Schwarz, S., L. Froelich, and A. Burns
2012. Pharmacological treatment of dementia. *Current Opinion in Psychiatry*, 25(6):542–550.

Seamon, J. G., T. N. Moskowitz, A. E. Swan, B. Zhong, A. Golembeski, C. Liong, A. C. Narzikul, and O. A. Sosan
2014. SenseCam reminiscence and action recall in memory-unimpaired people. *Memory*, 22(7):861–866.

Shah, T. M., M. Weinborn, G. Verdile, H. R. Sohrabi, and R. N. Martins
2017. Enhancing Cognitive Functioning in Healthly Older Adults: a Systematic Review of the Clinical Significance of Commercially Available Computerized Cognitive Training in Preventing Cognitive Decline.

SharpBrains
2013. Executive Summary: Infographic on the Digital Brain Health Market 2012–2020. Technical report.

SharpBrains
2014. Brain Training and Cognitive Assessment Market Surpassed $1.3 Billion In 2013.

SharpBrains
2016. The Digital Brain Health Market 2012-2020: Web-based, mobile and biometrics-based technology to assess, monitor and enhance cognition and brain functioning. Technical report.

Shatil, E.
2013. Does combined cognitive training and physical activity training enhance cognitive abilities more than either alone? A four-condition randomized controlled trial among healthy older adults. *Frontiers in Aging Neuroscience*.

Shimamura, A. P., J. M. Berry, J. A. Mangels, C. L. Rusting, and P. J. Jurica
1995. Memory and Cognitive-Abilities in University Professors - Evidence for Successful Aging. *Psychological Science*, 6(5):271–277.

Shipstead, Z., T. S. Redick, and R. W. Engle
2012. Is Working Memory Training Effective? *Psychological Bulletin*, 138(4):628–654.

Shu, L. and R. D. Schwarz
2014. IRT-estimated reliability for tests containing mixed item formats. *Journal of Educational Measurement*.

Siddarth, P., A. C. Burggren, H. A. Eyre, G. W. Small, and D. A. Merrill
2018. Sedentary behavior associated with reduced medial temporal lobe thickness in middle- aged and older adults. *Plos One*.

Simons, D.
2013. 19 questions about video games, multitasking, and aging (a HI-BAR commentary on a new Nature paper).

Simons, D. J., W. R. Boot, N. Charness, S. E. Gathercole, C. F. Chabris, D. Z. Hambrick, and E. A. L. Stine-Morrow
2016. Do "Brain-Training" Programs Work? *Psychological Science in the Public Interest*, 17(3):103–186.

Skidmore, E. R., M. B. Holm, E. M. Whyte, M. A. Dew, D. Dawson, and J. T. Becker
2011. The feasibility of meta-cognitive strategy training in acute inpatient stroke rehabilitation: Case report. *Neuropsychological Rehabilitation*, 21(2):208–223.

Small, G. W., T. D. Moody, P. Siddarth, and S. Y. Bookheimer
2009. Your Brain on Google: Patterns of Cerebral Activation during Internet Searching. *American Journal of Geriatric Psychiatry*, 17(2):116–126.

Smith, G. E., P. Housen, K. Yaffe, R. Ruff, R. F. Kennison, H. W. Mahncke, and E. M. Zelinski
2009. A Cognitive Training Program Based on Principles of Brain Plasticity: Results from the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) Study. *Journal of the American Geriatrics Society*, 57(4):594–603.

Snap Inc.
2016. Snap Inc.

Souders, D. J., W. R. Boot, K. Blocker, T. Vitale, N. A. Roque, and N. Charness
2017. Evidence for Narrow Transfer after Short-Term Cognitive Training in Older Adults. *Frontiers in Aging Neuroscience*, 9.

Sparrow, B., J. Liu, and D. M. Wegner
2011. Google Effects on Memory: Cognitive Consequences of Having Information at Our Fingertips. *Science*, 333(6043):776–778.

Spieler, D. H., D. A. Balota, and M. E. Faust
1996. Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. *Journal of Experimental Psychology-Human Perception and Performance*, 22(2):461–479.

Spira, A. P., L. P. Chen-Edinboro, M. N. Wu, and K. Yaffe
2014. Impact of sleep on the risk of cognitive decline and dementia.

Squires, J. E., L. Hayduk, A. M. Hutchinson, L. A. Cranley, M. Gierl, G. G. Cummings, P. G. Norton, and C. A. Estabrooks
2013. A protocol for advanced psychometric assessment of surveys. *Nurs Res Pract*, 2013:156782.

Statistics, O. f. N.
2013. Internet Access - Households and Individuals, 2013.

Statistics Canada
2014. Online activities of Canadian boomers and seniors.

Steenbergen, L., R. Sellaro, B. Hommel, U. Lindenberger, S. Kuhn, and L. S. Colzato
2016. "Unfocus" on foc.us: commercial tDCS headset impairs working memory. *Experimental Brain Research*, 234(3):637–643.

Stephan, Y., A. R. Sutin, J. Caudroit, and A. Terracciano
2016. Subjective age and changes in memory in older adults. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*.

Stern, Y.
2002. What is cognitive reserve? Theory and research application of the reserve concept. *J Int Neuropsychol Soc*, 8(3):448–460.

Stewart-Williams, S. and J. Podd
2004. The Placebo Effect: Dissolving the Expectancy Versus Conditioning Debate.

Storm, B. C. and S. M. Stone
2014. Saving-Enhanced Memory: The Benefits of Saving on the Learning and Remembering of New Information. *Psychological Science*.

Stricker, J. L., G. G. Brown, J. Wixted, J. V. Baldo, and D. C. Delis
2002. New semantic and serial clustering indices for the California Verbal Learning Test-Second edition: Background, rationale, and formulae. *Journal of the International Neuropsychological Society*.

Stroop, J. R.
1935. Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18:643–662.

Styliadis, C., P. Kartsidis, E. Paraskevopoulos, A. A. Ioannides, and P. D. Bamidis
2015. Neuroplastic effects of combined computerized physical and cognitive training in elderly individuals at risk for dementia: An eLORETA controlled study on resting states. *Neural Plasticity*.

Summers, J. J., N. Kang, and J. H. Cauraugh
2016. Does transcranial direct current stimulation enhance cognitive and motor functions in the ageing brain? A systematic review and meta- analysis.

Tang, Y. Y., Q. L. Lu, X. J. Geng, E. A. Stein, Y. H. Yang, and M. I. Posner
2010. Short-term meditation induces white matter changes in the anterior cingulate. *Proceedings of the National Academy of Sciences of the United States of America*, 107(35):15649–15652.

The Stanford Center on Longevity
2014. A Consensus on the Brain Training Industry from the Scientific Community.

Thibault, R. T., M. Lifshitz, and A. Raz
2016. The self-regulating brain and neurofeedback: Experimental science and clinical promise. *Cortex*, 74:247–261.

Thibault, R. T. and A. Raz
2016. When can neurofeedback join the clinical armamentarium? *The Lancet Psychiatry*, 3(6):497–498.

Thompson, T. W., M. L. Waskom, K. L. Garel, C. Cardenas-Iniguez, G. O. Reynolds, R. Winter, P. Chang, K. Pollard, N. Lala, G. A. Alvarez, and J. D. Gabrieli
2013. Failure of working memory training to enhance cognition or intelligence. *Plos One*, 8(5):e63614.

Thync
2017. Thync.

Toepper, M.
2017. Dissociating Normal Aging from Alzheimer's Disease: A View from Cognitive Neuroscience. *Journal of Alzheimer's Disease*.

Toril, P., J. M. Reales, and S. Ballesteros
2014. Video Game Training Enhances Cognition of Older Adults: A Meta-Analytic Study. *Psychology and aging*, 29(3):706–716.

Torous, J., P. Staples, E. Fenstermacher, J. Dean, and M. Keshavan
2016. Barriers, Benefits, and Beliefs of Brain Training Smartphone Apps: An Internet Survey of Younger US Consumers. *Frontiers in Human Neuroscience*, 10:180.

Troyer, A. K. and J. B. Rich
2002. Psychometric properties of a new metamemory questionnaire for older adults. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences*, 57(1):P19–P27.

Troyer, A. K. and J. B. Rich
2018. *Professional Manual Multifactorial Memory Questionnaire*. Toronto, ON: Baycrest Centre for Geriatric Care.

Tun, P. A. and M. E. Lachman
2010. The Association Between Computer Use and Cognition Across Adulthood: Use It So You Won't Lose It? *Psychology and aging*, 25(3):560–568.

Tusch, E. S., B. R. Alperin, E. Ryan, P. J. Holcomb, A. H. Mohammed, and K. R. Daffner
2016. Changes in Neural Activity Underlying Working Memory after Computerized Cognitive Training in Older Adults. *Frontiers in Aging Neuroscience*, 8.

Underwood, E.
2016. Cadaver study casts doubts on how zapping brain may boost mood, relieve pain.

van den Hoven, E.
2014. A future-proof past: Designing for remembering experiences. *Memory Studies*, 7(3):370–384.

van der Schaar, P. J., J. F. Dijksman, H. Broekhuizen-de Gast, J. Shimizu, N. van Lelyveld, H. Zou, V. Iordanov, C. Wanke, and P. D. Siersema
2013. A novel ingestible electronic drug delivery and monitoring device. *Gastrointestinal Endoscopy*, 78(3):520–528.

Vasylenko, O., M. M. Gorecka, and C. Rodríguez-Aranda
2018. Manual dexterity in young and healthy older adults. 2. Association with cognitive abilities. *Developmental Psychobiology*, Pp. 1–12.

Venkatesh, G.
2014. Brain wave.

Vitality Inc.
2014. Vitality: Products.

Volpp, K. G., A. B. Troxel, S. J. Mehta, L. Norton, J. S. Zhu, R. Lim, W. L. Wang, N. Marcus, C. Terwiesch, K. Caldarella, T. Levin, M. Relish, N. Negin, A. Smith-McLallen, R. Snyder, C. M. Spettell, B. Drachman, D. Kolansky, and D. A. Asch
2017. Effect of Electronic Reminders, Financial Incentives, and Social Support on Outcomes After Myocardial Infarction The HeartStrong Randomized Clinical Trial. *Jama Internal Medicine*, 177(8):1093–1101.

Vöröslakos, M., Y. Takeuchi, K. Brinyiczki, T. Zombori, A. Oliva, A. Fernández-Ruiz, G. Kozák, Z. T. Kincses, B. Iványi, G. Buzsáki, and A. Berényi
2018. Direct effects of transcranial electric stimulation on brain circuits in rats and humans. *Nature Communications*.

Wadley, V. G., R. L. Benz, K. K. Ball, D. L. Roenker, J. A. Edwards, and D. E. Vance
2006. Development and evaluation of home-based speed-of-processing training for older adults. *Archives of Physical Medicine and Rehabilitation*, 87(6):757–763.

Walhovd, K. B., S. K. Krogsrud, I. K. Amlien, H. Bartsch, A. Bjørnerud, P. Due-Tønnessen, H. Grydeland, D. J. Hagler, A. K. Håberg, W. S. Kremen, L. Ferschmann, L. Nyberg, M. S. Panizzon, D. A. Rohani, J. Skranes, A. B. Storsve, A. E. Sølsnes, C. K. Tamnes, W. K. Thompson, C. Reuter, A. M. Dale, and A. M. Fjell
2016. Neurodevelopmental origins of lifespan changes in brain and cognition. *Proceedings of the National Academy of Sciences*.

Walker, R. B., R. F. Evans, R. Hanson, and M. F. Burrow
1997. Medication delivery and monitoring system and methods.

Walsh, V. Q.
2013. Ethics and Social Risks in Brain Stimulation. *Brain Stimulation*, 6(5):715–717.

Walton, C. C., A. Kavanagh, L. A. Downey, J. Lomas, D. A. Camfield, and C. Stough
2015. Online cognitive training in healthy older adults: a preliminary study on the effects of single versus multi-domain training . *Translational Neuroscience*, 6:13–19.

Wampold, B. E. and Z. E. Imel
2007. The story of placebo effects in medicine: Evidence in context. *Journal of Clinical Psychology*, 63(4):379–390.

Wang, L., G. van Belle, P. K. Crane, W. A. Kukull, J. D. Bowen, W. C. McCormick, and E. B. Larson
2004. Subjective memory deterioration and future dementia in people aged 65 and older. *Journal of the American Geriatrics Society*, 52(12):2045–2051.

Ward, N., E. Paul, P. Watson, G. E. Cooke, C. H. Hillman, N. J. Cohen, A. F. Kramer, and A. K. Barbey
2017. Enhanced Learning through Multimodal Training: Evidence from a Comprehensive Cognitive, Physical Fitness, and Neuroscience Intervention. *Scientific Reports*.

Wernick, A.
2014. Your video games may revolutionize health and scientific research.

Wesnes, K. A.
2014. Moving beyond the pros and cons of automating cognitive testing in pathological aging and dementia: the case for equal opportunity. *Alzheimers Research & Therapy*, 6(5).

Wiethoff, S., M. Hamada, and J. C. Rothwell
2014. Variability in response to transcranial direct current stimulation of the motor cortex. *Brain Stimulation*.

Wild, K., D. Howieson, F. Webbe, A. Seelye, and J. Kaye
2008. Status of computerized cognitive testing in aging: a systematic review. *Alzheimers & Dementia*, 4(6):428–437.

Williams, L. M., K. J. Brown, D. Palmer, B. J. Liddell, A. H. Kemp, G. Olivieri, A. Peduto, and E. Gordon
2006. The mellow years?: Neural basis of improving emotional stability over age. *Journal of Neuroscience*, 26(24):6422–6430.

Wilms, I. L. and S. Nielsen
2014. Normative perceptual estimates for 91 healthy subjects age 60-75: impact of age, education, employment physical exercise, alcohol, and video gaming. *Frontiers in Psychology*, 5.

Wolinsky, F. D., F. W. Unverzagt, D. M. Smith, R. Jones, E. Wright, and S. L. Tennstedt
2006. The effects of the ACTIVE cognitive training trial on clinically relevant declines in health-related quality of life. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, 61(5):S281–S287.

Wolinsky, F. D., M. W. Vander Weg, M. B. Howren, M. P. Jones, and M. M. Dotson
2015. The Effect of Cognitive Speed of Processing Training on the Development of Additional IADL Difficulties and the Reduction of Depressive Symptoms: Results From the IHAMS Randomized Controlled Trial. *J Aging Health*, 27(2):334–354.

Wong, L. Y. X., S. J. Gray, and D. A. Gallo
2018. Does tDCS Over Prefrontal Cortex Improve Episodic Memory Retrieval? Potential Importance of Time of Day. *Cognitive Neuroscience*.

Woodberry, E., G. Browne, S. Hodges, P. Watson, N. Kapur, and K. Woodberry
2014. The use of a wearable camera improves autobiographical memory in patients with Alzheimer's disease. *Memory*.

Wurzman, R., R. H. Hamilton, A. Pascual-Leone, and M. D. Fox
2016. An Open Letter Concerning Do-It- Yourself Users of Transcranial Direct Current Stimulation. *Annals of Neurology*, 80(1):1–4.

Yamaguchi, S., H. Ayaz, S. Ballesteros, C. Voelcker-Rehage, and L. Bherer
2018. Editorial: Cognitive and Brain Plasticity Induced by Physical Exercise, Cognitive Training, Video Games, and Combined Interventions. 12.

Zanto, T. P. and A. Gazzaley
2014. Attention and Ageing. In *The Oxford Handbook of Attention*, chapter 32.

Zeidan, F., S. K. Johnson, N. S. Gordon, and P. Goolkasian
2010. Effects of Brief and Sham Mindfulness Meditation on Mood and Cardiovascular Variables. *The Journal of Alternative and Complementary Medicine*, 16(8):867–873.

Zelinski, E. M., L. M. Spina, K. Yaffe, R. Ruff, R. F. Kennison, H. W. Mahncke, and G. E. Smith
2011. Improvement in Memory with Plasticity-Based Adaptive Cognitive Training: Results of the 3-Month Follow-Up. *Journal of the American Geriatrics Society*, 59(2):258–265.

Zhao, H. C., L. Qiao, D. Q. Fan, S. Y. Zhang, O. Turel, Y. H. Li, J. Li, G. Xue, A. T. Chen, and Q. H. He
2017. Modulation of Brain Activity with Noninvasive Transcranial Direct Current Stimulation (tDCS): Clinical Applications and Safety Concerns. *Frontiers in Psychology*, 8.

Zickuhr, K. and M. Madden
2012. Older adults and internet use: For the first time, half of adults ages 65 and older are online. Technical report.

Appendix A

A.1 Computerized Cognitive Training Version of the Expectation Assessment Scale (EAS-CCT; full web version)

The following version of the EAS contains both the High and Low expectation priming messages. We used this version in our web-based studies, counterbalancing the order in which we presented the High and Low expectation messages, to probe expectations of computerized cognitive training in hypothetical scenarios. We used a condensed version of this scale, containing only the appropriate expectation priming message, in our cognitive training trial.

Welcome

What Are Your Perceptions on Cognitive Training? (I)
Welcome to the study on Neuropsychological Influences on Cognitive Training, conducted by the Neuropsychology Laboratory at the University of Ottawa. The following survey is part I of a large-scale study aiming to determine factors that improve cognitive function and psychological wellbeing in younger and older adults. We will ask you questions about your perceptions of cognitive training as well as a series of non-identifying background information. Before beginning the survey, please ensure that you have fully read and understood the information in the consent form below. Project Title: Neuropsychological Influences on Cognitive Training in Aging **Student Researcher:** Sheida Rabipour, MSc, doctoral student in Experimental Psychology, School of Psychology, University of Ottawa **Principal Investigator:** Patrick Davidson PhD, Assistant Professor, School of Psychology, University of Ottawa **PURPOSE OF THE STUDY**: The purpose of this study is to evaluate the neural and behavioural effects of computerized cognitive training in younger and older adults. **INCLUSION/EXCLUSION CRITERIA:** To participate in this study, you must be in good health, over 18 years of age, with normal or corrected-to-normal vision and hearing. **STUDY PROCEDURES:** Your participation will require you to fill out the entirety of this survey. Personal identifying information will not be required of you. **POSSIBLE RISKS AND DISCOMFORTS:** You may experience some temporary fatigue or boredom during the survey, as it requires you to remain alert for a certain period of time. Please note, however, that duration of the survey should not exceed 30 minutes; participants are expected to complete it in less time. You do not have to worry about your performance, as this is not a competition or a test. We simply ask you to be honest and do your best. **RIGHTS AND CONFIDENTIALITY:** Your participation is strictly voluntary and you

maintain the right to withdraw from the study at any time. In case of voluntary withdrawal, you may ask that all the data concerning your participation to be destroyed. Your anonymity and confidentiality will be protected. We do not ask to provide any personal identifying information (e.g., your name), and access to the survey will be via a secured link that is password-protected, on an invite-only basis. The data will be kept for a period of five years after their publication.

POSSIBLE BENEFITS: Although we cannot guarantee that you will experience direct benefits from this study, your participation will provide valuable information that will help understand how computer-training programs affect brain function and health in adults. For participants recruited from the University of Ottawa ISPR, one credit will be given.

The information obtained from this study may be presented at scientific conferences or in scientific journals, but no personal identifiers will ever appear in any public document.

STATEMENT OF CONSENT

Neuropsychological Influences on Cognitive Training in Aging

By clicking "Next", I attest that I have read and understood the informed consent form, and consent voluntarily to participate in this study.

Please enter your current age, in years.

Baseline

Background information

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Cognitive training refers to activities that aim to improve a specific cognitive function by training within a specific timeframe (i.e., several weeks or months).

Computerized cognitive training refers to a set of tasks, often simple computer games, which use a particular cognitive function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

Based on your prior knowledge, how successful would you expect computerized cognitive training to be at improving your **cognitive function** (Note: disregard potential issues of practicality)?

1 - Completely unsuccessful: no change in brain activity or noticeable behaviour. Such a procedure would be a waste of time and resources.

2 - Fairly unsuccessful: possible changes in specific brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life. Such a procedure would be a waste of time and resources.

3 - Somewhat unsuccessful: possible changes in general brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life.

4 - I have absolutely no expectations.

5 - Somewhat successful: possible changes in specific brain activity and behaviour. Such a procedure would NOT be a waste of time or resources.

6 - Fairly successful: possible changes in general brain activity as well as noticeable behavioural changes.

7 - Completely successful: changes in general brain activity as well as noticeable changes in overall thought and behaviour that positively impact daily life. Such a procedure would be a good investment of time and resources.

Are you confident in your previous answer?

Yes

No

Background information

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.
Cognitive training refers to activities that aim to improve a specific cognitive function by training within a specific timeframe (i.e., several weeks or months).
Computerized cognitive training refers to a set of tasks, often simple computer games, which use a particular cognitive function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful would you expect a computerized cognitive training program to be at improving your **memory**?

1- Completely unsuccessful
2- Fairly unsuccessful
3- Somewhat unsuccessful
4 - I have absolutely no expectations
5 - Somewhat successful
6 - Fairly successful
7 - Completely successful

Are you confident in your previous answer?

Yes
No

Background information

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.
Cognitive training refers to activities that aim to improve a specific cognitive function by training within a specific timeframe (i.e., several weeks or months).
Computerized cognitive training refers to a set of tasks, often simple computer games, which use a particular cognitive function.

Read each question carefully and answer to the best of your ability. Please record the *first answer that comes to your mind.*

How successful would you expect a computerized cognitive training program to be at improving your **concentration** (i.e., raising how much you lose focus on a task)?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Background information

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Cognitive training refers to activities that aim to improve a specific cognitive function by training within a specific timeframe (i.e., several weeks or months).

Computerized cognitive training refers to a set of tasks, often simple computer games, which use a particular cognitive function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful would you expect a computerized cognitive training program to be at reducing your **distractibility** (i.e., lowering how much you lose focus on a task)?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Background information

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Cognitive training refers to activities that aim to improve a specific cognitive function by training within a specific timeframe (i.e., several weeks or months).

Computerized cognitive training refers to a set of tasks, often simple computer games, which use a particular cognitive function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful would you expect a computerized cognitive training program to be at improving your **reasoning ability** (i.e., how well you can weigh options when faced with a problem)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Background information

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Cognitive training refers to activities that aim to improve a specific cognitive function by training within a specific timeframe (i.e., several weeks or months).

Computerized cognitive training refers to a set of tasks, often simple computer games, which use a particular cognitive function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful would you expect a computerized cognitive training program to be at improving your **multi-tasking ability** (i.e., how well you can manage multiple tasks at the same time)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Background information

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Cognitive training refers to activities that aim to improve a specific cognitive function by training within a specific timeframe (i.e., several weeks or months).
Computerized cognitive training refers to a set of tasks, often simple computer games, which use a particular cognitive function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful would you expect a computerized cognitive training program to be at improving your **performance in everyday tasks** (e.g., driving, remembering important dates, managing finances, etc.)?

1 - Completely unsuccessful
2 - Fairly unsuccessful
3 - Somewhat unsuccessful
4 - I have absolutely no expectations
5 - Somewhat successful
6 - Fairly successful
7 - Completely successful

Are you confident in your previous answer?

Yes
No

H

Assume you are participating in a cognitive training program.
Consider the following information:
You are about to begin a cognitive training program designed by neuroscientists, based on work proven effective in scientific studies.
Research shows that this program can improve mental functions such as memory, concentration, learning, and reasoning. This is similar to the way physical exercise improves muscle tone and performance. Just like training your body, training your brain

can help you feel better.

The technology of the program adapts to your performance, creating training sessions that are optimal for your personal needs – just like a personal trainer at the gym. In other words, the levels of the program increase at a rate that challenges you according to your individual capacities and provides the benefits you hope to achieve with cognitive training.

This occurs through neuroplasticity, a process through which your brain changes itself in response to certain types of activity, including cognitive training. Research shows that cognitive training can produce real changes that last up to several years.

Below are examples of points made in scientific articles that support cognitive training (citations provided for your reference):

"Several studies indicate that attention training using computer based exercises can lead to improved attention in children and adults." Tang & Posner, *Trends in Cognitive Science*, 2010

"This study offers neural and behavioural evidence of generalized positive effects from video game training on cognitive control abilities of older adults." Anguera et al., *Nature*, 2013

"Older adults who underwent a brief course of brain exercises saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the course ended, according to results from the largest study ever on cognitive training." Steenhuysen, *Reuters*, 2014.

After reading this message, how successful would you expect cognitive training to be at improving your **cognitive function**?

1 - Completely unsuccessful: no change in brain activity or noticeable behaviour. Such a procedure would be a waste of time and resources.

2 - Fairly unsuccessful: possible changes in specific brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life. Such a procedure would be a waste of time and resources.

3 - Somewhat unsuccessful: possible changes in general brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life.

4 - I have absolutely no expectations.

5 - Somewhat successful: possible changes in specific brain activity and behaviour. Such a procedure would NOT be a waste of time or resources.

6 - Fairly successful: possible changes in general brain activity as well as noticeable behavioural changes.

7 - Completely successful: changes in general brain activity as well as noticeable changes in overall

thought and behaviour that positively impact daily life. Such a procedure would be a good investment of time and resources.

Are you confident in your previous answer?

Yes

No

Do you believe this message changed your initial expectations?

Yes

No

Below are examples of points made in scientific articles that support cognitive training (citations provided for your reference):
"Several studies indicate that attention training using computer based exercises can lead to improved attention in children and adults." Tang & Posner, Trends in Cognitive Science, 2010
"This study offers neural and behavioural evidence of generalized positive effects from video game training on cognitive control abilities of older adults." Anguera et al., Nature, 2013
"Older adults who underwent a brief course of brain exercises saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the course ended, according to results from the largest study ever on cognitive training." Steenhuysen, Reuters, 2014.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **memory**?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support cognitive training (citations provided for your reference):
“Several studies indicate that attention training using computer based exercises can lead to improved attention in children and adults.” Tang & Posner, Trends in Cognitive Science, 2010
“This study offers neural and behavioural evidence of generalized positive effects from video game training on cognitive control abilities of older adults.” Anguera et al., Nature, 2013
“Older adults who underwent a brief course of brain exercises saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the course ended, according to results from the largest study ever on cognitive training.” Steenhuysen, Reuters, 2014.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **concentration** (i.e., raising how much you focus on a task)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support cognitive training (citations provided for your reference):

"Several studies indicate that attention training using computer based exercises can lead to improved attention in children and adults." Tang & Posner, Trends in Cognitive Science, 2010

"This study offers neural and behavioural evidence of generalized positive effects from video game training on cognitive control abilities of older adults." Anguera et al., Nature, 2013

"Older adults who underwent a brief course of brain exercises saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the course ended, according to results from the largest study ever on cognitive training." Steenhuysen, Reuters, 2014.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **distractibility** (i.e., lowering how much you lose focus on a task)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support cognitive training (citations provided for your reference):

“Several studies indicate that attention training using computer based exercises can lead to improved attention in children and adults.” Tang & Posner, Trends in Cognitive Science, 2010

“This study offers neural and behavioural evidence of generalized positive effects from video game training on cognitive control abilities of older adults.” Anguera et al., Nature, 2013

“Older adults who underwent a brief course of brain exercises saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the course ended, according to results from the largest study ever on cognitive training.” Steenhuysen, Reuters, 2014.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **reasoning ability** (i.e., how well you can weigh options when faced with a problem)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support cognitive training (citations provided for your reference):

“Several studies indicate that attention training using computer based exercises can lead to improved attention in children and adults.” Tang & Posner, Trends in Cognitive Science, 2010

“This study offers neural and behavioural evidence of generalized positive effects from video game training on cognitive control abilities of older adults.” Anguera et al., Nature, 2013

“Older adults who underwent a brief course of brain exercises saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the course ended, according to results from the largest study ever on cognitive training.” Steenhuysen, Reuters, 2014.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **multi-tasking ability** (i.e., how well you can manage multiple tasks at the same time)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support cognitive training (citations provided for your reference):

“Several studies indicate that attention training using computer based exercises can lead to improved attention in children and adults.” Tang & Posner, Trends in Cognitive Science, 2010

“This study offers neural and behavioural evidence of generalized positive effects from video game training on cognitive control abilities of older adults.” Anguera et al., Nature, 2013

“Older adults who underwent a brief course of brain exercises saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the course ended, according to results from the largest study ever on cognitive training.” Steenhuysen, Reuters, 2014.

After reading the message, how successful do you expect computerized cognitive training to be at improving your **performance in everyday tasks** (e.g., driving, remembering important dates, managing finances, etc.)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support cognitive training (citations provided for your reference):
"Several studies indicate that attention training using computer based exercises can lead to improved attention in children and adults." Tang & Posner, Trends in Cognitive Science, 2010
"This study offers neural and behavioural evidence of generalized positive effects from video game training on cognitive control abilities of older adults." Anguera et al., Nature, 2013
"Older adults who underwent a brief course of brain exercises saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the course ended, according to results from the largest study ever on cognitive training." Steenhuysen, Reuters, 2014.

How successful was the message in shaping your expectations (i.e., how much did reading the message influence your response)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Perception_CT Schedule

Background information

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Cognitive training refers to activities that aim to improve a specific cognitive function by training within a specific timeframe (i.e., several weeks or months).

Computerized cognitive training refers to a set of tasks, often simple computer games, which use a particular cognitive function.

For the following set of questions, assume you would like to take part in a computerized cognitive training program. Please read each question carefully.

Before beginning the computerized cognitive training program, you are given the following choice of schedules, each totaling 25-30 hours of training (NOTE: you may take a short break after each 15-minute interval):

A) Training for 30 minutes at a time, 5 times per week, over 10 weeks

B) Training for 60 minutes at a time, 3 times per week, over 10 weeks

C) Training for 90 minutes at a time, 2 times per week, over 10 weeks

Based on these distributions, and assuming complete adherence to the schedule, please rank how effective you think each schedule will be at improving your cognitive function relative to the others:

A-B-C (i.e., schedule A is most effective, then schedule B, and schedule C is least effective)

B-A-C

C-A-B

A-C-B

B-C-A

C-B-A

Which of the distributions shown in the previous question do you expect to fit best into your weekly schedule? Please rank:

A-B-C (i.e., schedule A fits best, then schedule B, and schedule C is the most inconvenient)

B-A-C

C-A-B

A-C-B

B-C-A

C-B-A

Neutral

Background information

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Cognitive training refers to activities that aim to improve a specific cognitive function by training within a specific timeframe (i.e., several weeks or months).

Computerized cognitive training refers to a set of tasks, often simple computer games, which use a particular cognitive function.

For the following set of questions, assume you would like to take part in a computerized cognitive training program. Please read each question carefully.

Cognitive training programs are often designed to look like simple computer games. For example, training tasks might ask players to fill in a puzzle, match pictures, track an object as it moves across the screen, or rank different things according to a category.

Assuming perfect compliance, how successful would you expect 25-30 hours of training with this type of program to be at improving your **cognitive function**?

1 - Completely unsuccessful: no change in brain activity or noticeable behaviour. Such a procedure would be a waste of time and resources.

2 - Fairly unsuccessful: possible changes in specific brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life. Such a procedure would be a waste of time and resources.

3 - Somewhat unsuccessful: possible changes in general brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life.

4 - I have absolutely no expectations.

5 - Somewhat successful: possible changes in specific brain activity and behaviour. Such a procedure would NOT be a waste of time or resources.

6 - Fairly successful: possible changes in general brain activity as well as noticeable behavioural changes.

7 - Completely successful: changes in general brain activity as well as noticeable changes in overall thought and behaviour that positively impact daily life. Such a procedure would be a good investment of time and resources.

Are you confident in your previous answer?

Yes

No

Cognitive training programs are often designed to look like simple computer games. For example, training tasks might ask players to fill in a puzzle, match pictures, track an object as it moves across the screen, or rank different things according to a category.

Assuming perfect compliance, how successful would you expect 25-30 hours of training with this type of program to be at improving your **memory**?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Cognitive training programs are often designed to look like simple computer games. For example, training tasks might ask players to fill in a puzzle, match pictures, track an object as it moves across the screen, or rank different things according to a category.

Assuming perfect compliance, how successful would you expect 25-30 hours of training with this type of program to be at improving your **concentration** (i.e., raising how much you focus on a task)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Cognitive training programs are often designed to look like simple computer games. For example, training tasks might ask players to fill in a puzzle, match pictures, track an object as it moves across the screen, or rank different things according to a category.

Assuming perfect compliance, how successful would you expect 25-30 hours of training with this type of program to be at improving your **distractibility** (i.e., lowering how much you lose focus on a task)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Cognitive training programs are often designed to look like simple computer games. For example, training tasks might ask players to fill in a puzzle, match pictures, track an object as it moves across the screen, or rank different things according to a category.

Assuming perfect compliance, how successful would you expect 25-30 hours of training with this type of program to be at improving your **reasoning ability** (i.e., how well you can weigh options when faced with a problem)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Cognitive training programs are often designed to look like simple computer games. For example, training tasks might ask players to fill in a puzzle, match pictures, track an object as it moves across the screen, or rank different things according to a category.

Assuming perfect compliance, how successful would you expect 25-30 hours of training with this type of program to be at improving your **multi-tasking ability** (i.e., managing multiple tasks at the same time)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Cognitive training programs are often designed to look like simple computer games. For example, training tasks might ask players to fill in a puzzle, match pictures, track an object as it moves across the screen, or rank different things according to a category.

Assuming perfect compliance, how successful would you expect 25-30 hours of training with this type of program to be at improving your **performance in everyday tasks** (e.g., driving, remembering important dates, managing finances, etc.)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

L

Assume you are about to begin a computerized cognitive training program. Consider the following information:

You are about to begin a cognitive training program, designed based on unconfirmed theories about brain function.
Controversial theories state that brain exercise might improve mental functions. Companies and other unscientific sources exploit these theories by claiming that, just like training your body, training your brain can help you feel better. These claims are not proven scientifically.

No program has been shown to prevent or even slow down the death of neurons resulting from age, injury, or disease. This process is believed to cause mental decline.

No real change can result from cognitive training, academics argue, and even the perception of improvement would not last.

Below are examples of points made in scientific articles that criticize cognitive training (citations provided for your reference):

“The largest trial to date of 'brain-training' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […] A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning." Katsnelson, Nature News, 2010.

"[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity." Shipstead et al., Psychological Bulletin, 2012

"Available evidence regarding cognitive training remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from cognitive training." Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading this message, how successful would you expect computerized cognitive training to be at improving your **cognitive function**? (Note: disregard potential issues of practicality)

1 - Completely unsuccessful: no change in brain activity or noticeable behaviour. Such a procedure would be a waste of time and resources.

2 - Fairly unsuccessful: possible changes in specific brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life. Such a procedure would be a waste of time and resources.

3 - Somewhat unsuccessful: possible changes in general brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life.

4 - I have absolutely no expectations.

5 - Somewhat successful: possible changes in specific brain activity and behaviour. Such a procedure would NOT be a waste of time or resources.

6 - Fairly successful: possible changes in general brain activity as well as noticeable behavioural changes.

7 - Completely successful: changes in general brain activity as well as noticeable changes in overall thought and behaviour that positively impact daily life. Such a procedure would be a good investment of time and resources.

Are you confident in your previous answer?

Yes

No

Do you believe this message changed your initial expectations?

Yes

No

Below are examples of points made in scientific articles that criticize cognitive training (citations provided for your reference):

“The largest trial to date of 'brain-training' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […] A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning.” Katsnelson, Nature News, 2010.

“[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity.” Shipstead et al., Psychological Bulletin, 2012

“Available evidence regarding cognitive training remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from cognitive training.” Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **memory**?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize cognitive training (citations provided for your reference):

“The largest trial to date of 'brain-training' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […] A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning.” Katsnelson, Nature News, 2010.

“[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity.” Shipstead et al., Psychological Bulletin, 2012

“Available evidence regarding cognitive training remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from cognitive training.” Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **concentration** (i.e., raising how much you focus on a task)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize cognitive training (citations provided for your reference):

“The largest trial to date of 'brain-training' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […] A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning.” Katsnelson, Nature News, 2010.

“[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity.” Shipstead et al., Psychological Bulletin, 2012

“Available evidence regarding cognitive training remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from cognitive training.” Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **distractibility** (i.e., lowering how much you lose focus on a task)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize cognitive training (citations provided for your reference):

"The largest trial to date of 'brain-training' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […] A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning." Katsnelson, Nature News, 2010.

"[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity." Shipstead et al., Psychological Bulletin, 2012

"Available evidence regarding cognitive training remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from cognitive training." Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **reasoning ability** (i.e., how well you can weigh options when faced with a problem)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize cognitive training (citations provided for your reference):

“The largest trial to date of 'brain-training' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […] A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning.” Katsnelson, Nature News, 2010.

“[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity.” Shipstead et al., Psychological Bulletin, 2012

“Available evidence regarding cognitive training remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from cognitive training.” Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **multi-tasking ability** (i.e., how well you manage multiple tasks at the same time)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize cognitive training (citations provided for your reference):

“The largest trial to date of 'brain-training' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […] A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning.” Katsnelson, Nature News, 2010.

“[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity.” Shipstead et al., Psychological Bulletin, 2012

“Available evidence regarding cognitive training remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from cognitive training.” Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **performance in everyday tasks** (e.g., driving, remembering important dates, managing finances, etc.)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize cognitive training (citations provided for your reference):

"The largest trial to date of 'brain-training' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […] A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning." Katsnelson, Nature News, 2010.

"[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity." Shipstead et al., Psychological Bulletin, 2012

"Available evidence regarding cognitive training remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from cognitive training." Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

How successful was the message in shaping your expectations (i.e., how much did reading the message influence your response)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Background information

The following set of questions asks about your general background information. Please answer each question truthfully, and to the best of your ability.

Please enter the numerical ID code assigned to you. For students enrolled in ISPR at the University of Ottawa, please enter your 6-digit ISPR number to receive credit.
If you do not have an ID assigned through our lab, please leave this blank.

What is your gender?

Female

Male

In what country do you currently live?

Canada

USA

Other

In what country did you spend your formative years?

Canada

USA

Other

Are you currently enrolled in school?

Yes

No

What program did you study, or are you currently studying, in school?

Psychology, linguistics, cognitive science, neuroscience, education, or related

Health sciences: medicine, nursing, biomedical sciences, biochemistry, microbiology, immunology, or related

Natural sciences: engineering, physics, chemistry, math, computer science, geology, or related

Business, marketing, finance, accounting, law, liberal arts, fine arts, or related

Other; please specify

What is your highest level of education?

1. High school (no diploma)
2. High school degree
3. College / CEGEP or trade school (no diploma)
4. College / CEGEP or trade school degree
5. Bachelor's or equivalent (no diploma)
6. Bachelor's degree or equivalent
7. Master's degree or equivalent
8. Professional degree (e.g., accounting, dentistry, law, medicine, pharmacy, teaching, etc.)
9. Doctorate (PhD) degree

How many years of education do you have (beginning with Grade 1)?

On average, how much exposure to computers (i.e., desktop or laptop computer) do you get?

1. 0-2 hours per week
2. 3-5 hours per week
3. 0-2 hours per day
4. >2 hours per day

Do you have any experience with computer programming? If so, please specify.

Yes

No

Do you have any experience or familiarity with online games (cognitive or otherwise)? Please specify what games.

Yes

No

Do you have any experience or familiarity with cognitive training? Please explain.

Yes

No

How much did you know about cognitive training before taking part in this survey? Please specify in the space below the corresponding option.

I have participated in cognitive training (e.g., as part of a study or for personal use)

I have learned about cognitive training through courses, articles, books, and/or documentaries

I have heard about cognitive training through word of mouth, but do not know anything specific about it

I have absolutely no knowledge of cognitive training; I first heard of it through this survey

Are you familiar with media reports that certain activities and training can improve cognitive function? Please specify which reports or advertisements you have seen, by whom, and what the general claims were.

Are you taking any medications? Please list any medications you are currently taking, and specify what each is for.

Yes

No

In the past 5 years, have you taken medication for mental or emotional problems? If so, please specify.

Yes

No

Do you or people close to you notice any declines in your memory, focus, distractibility, or other cognitive functions?

Yes

No

Are you concerned that your memory, concentration, or other cognitive functions are worse than they used to be? Please specify.

Yes

No

Are your friends or family members concerned that your memory, concentration, or other cognitive functions are worse than they used to be? Please specify.

Yes

No

How often do you engage in physical activity?

1. Rarely; I do not exercise or walk/move around often in my day-to-day life

2. Sometimes; I do not walk/move around often in my day-to-day life but I try to exercise from time to time irregular schedule (1-3 times per month)

3. Regularly; I regularly walk/move around in my day-to-day life AND/OR I exercise 1-2 times per week

4. Often; I lead a very active lifestyle which involves exercising at least 3 times per week

How often do you exercise (i.e., engage in a specific exercise routine)?

1. 0-2 times per month
2. 3-4 times per month (approximately once per week, or every 2 weeks)
3. 2-3 times per week
4. 4-5 times per week
5. 1-2 times per day

What kind of exercise do you engage in?

Cardiovascular (e.g., jogging/running, cycling, swimming, skating, etc.)

Strength (e.g., weight training, pilates, etc.)

Yoga

Other

Do you engage in other activities? Please select all that apply.

None

Meditation

Playing a musical instrument

Learning a new language

Other

How long have you been engaging in these activities? Please specify which activities you are referring to in the comment box, and for how long.

1. 0-6 months

2. 6 months - 1 year

3. 1-5 years

4. 10+ years

How many languages do you speak?

1

2

3

4

More than 4 languages

How did you hear about this study?

Flyer

Newspaper avertisement

Through a friend or family member who participated in this study

Other

The survey is now complete. Thank you for your participation.

Powered by Qualtrics

A.2 Non-Invasive Brain Stimulation Version of the Expectation Assessment Scale (EAS-NIBS; full web version)

The following version of the EAS contains both the High and Low expectation priming messages. We used this version in our web-based studies, counterbalancing the order in which we presented the High and Low expectation messages, to probe expectations of non-invasive brain stimulation in hypothetical scenarios. We used a condensed version of this scale, containing only the appropriate expectation priming message, in our non-invasive brain stimulation trial.

Welcome

What Are Your Perceptions of Brain Stimulation? (I)
Welcome to the study, conducted by the Neuropsychology Laboratory at the University of Ottawa. The following survey is part I of a large-scale study aiming to determine factors that improve cognitive function and psychological wellbeing in younger and older adults. We will ask you questions about your perceptions of brain stimulation as well as a series of non-identifying background questions. Before beginning the survey, please ensure that you have fully read and understood the information in the consent form below. Project Title: Neuropsychological Influences on Cognitive Training in Aging **Student Researcher:** Sheida Rabipour, MSc, doctoral student in Experimental Psychology, School of Psychology, University of Ottawa **Principal Investigator:** Patrick Davidson PhD, Assistant Professor, School of Psychology, University of Ottawa **PURPOSE OF THE STUDY**: The purpose of this study is to evaluate the neural and behavioural effects of computerized cognitive training in younger and older adults. **INCLUSION/EXCLUSION CRITERIA:** To participate in this study, you must be in good health, over 18 years of age, with normal or corrected-to-normal vision and hearing. **STUDY PROCEDURES:** Your participation will require you to fill out the entirety of this survey. Personal identifying information will not be required of you. **POSSIBLE RISKS AND DISCOMFORTS:** You may experience some temporary fatigue or boredom during the survey, as it requires you to remain alert for a certain period of time. Please note, however, that duration of the survey should not exceed 30 minutes; participants are expected to complete it in less time. You do not have to worry about your performance, as this is not a competition or a test. We simply ask you to be honest and do your best. **RIGHTS AND CONFIDENTIALITY:** Your participation is strictly voluntary and you maintain the right to withdraw from the study at any time. In case of voluntary

withdrawal, you may ask that all the data concerning your participation to be destroyed. Your anonymity and confidentiality will be protected. We do not ask to provide any personal identifying information (e.g., your name), and access to the survey will be via a secured link that is password-protected, on an invite-only basis. The data will be kept for a period of five years after their publication.

POSSIBLE BENEFITS: Although we cannot guarantee that you will experience direct benefits from this study, your participation will provide valuable information that will help understand how computer-training programs affect brain function and health in adults. For participants recruited from the University of Ottawa ISPR, one credit will be given.

The information obtained from this study may be presented at scientific conferences or in scientific journals, but no personal identifiers will ever appear in any public document.

STATEMENT OF CONSENT

Neuropsychological Influences on Cognitive Training in Aging

By clicking "Next", I attest that I have read and understood the informed consent form, and consent voluntarily to participate in this study.

Please enter your current age, in years.

Baseline

Background information:

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Brain stimulation refers to techniques that aim to modulate a specific brain function by delivering electricity or magnetism

Non-invasive brain stimulation is a form of brain stimulation that delivers weak currents through the surface of the scalp over a brain region, aiming to improve cognitive or motor function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

Based on your prior knowledge of brain stimulation, how successful would you expect non-invasive brain stimulation to be at improving your **cognitive function**? (Note: disregard potential issues of practicality)

1 - Completely unsuccessful: no change in brain activity or noticeable behaviour. Such a procedure would be a waste of time and resources.

2 - Fairly unsuccessful: possible changes in specific brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life. Such a procedure would be a waste of time and resources.

3 - Somewhat unsuccessful: possible changes in general brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life.

4 - I have absolutely no expectations.

5 - Somewhat successful: possible changes in specific brain activity and behaviour. Such a procedure would NOT be a waste of time or resources.

6 - Fairly successful: possible changes in general brain activity as well as noticeable behavioural changes.

7 - Completely successful: changes in general brain activity as well as noticeable changes in overall thought and behaviour that positively impact daily life. Such a procedure would be a good investment of time and resources.

Are you confident in your previous answer?

Yes

No

Background information:

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Brain stimulation refers to techniques that aim to modulate a specific brain function by delivering electricity or magnetism

Non-invasive brain stimulation is a form of brain stimulation that delivers weak currents through the surface of the scalp over a brain region, aiming to improve cognitive or motor function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful do you expect non-invasive brain stimulation to be at improving your **memory**?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Background information:

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Brain stimulation refers to techniques that aim to modulate a specific brain function by delivering electricity or magnetism

Non-invasive brain stimulation is a form of brain stimulation that delivers weak currents through the surface of the scalp over a brain region, aiming to improve cognitive or motor function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful do you expect non-invasive brain stimulation to be at improving your **concentration** (i.e., raising how much you lose focus on a task)?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Background information:

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Brain stimulation refers to techniques that aim to modulate a specific brain function by delivering electricity or magnetism

Non-invasive brain stimulation is a form of brain stimulation that delivers weak currents through the surface of the scalp over a brain region, aiming to improve cognitive or motor function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful do you expect non-invasive brain stimulation to be at improving your **distractibility** (i.e., how much you lose focus on a task)?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Background information:

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Brain stimulation refers to techniques that aim to modulate a specific brain function by delivering electricity or magnetism

Non-invasive brain stimulation is a form of brain stimulation that delivers weak currents through the surface of the scalp over a brain region, aiming to improve cognitive or motor function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful do you expect non-invasive brain stimulation to be at improving your **reasoning ability**?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Background information:

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Brain stimulation refers to techniques that aim to modulate a specific brain function by delivering electricity or magnetism

Non-invasive brain stimulation is a form of brain stimulation that delivers weak currents through the surface of the scalp over a brain region, aiming to improve cognitive or motor function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful do you expect non-invasive brain stimulation to be at improving your **multi-tasking ability** (i.e., managing multiple tasks at the same time)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Background information:

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Brain stimulation refers to techniques that aim to modulate a specific brain function by delivering electricity or magnetism

Non-invasive brain stimulation is a form of brain stimulation that delivers weak currents through the surface of the scalp over a brain region, aiming to improve cognitive or motor function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

How successful do you expect non-invasive brain stimulation to be at improving your **performance in everyday tasks** (e.g., driving, remembering important dates, managing finances, etc.)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

H

Assume you are participating in a non-invasive brain stimulation program. Consider the following information:

You are about to begin a brain stimulation program designed by neuroscientists, based on work proven effective in scientific studies.

Research shows that this program can improve mental functions such as memory, concentration, learning, and reasoning. This is similar to the way physical exercise improves muscle tone and performance. Just like stimulating your body with exercise, stimulating your brain can help you feel better.

The technology of the program adapts to your performance, creating brain stimulation sessions that are optimal for your personal needs – just like a personal trainer at the gym. In other words, the levels of the stimulation increase at a rate according to your individual capacities and provides the benefits you hope to achieve with brain stimulation.

This occurs through neuroplasticity, a process through which your brain changes itself in response to certain types of activity, including brain stimulation. Research shows that

brain stimulation can produce real changes that last up to several years.
Below are examples of points made in scientific articles that support brain stimulation (citations provided for your reference):
“Several studies indicate that 'brain stimulation' can lead to improved attention in children and adults.” Tang & Posner, Trends in Cognitive Science, 2010
“This study offers neural and behavioural evidence of generalized positive effects from 'brain stimulation' on cognitive control abilities of older adults.” Anguera et al., Nature, 2013
“Older adults who underwent a brief course of 'brain stimulation' saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the stimulation ended, according to results from the largest study ever on brain stimulation.” Steenhuysen, Reuters, 2014.

After reading this message, how successful would you expect non-invasive brain stimulation to be at improving your **cognitive function**? (Note: disregard potential issues of practicality)

1 - Completely unsuccessful: no change in brain activity or noticeable behaviour. Such a procedure would be a waste of time and resources.

2 - Fairly unsuccessful: possible changes in specific brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life. Such a procedure would be a waste of time and resources.

3 - Somewhat unsuccessful: possible changes in general brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life.

4 - I have absolutely no expectations.

5 - Somewhat successful: possible changes in specific brain activity and behaviour. Such a procedure would NOT be a waste of time or resources.

6 - Fairly successful: possible changes in general brain activity as well as noticeable behavioural changes.

7 - Completely successful: changes in general brain activity as well as noticeable changes in overall thought and behaviour that positively impact daily life. Such a procedure would be a good investment of time and resources.

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support brain stimulation (citations provided for your reference):
“Several studies indicate that 'brain stimulation' can lead to improved attention in children and adults.” Tang & Posner, Trends in Cognitive Science, 2010
“This study offers neural and behavioural evidence of generalized positive effects from 'brain stimulation' on cognitive control abilities of older adults.” Anguera et al., Nature, 2013
“Older adults who underwent a brief course of 'brain stimulation' saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the stimulation ended, according to results from the largest study ever on brain stimulation.” Steenhuysen, Reuters, 2014.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **memory**?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support brain stimulation (citations provided for your reference):
“Several studies indicate that 'brain stimulation' can lead to improved attention in children and adults.” Tang & Posner, Trends in Cognitive Science, 2010
“This study offers neural and behavioural evidence of generalized positive effects from

'brain stimulation' on cognitive control abilities of older adults." Anguera et al., Nature, 2013

"Older adults who underwent a brief course of 'brain stimulation' saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the stimulation ended, according to results from the largest study ever on brain stimulation." Steenhuysen, Reuters, 2014.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **concentration** (i.e., raising how much you focus on a task)?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support brain stimulation (citations provided for your reference):

"Several studies indicate that 'brain stimulation' can lead to improved attention in children and adults." Tang & Posner, Trends in Cognitive Science, 2010

"This study offers neural and behavioural evidence of generalized positive effects from 'brain stimulation' on cognitive control abilities of older adults." Anguera et al., Nature, 2013

"Older adults who underwent a brief course of 'brain stimulation' saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the stimulation ended, according to results from the largest study ever on brain stimulation." Steenhuysen, Reuters, 2014.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **distractibility** (i.e., how much you lose focus on a task)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support brain stimulation (citations provided for your reference):
"Several studies indicate that 'brain stimulation' can lead to improved attention in children and adults." Tang & Posner, Trends in Cognitive Science, 2010
"This study offers neural and behavioural evidence of generalized positive effects from 'brain stimulation' on cognitive control abilities of older adults." Anguera et al., Nature, 2013
"Older adults who underwent a brief course of 'brain stimulation' saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the stimulation ended, according to results from the largest study ever on brain stimulation." Steenhuysen, Reuters, 2014.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **reasoning ability**?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support brain stimulation (citations provided for your reference):
“Several studies indicate that 'brain stimulation' can lead to improved attention in children and adults.” Tang & Posner, Trends in Cognitive Science, 2010
“This study offers neural and behavioural evidence of generalized positive effects from 'brain stimulation' on cognitive control abilities of older adults.” Anguera et al., Nature, 2013
“Older adults who underwent a brief course of 'brain stimulation' saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the stimulation ended, according to results from the largest study ever on brain stimulation.” Steenhuysen, Reuters, 2014.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **multi-tasking ability** (i.e., managing multiple tasks at the same time)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that support brain stimulation (citations provided for your reference):
“Several studies indicate that 'brain stimulation' can lead to improved attention in children and adults.” Tang & Posner, Trends in Cognitive Science, 2010
“This study offers neural and behavioural evidence of generalized positive effects from 'brain stimulation' on cognitive control abilities of older adults.” Anguera et al., Nature, 2013
“Older adults who underwent a brief course of 'brain stimulation' saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the stimulation ended, according to results from the largest study ever on brain stimulation.” Steenhuysen, Reuters, 2014.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **performance in everyday tasks** (e.g., driving, remembering important dates, managing finances, etc.)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Neutral

Background information:

Cognitive function refers to functions such as attention, memory, visual perception, information processing, and reasoning.

Brain stimulation refers to techniques that aim to modulate a specific brain function by delivering electricity or magnetism

Non-invasive brain stimulation is a form of brain stimulation that delivers weak currents through the surface of the scalp over a brain region, aiming to improve cognitive or motor function.

Read each question carefully and answer to the best of your ability. Please record the first answer that comes to your mind.

Transcranial direct-current stimulation (TDCS) is a form of non-invasive brain stimulation that uses a weak electrical current to stimulate the brain. TDCS can be designed to work with common technological devices. For example, smartphone apps may connect to TDCS devices for gaming purposes.

Based on your prior knowledge of brain stimulation, how successful would you expect non-invasive brain stimulation to be at improving your **cognitive function**? (Note: disregard potential issues of practicality)

1 - Completely unsuccessful: no change in brain activity or noticeable behaviour. Such a procedure would be a waste of time and resources.

2 - Fairly unsuccessful: possible changes in specific brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life. Such a procedure would be a waste of time and resources.

3 - Somewhat unsuccessful: possible changes in general brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life.

4 - I have absolutely no expectations.

5 - Somewhat successful: possible changes in specific brain activity and behaviour. Such a procedure would NOT be a waste of time or resources.

6 - Fairly successful: possible changes in general brain activity as well as noticeable behavioural changes.

7 - Completely successful: changes in general brain activity as well as noticeable changes in overall thought and behaviour that positively impact daily life. Such a procedure would be a good investment of time and resources.

Are you confident in your previous answer?

Yes

No

Transcranial direct-current stimulation (TDCS) is a form of non-invasive brain stimulation that uses a weak electrical current to stimulate the brain. TDCS can be designed to work with common technological devices. For example, smartphone apps may connect to TDCS devices for gaming purposes.

How successful do you expect non-invasive brain stimulation to be at improving your **memory**?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Transcranial direct-current stimulation (TDCS) is a form of non-invasive brain stimulation that uses a weak electrical current to stimulate the brain. TDCS can be designed to work with common technological devices. For example, smartphone apps may connect to

TDCS devices for gaming purposes.

How successful do you expect non-invasive brain stimulation to be at improving your **concentration** (i.e., raising how much you lose focus on a task)?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Transcranial direct-current stimulation (TDCS) is a form of non-invasive brain stimulation that uses a weak electrical current to stimulate the brain. TDCS can be designed to work with common technological devices. For example, smartphone apps may connect to TDCS devices for gaming purposes.

How successful do you expect non-invasive brain stimulation to be at improving your **distractibility** (i.e., how much you lose focus on a task)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Transcranial direct-current stimulation (TDCS) is a form of non-invasive brain stimulation that uses a weak electrical current to stimulate the brain. TDCS can be designed to work with common technological devices. For example, smartphone apps may connect to TDCS devices for gaming purposes.

How successful do you expect non-invasive brain stimulation to be at improving your **reasoning ability**?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Transcranial direct-current stimulation (TDCS) is a form of non-invasive brain stimulation that uses a weak electrical current to stimulate the brain. TDCS can be designed to work with common technological devices. For example, smartphone apps may connect to TDCS devices for gaming purposes.

How successful do you expect non-invasive brain stimulation to be at improving your **multi-tasking ability** (i.e., managing multiple tasks at the same time)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Transcranial direct-current stimulation (TDCS) is a form of non-invasive brain stimulation that uses a weak electrical current to stimulate the brain. TDCS can be designed to work with common technological devices. For example, smartphone apps may connect to TDCS devices for gaming purposes.

How successful do you expect non-invasive brain stimulation to be at improving your **performance in everyday tasks** (e.g., driving, remembering important dates, managing finances, etc.)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

L

Assume you are about to begin a non-invasive brain stimulation program.

Consider the following information:

You are about to begin a brain stimulation program, designed based on unconfirmed theories about brain function.
Controversial theories state that brain stimulation might improve mental functions. Companies and other unscientific sources exploit these theories by claiming that, just like stimulating your body with exercise, stimulating your brain can help you feel better. These claims are not proven scientifically.

No program has been shown to prevent or even slow down the death of neurons resulting from age, injury, or disease. This process is believed to cause mental decline.

No real change can result from brain stimulation, academics argue, and even the perception of improvement would not last.

Below are examples of points made in scientific articles that criticize brain stimulation (citations provided for your reference):
“The largest trial to date of 'brain-stimulation’ computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […]A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning.” Katsnelson, Nature News, 2010.
“[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity.” Shipstead et al., Psychological Bulletin, 2012
“Available evidence regarding brain stimulation remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from brain stimulation.” Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading this message, how successful would you expect non-invasive brain stimulation to be at improving your **cognitive function**? (Note: disregard potential issues of practicality)

1 - Completely unsuccessful: no change in brain activity or noticeable behaviour. Such a procedure would be a waste of time and resources.

2 - Fairly unsuccessful: possible changes in specific brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life. Such a procedure would be a waste of time and resources.

3 - Somewhat unsuccessful: possible changes in general brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life.

4 - I have absolutely no expectations.

5 - Somewhat successful: possible changes in specific brain activity and behaviour. Such a procedure would NOT be a waste of time or resources.

6 - Fairly successful: possible changes in general brain activity as well as noticeable behavioural changes.

7 - Completely successful: changes in general brain activity as well as noticeable changes in overall thought and behaviour that positively impact daily life. Such a procedure would be a good investment of time and resources.

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize brain stimulation (citations provided for your reference):

"The largest trial to date of 'brain-stimulation' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […]A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning." Katsnelson, Nature News, 2010.
"[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity." Shipstead et al., Psychological Bulletin, 2012
"Available evidence regarding brain stimulation remains limited, and the quality of the

evidence needs to improve. However, there is still no indication of any significant benefit derived from brain stimulation." Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **memory**?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize brain stimulation (citations provided for your reference):

"The largest trial to date of 'brain-stimulation' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […]A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning." Katsnelson, Nature News, 2010.

"[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity." Shipstead et al., Psychological Bulletin, 2012

"Available evidence regarding brain stimulation remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from brain stimulation." Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading the message, how successful would you expect computerized cognitive training to be at improving your **concentration** (i.e., raising how much you focus on a task)?

1- Completely unsuccessful

2- Fairly unsuccessful

3- Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize brain stimulation (citations provided for your reference):

"The largest trial to date of 'brain-stimulation' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […]A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning." Katsnelson, Nature News, 2010.

"[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity." Shipstead et al., Psychological Bulletin, 2012

"Available evidence regarding brain stimulation remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from brain stimulation." Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **distractibility** (i.e., how much you lose focus on a task)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize brain stimulation (citations provided for your reference):

“The largest trial to date of 'brain-stimulation’ computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […]A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning.” Katsnelson, Nature News, 2010.

“[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity.” Shipstead et al., Psychological Bulletin, 2012

“Available evidence regarding brain stimulation remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from brain stimulation.” Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **reasoning ability**?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize brain stimulation (citations provided for your reference):

“The largest trial to date of 'brain-stimulation’ computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […]A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning.” Katsnelson, Nature News, 2010.

“[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity.” Shipstead et al., Psychological Bulletin, 2012

“Available evidence regarding brain stimulation remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from brain stimulation.” Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **multi-tasking ability** (i.e., managing multiple tasks at the same time)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Below are examples of points made in scientific articles that criticize brain stimulation (citations provided for your reference):

"The largest trial to date of 'brain-stimulation' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […]A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning." Katsnelson, Nature News, 2010.

"[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity." Shipstead et al., Psychological Bulletin, 2012

"Available evidence regarding brain stimulation remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from brain stimulation." Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving your **performance in everyday tasks** (e.g., driving, remembering important dates, managing finances, etc.)?

1 - Completely unsuccessful

2 - Fairly unsuccessful

3 - Somewhat unsuccessful

4 - I have absolutely no expectations

5 - Somewhat successful

6 - Fairly successful

7 - Completely successful

Are you confident in your previous answer?

Yes

No

Background Information

The following set of questions asks about your general background information. Please answer each question truthfully, and to the best of your ability.

Please enter the numerical ID code assigned to you. For students enrolled in ISPR at the University of Ottawa, please enter your 6-digit ISPR number to receive credit.
If you do not have a code, leave this blank.

What is your gender?

Female

Male

In what country do you currently live?

Canada

USA

Other

In what country did you spend your formative years?

Canada

USA

Other

Are you currently enrolled in school?

Yes

No

What program did you study, or are you currently studying, in school?

Psychology, linguistics, cognitive science, neuroscience, education, or related

Health sciences: medicine, nursing, biomedical sciences, biochemistry, microbiology, immunology, or related

Natural sciences: engineering, physics, chemistry, math, computer science, geology, or related

Business, marketing, finance, accounting, law, liberal arts, fine arts, or related

Other; please specify

What is your highest level of education?

1. High school (no diploma)
2. High school degree
3. College / CEGEP or trade school (no diploma)
4. College / CEGEP or trade school degree
5. Bachelor's or equivalent (no diploma)
6. Bachelor's degree or equivalent
7. Master's degree or equivalent
8. Professional degree (e.g., accounting, dentistry, law, medicine, pharmacy, teaching, etc.)
9. Doctorate (PhD) degree

How many years of education do you have (beginning with Grade 1)?

On average, how much exposure to computers (i.e., desktop or laptop computer) do you get?

1. 0-2 hours per week
2. 3-5 hours per week
3. 0-2 hours per day
4. >2 hours per day

Do you have any experience with computer programming? If so, please specify.

Yes

No

Do you have any experience or familiarity with online games (cognitive or otherwise)? Please specify what games.

Yes

No

Do you have any experience or familiarity with cognitive training? Please explain.

Yes

No

How much did you know about cognitive training before taking part in this survey? Please specify in the space below the corresponding option.

I have participated in cognitive training (e.g., as part of a study or for personal use)

I have learned about cognitive training through courses, articles, books, and/or documentaries

I have heard about cognitive training through word of mouth, but do not know anything specific about it

I have absolutely no knowledge of cognitive training; I first heard of it through this survey

Are you familiar with media reports that certain activities and training can improve cognitive function? Please specify which reports or advertisements you have seen, by whom, and what the general claims were.

Are you taking any medications? Please list any medications you are currently taking, and specify what each is for.

Yes

No

In the past 5 years, have you taken medication for mental or emotional problems? If so, please specify.

Yes

No

Do you or people close to you notice any declines in your memory, focus, distractibility, or other cognitive functions?

Yes

No

Are you concerned that your memory, concentration, or other cognitive functions are worse than they used to be? Please specify.

Yes

No

Are your friends or family members concerned that your memory, concentration, or other cognitive functions are worse than they used to be? Please specify.

Yes

No

How often do you engage in physical activity?

1. Rarely; I do not exercise or walk/move around often in my day-to-day life

2. Sometimes; I do not walk/move around often in my day-to-day life but I try to exercise from time to time irregular schedule (1-3 times per month)

3. Regularly; I regularly walk/move around in my day-to-day life AND/OR I exercise 1-2 times per week

4. Often; I lead a very active lifestyle which involves exercising at least 3 times per week

How often do you exercise (i.e., engage in a specific exercise routine)?

1. 0-2 times per month

2. 3-4 times per month (approximately once per week, or every 2 weeks)

3. 2-3 times per week

4. 4-5 times per week

5. 1-2 times per day

What kind of exercise do you engage in?

Cardiovascular (e.g., jogging/running, cycling, swimming, skating, etc.)

Strength (e.g., weight training, pilates, etc.)

Yoga

Other

Do you engage in other activities? Please select all that apply.

None

Meditation

Playing a musical instrument

Learning a new language

Other

How long have you been engaging in these activities? Please specify which activities you are referring to in the comment box, and for how long.

1. 0-6 months

2. 6 months - 1 year

3. 1-5 years

4. 10+ years

How many languages do you speak?

1

2

3

4

More than 4 languages

How did you hear about this study?

Flyer

Newspaper avertisement

Through a friend or family member who participated in this study

Other

The survey is now complete. Thank you for your participation.

Appendix B

B.1 Long-term Psychosocial Outcomes of CCT in Older Adults

The supplemental figures below show self-rated psychosocial function scores from older adults at baseline, immediately after participation in the 5-week CCT program, and 6-months following completion of the program, as part of our long-term follow-up. As depicted, ratings did not significantly change over time or differ based on expectation priming or training program received.

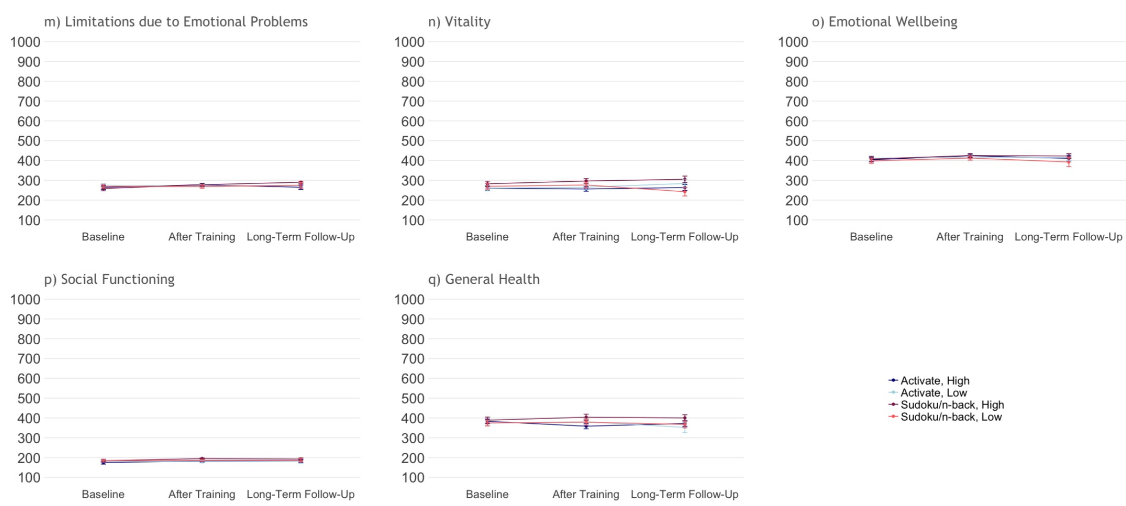


Figure 1. Ratings with respect to a) emotional problems, b) energy and fatigue (i.e., vitality), c) emotional wellbeing, d) social functioning, and e) general health on the Short Form Health Survey at baseline, following five weeks of training, and six months following completion of the training program.

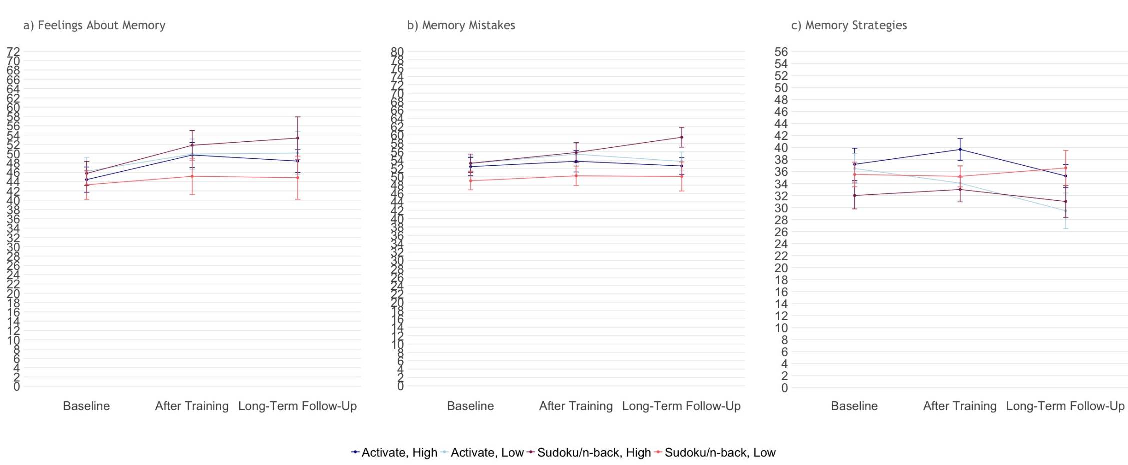


Figure 2. Ratings on the a) "Feelings About Memory", b) "Memory Mistakes", and c) "Memory Strategies" subscales of the Multifactorial Memory Questionnaire at baseline, following five weeks of training, and six months following completion of the training program. Higher scores on each of the three subscales indicate greater confidence in memory, larger number of memory-related mistakes, and more frequent strategy use, respectively.

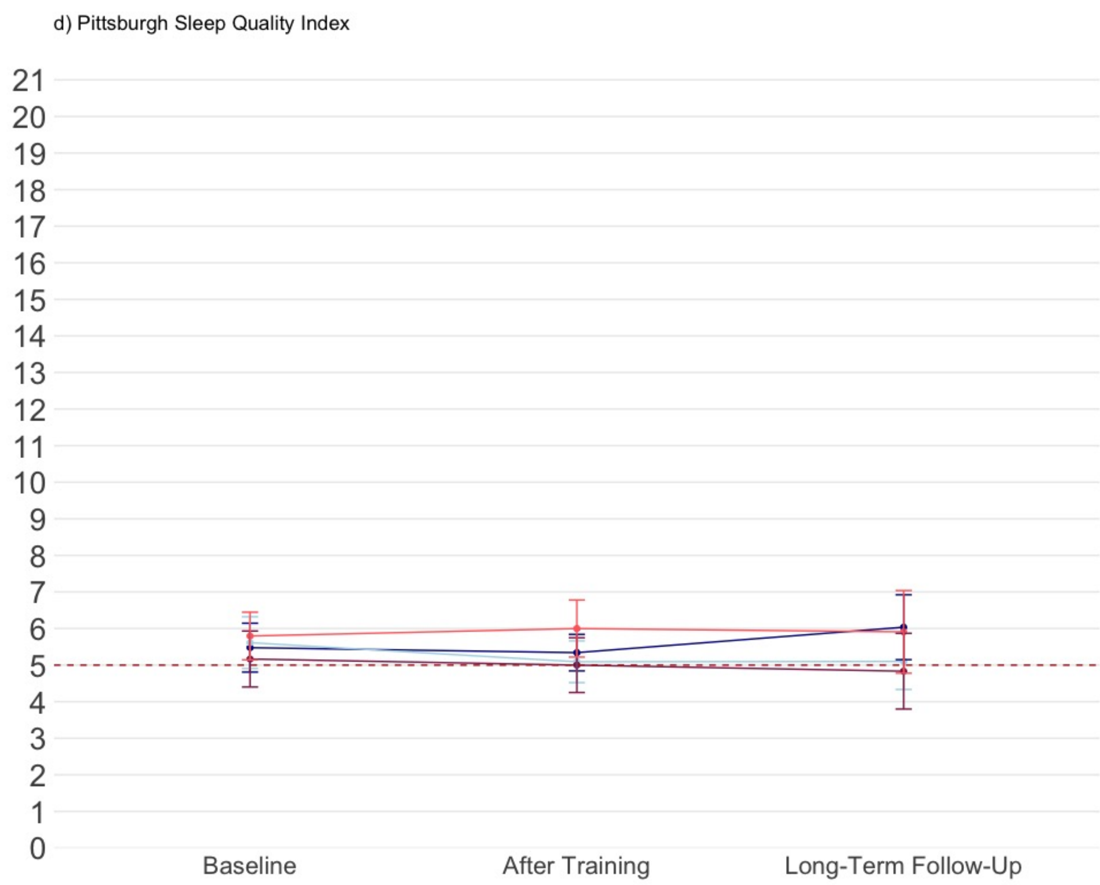


Figure 3. Ratings on the Pittsburgh Sleep Quality Inventory at baseline, following five weeks of training, and six months following completion of the training program. Lower scores indicate fewer sleep-related issues. Dashed line represents clinical cutoff (i.e., total score greater then 5).

B.2 'Tester Expectations' of CCT

The supplemental figure below illustrates expectation ratings on the web-based CCT version of the EAS when participants were asked to respond in a way they believed the experimenters wanted or expected them to. Specifically, we presented participants with the same EAS used in the studies above, but told participants to "[a]nswer what you think the researchers WANT you to answer, based on the structure of the survey, not necessarily what you think the answer is. Then rate if you are confident that this is what the researchers who made the survey would have expected." Responses show more extreme ratings conforming to positive or negative expectations in response to the high or low expectation priming messages, respectively.

We performed this pilot experiment as a step towards verifying that responses would be measurably different under these conditions compared to regular conditions, where participants respond based on their perceived expectations of outcomes. Because a comprehensive evaluation of responses under different conditions (e.g., to account for possible demand characteristics) was beyond the scope of this work, we did not follow up or publish these results.

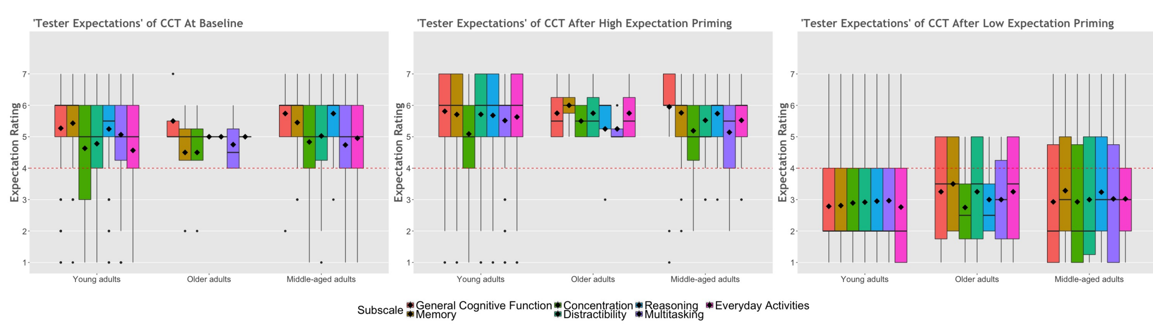


Figure 4. Participant EAS ratings at baseline and after receiving each expectation priming message under conditions where responses represented what participants believed the experimenters wanted. Ratings of expected outcomes were on a scale of "1" ("completely unsuccessful") to "7" ("completely successful") for each subscale (i.e., cognitive domain). Red dashed lines represent a neutral rating of "4" ("no expectation"). Solid lines represent group medians; diamonds represent group means.

Appendix C

Preprint: Expectations May Influence the Effects of Transcranial Direct Current Stimulation

The following manuscript preprint (available at biorxiv.org) describes collaborative work between Sheida Rabipour and Dr. Patrick Davidson at the University of Ottawa, and Drs. Marco Iacoboni and Allan Wu at the University of California, Los Angeles. An updated version of this work has been published in *Neuropsychologia*.

Expectations May Influence the Effects of Transcranial Direct Current Stimulation

Sheida Rabipour[1], Allan D. Wu[2,3], Patrick S. R. Davidson[1,4,5], Marco Iacoboni[2,6,7]

Affiliations:

[1]School of Psychology, University of Ottawa, Ottawa, Ontario, Canada

[2]Ahmanson-Lovelace Brain Mapping Center, University of California, Los Angeles, USA

[3]Department of Neurology, David Geffen School of Medicine, University of California, Los Angeles, USA

[4]Heart and Stroke Foundation of Ontario Canadian Partnership for Stroke Recovery, Ontario, Canada

[5]Bruyère Research Institute, Bruyère Continuing Care, Ottawa, Ontario, Canada

[6]Department of Psychiatry and Biobehavioral Sciences, David Geffen School of Medicine, University of California, Los Angeles, USA

[7]Brain Research Institute, University of California, Los Angeles, USA

Abstract

Growing interest surrounds transcranial direct current stimulation (tDCS) as a safe and inexpensive method for improving cognitive functions and mood. Nevertheless, tDCS studies rarely examine psychological factors such as expectations of outcomes, which may influence tDCS responsiveness through placebo-like effects. Here we sought to evaluate the potential influence of expectations on tDCS intervention outcomes. We assessed expectations of tDCS outcomes in 88 healthy young adults on three occasions: i) at baseline; ii) after reading information implying either high or low effectiveness of stimulation; and iii) after a single-session of sham-controlled anodal tDCS applied to the left dorsolateral prefrontal cortex, during working memory (WM) training. Participants were largely uncertain about the effectiveness of stimulation in improving cognitive function at baseline. High or low expectation priming using simple positive or cautionary messages significantly increased or decreased expectation ratings, respectively, but ratings significantly decreased following stimulation in all groups. We found greater improvement in participants who received high compared to low expectation priming. Participants who received active stimulation and low expectation priming exhibited the lowest performance, suggesting that expectation priming and stimulation may have interacted. We did not find a significant effect of baseline expectations, belief of group assignment, or individual characteristics on measures of WM and verbal fluency. However, controlling for baseline expectations revealed greater post-intervention improvement on the executive function measures in participants who received high (compared to low) expectation priming. People randomly assigned to receive high expectation priming reported having a more pleasant experience overall, including greater satisfaction. Our findings suggest that expectations of outcomes should be taken into account in tDCS-based experimental studies and clinical trials.

Keywords: Expectations; Non-invasive brain stimulation; Placebo; Priming; Transcranial direct current stimulation; Working memory.

Highlights:

- Based on prior knowledge, healthy subjects are uncertain about NIBS effectiveness.
- Expectations of NIBS can change after a single exposure to simple written messages.
- Expectations of outcomes may influence cognitive performance.
- High expectations may lead to a more positive experience and motivation to perform.
- Low expectations may be counterproductive to NIBS.

Introduction

Non-invasive brain stimulation (NIBS) using magnetic fields or electrical currents is increasingly used in health and disease (Bennabi et al., 2014; Coffman, Clark, & Parasuraman, 2014; Kekic, Boysen, Campbell, & Schmidt, 2016). With low cost and relatively simple administration, NIBS holds understandable appeal for the investigation and modulation of cognitive mechanisms (Filmer, Dux, & Mattingley, 2014), treatment of clinical populations (Freitas et al., 2011; Gandiga, Hummel, & Cohen, 2006; Zhao et al., 2017) and specialized training of high-performing individuals (Scheldrup et al., 2014).

Transcranial direct current stimulation (tDCS) is a portable and generally safe (Bikson et al., 2016; Nitsche et al., 2008) form of NIBS alleged to enhance a vast set of functions. These include learning and implicit decision-making (Kincses et al., 2004), language production (Monti et al., 2013), episodic memory (Sandrini et al., 2014), and executive functions (Au et al., 2016; Dockery et al., 2009; McIntire, McKinley, Goodyear, & Nelson, 2014; Ruf, Fallgatter, & Plewnia, 2017).

Nevertheless, growing excitement among researchers, clinicians, and individual consumers is contrasted by a lack of reproducible findings across the tDCS literature (Berlim, Van den Eynde, & Daskalakis, 2013; Horvath, Forte, & Carter, 2015a, 2015b; Mancuso, Ilieva, Hamilton, & Farah, 2016; Medina & Cason, 2017; To, Hart, De Ridder, & Vanneste, 2016). In addition to considerable variability in reported effects, studies suggest high inter-individual differences in responsiveness to tDCS (Li, Uehara, & Hanakawa, 2015; Lopez-Alonso, Cheeran, Rio-Rodriguez, & Fernandez-del-Olmo, 2014). Factors such as electrode placement (Penolazzi, Pastore, & Mondini, 2013), strength of current (Chew, Ho, & Loo, 2015; Underwood, 2016), and stimulation schedule (Au et al., 2016) may contribute to differential effects, but do not appear to fully explain this variability. A recent study found that current intensities conventionally used in NIBS studies are likely insufficient to affect neuronal circuits directly, suggesting that reported behavioural and cognitive effects may result from indirect mechanisms (Voroslakos et al., 2018). Moreover, some researchers have argued that published tDCS studies for cognition and working memory (WM) are underpowered and have little evidential value (Medina & Cason, 2017). These findings highlight the uncertainty about the mechanisms through which tDCS influences cognition and behaviour (Farah, 2015; Walsh, 2013), as well as the need for greater scientific rigour in evaluations of tDCS (Riggall et al., 2015).

Crucially, studies of tDCS have rarely examined psychological factors such as expectations of outcomes, which may influence tDCS responsiveness through placebo or Hawthorne-like effects (McCambridge, Witton, & Elbourne, 2014; Shiozawa, Duailibi, da Silva, & Cordeiro, 2014). Evidence for the influence of expectations on cognitive interventions (Foroughi, Monfort, Paczynski, McKnight, & Greenwood, 2016; Rabipour, Andringa, Boot, & Davidson, 2017; Rabipour & Davidson, 2015) and performance (Schwarz, Pfister, & Buchel, 2016), coupled with the possible influence of factors such as emotional state (Sarkar, Dowker, & Cohen Kadosh, 2014) and motivation (Jones, Gozenman, & Berryhill, 2015) on responsiveness to tDCS, underline the importance of examining the potential influence of expectations on tDCS. Furthermore, such expectations may at least partially account for the individual differences in tDCS responsiveness as well as variability in reported tDCS effects.

In the present study we assessed expectations of NIBS and examined the effects of expectation priming on cognitive performance following tDCS in healthy young adults (see also Rabipour et al., 2017; Rabipour & Davidson, 2015). Specifically, we asked: i) whether people tend to have neutral, optimistic, or pessimistic expectations of NIBS; ii) whether expectations of

NIBS outcomes can be modified based on information indicating that the procedure either can or cannot enhance cognitive function; and iii) whether expectations of NIBS interact with the effects of anodal tDCS during performance of a cognitively challenging task. Our study represents a conceptual replication and extension of previous research reporting enhanced WM performance following a single session of anodal tDCS applied to the left dlLFC, and showing greater within- and between-session improvements following concurrent (i.e., “online”) rather than sequential (i.e., “offline”) task performance (Martin, Liu, Alonzo, Green, & Loo, 2014; see also Ruf et al., 2017).

Materials and Methods

Participants

We recruited 90 healthy young adults with normal or corrected-to-normal vision and hearing from the Psychology subject pool at the University of California, Los Angeles (UCLA). Participants were enrolled during an initial single-blind round of data collection: n = 52, 31 women, age=20.47±1.85 years, with one woman excluded following in-person screening; and during a follow-up double-blind round: n = 38, 22 women, age=20.61±3.35 years, with one woman excluded due to technical difficulties preventing completion of testing. We screened participants based on the following exclusion criteria: i) seizure disorder; ii) history of serious head trauma; iii) presence of metal, other than dental work, in the head; iv) presence of foreign object in body (e.g., pacemaker); v) electroconvulsive therapy in the past six months; vi) current pregnancy; vii) hospitalization for psychiatric reasons in the past six months; viii) change in antipsychotic medication in the past three months; ix) a major depressive episode in the past month; or x) active abuse of drugs or alcohol in the past six months. We received ethical approval to conduct this study from the UCLA Institutional Review Board and the University of Ottawa Research Ethics Board.

Experimental Protocol

After providing consent, participants were assigned to one of two expectation priming conditions: i) High expectation priming, in which participants were told they would receive a type of brain stimulation known to improve performance (Fig. 1A); and ii) Low expectation priming, in which participants were told they would receive a type of brain stimulation with no known benefits (Fig. 1B). We then randomized participants to receive one of two stimulation conditions: active anodal or sham tDCS. All participants proceeded to complete a single session of tDCS based on their randomized group assignment (Table 1) while performing an online WM task.

Table 1. Random assignment of participants (*n* women) into the experimental conditions based on recruitment as part of an initial single blind or follow-up double blind protocol.

	Active, High	**Active, Low**	**Sham, High**	**Sham, Low**
Single blind	12 (8)	12 (7)	14 (8)	13 (8)
Double blind	12 (4)	9 (8)	6 (4)	10 (5)

Expectation Assessment

Participants rated their expectations of tDCS effectiveness using the Expectation Assessment Scale (EAS), described in our previous work (Rabipour et al., 2017; Rabipour & Davidson, 2015; Rabipour, Davidson, & Kristjansson, 2018), on three occasions: i) at baseline; ii) after receiving High or Low expectation priming; and iii) after the tDCS session. Briefly, participants rated their expectations of outcomes on a scale from 1-7 (1 = "completely unsuccessful," 2 = "fairly unsuccessful," 3 = "somewhat unsuccessful," 4 = neutral/"I have absolutely no expectations," 5 = "somewhat successful," 6 = "fairly successful," 7 = "completely

A) Information for High Expectation Priming

You are about to begin a brain stimulation program designed by neuroscientists, based on work proven effective in scientific studies.

Research shows that this program can improve mental functions such as memory, concentration, learning, and reasoning. This is similar to the way physical exercise improves muscle tone and performance. Just like stimulating your body with exercise, stimulating your brain can help you feel better.

The technology of the program adapts to your performance, creating brain stimulation sessions that are optimal for your personal needs – just like a personal trainer at the gym. In other words, the levels of the stimulation increase at a rate according to your individual capacities and provides the benefits you hope to achieve with brain stimulation.

This occurs through neuroplasticity, a process through which your brain changes itself in response to certain types of activity, including brain stimulation. Research shows that brain stimulation can produce real changes that last up to several years.

Below are examples of points made in scientific articles that support brain stimulation (citations provided for your reference):

"Several studies indicate that 'brain stimulation' can lead to improved attention in children and adults." Tang & Posner, Trends in Cognitive Science, 2010

"This study offers neural and behavioural evidence of generalized positive effects from 'brain stimulation' on cognitive control abilities of older adults." Anguera et al., Nature, 2013

"Older adults who underwent a brief course of 'brain stimulation' saw improvements in reasoning skills and processing speed that could be detected as long as 10 years after the stimulation ended, according to results from the largest study ever on 'brain stimulation'." Steenhuysen, Reuters, 2014.

B) Information for Low Expectation Priming

You are about to begin a brain stimulation program, designed based on unconfirmed theories about brain function.

Controversial theories state that brain stimulation might improve mental functions. Companies and other unscientific sources exploit these theories by claiming that, just like stimulating your body with exercise, stimulating your brain can help you feel better. These claims are not proven scientifically.

No program has been shown to prevent or even slow down the death of neurons resulting from age, injury, or disease. This process is believed to cause mental decline.

No real change can result from brain stimulation, academics argue, and even the perception of improvement would not last.

Below are examples of points made in scientific articles that criticize brain stimulation (citations provided for your reference):

"The largest trial to date of 'brain-stimulation' computer games suggests that people who use the software to boost their mental skills are likely to be disappointed. […]A total of 11,430 volunteers aged from 18 to 60 completed the study, and although they improved on the tasks, the researchers believe that none of the groups boosted their performance on tests measuring general cognitive abilities such as memory, reasoning and learning." Katsnelson, Nature News, 2010.

"[…] we express concern that many of the most promising results (e.g., increased intelligence) cannot be readily attributed to changes in [cognitive] capacity." Shipstead et al., Psychological Bulletin, 2012

"Available evidence regarding 'brain stimulation' remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from 'brain stimulation'." Bahar-Fuchs, Clare, & Woods, The Cochrane Collaboration, 2013.

Fig. 1 A) High and B) Low expectation priming messages delivered to participants.

successful"). We probed expectations on nine outcomes: i) general cognitive function; ii) memory; iii) concentration; iv) distractibility; v) reasoning ability; vi) multitasking ability; vii) performance in everyday activities; viii) task accuracy; and ix) response time. Due to missing data for "concentration", "task accuracy", and "response time", we excluded those domains from our repeated-measures analyses.

In the event of participants probing further about the study objectives and hypotheses, researchers were instructed to respond in line with the nature of the participant's assigned expectation priming condition: for participants who received high expectation priming, experimenters explained that NIBS has been shown to be effective and the study aims to confirm previously reported effects; for participants who received low expectation priming, researchers explained that the body of research is contentious and that the present study aims to confirm no effect of the intervention. During data collection, however, participants rarely inquired further about the study after reading the expectation priming messages.

Stimulation Procedure

During our initial single-blind round of data collection, we delivered tDCS through a battery-driven constant direct current stimulator (ActivaDose II, ActivaTek Inc, USA) using a pair of electrodes in 5 x 7cm saline-soaked synthetic sponges. The anodal electrode was placed at the F3 scalp location based on the International 10/20 system. The cathode was placed along the supraorbital nerve, 2-3cm lateral to the nasion-inion line on the contralateral side. The electrodes were held against the head with a standard head strap provided by Soterix Medical and an additional custom strap of Lycra synthetic fibre. For both active and sham conditions, the current was turned on and increased in a ramp-like fashion over approximately 30 seconds until reaching a strength of 2.0mA, with a current density equal to 0.04mA/cm^2. Stimulation in the active tDCS condition was maintained for 20 minutes at 2.0mA, and then ramped down to 0.0mA over 30 seconds. For participants in the sham condition, the current was applied for only 30s and then ramped down to 0.0mA over 30 seconds. This allowed participants in each group to experience the same initial sensations (i.e., mild tingling). Participants habituate rapidly to the tingling sensations on the scalp, thus preserving the sham manipulation (Poreisz, Boros, Antal, & Paulus, 2007). The safety and potential cognitive effects of these stimulation parameters have been previously validated in healthy participants (Bikson et al., 2016; Iyer et al., 2005).

We recruited additional participants to undergo the same procedure using a NeuroConn Direct-Current Stimulator Plus (neuroCare Group, GmbH) with pre-programmed codes to deliver active vs. sham conditions in a double-blind manner. Stimulation montage and ramping conditions were identical in both phases, with the exception that current was held at 2.0mA for 40s in the sham condition before ramping down to 0.0mA.

Online Working Memory Task

All participants performed a custom designed n-back task for 20 minutes, concurrent with active or sham tDCS. In our initial round of data collection, participants performed three different types of n-back, presented randomly over the course of the 20 minutes. Specifically, the task required participants to identify either: i) a letter or number repeated after n = 3 frames, among a random sequence of letters and numbers; ii) an image repeated after n = 3 frames, among a random series of images; or iii) the spatial position of a single image moving across a 3 x 3 grid, repeated after n = 3 frames.

The n-back exercises were originally designed for a five-week, multi-session cognitive training program. Each type of n-back task was subdivided into trial blocks lasting 180s (letter-number and spatial type of n-back; 150 trials within each block) or 1080s (image type of n-back; 900 trials within each block) in total, wherein stimuli were presented in immediate succession and participants had 1200ms to respond. For the majority of participants (*n* = 64), the software randomly generated the type of n-back task that each participant completed. Technical issues with the software prevented us from accessing data pertaining to the nature of correct responses (i.e., hits vs. correct rejections). After updating the database to rectify these issues, we removed the randomization of n-back types and instructed the remaining participants (*n* = 24) to complete only the letter-number n-back task.

During both rounds of data collection, participants were first allowed to practice with a 2-back task and then graduated to a 3-back task, until comfortable with the rules. Practice time was maintained within 10 minutes. The experimenter manually terminated the task once the stimulation protocol was complete. Due to technical difficulties with the software, we were unable to store complete data for 16 participants (single blind: *n* = 1; double blind: *n* = 15).

Neuropsychological Assessment

To assess changes in cognitive performance, we administered a brief battery of neuropsychological tests measuring executive functioning, with a focus on working memory and verbal fluency, both before and after receiving brain stimulation. All of the administered tests were timed with a digital stopwatch.

Letter-Number Sequencing Task: The letter-number sequencing (LNS) task, a subtest of the Wechsler Adult Intelligence Scale, is a brief, standardized measure of executive function that indexes verbal and visuospatial WM performance, as well as processing speed (Crowe, 2000). During the task, examiners read a series of scrambled letters and numbers to participants, who must then recite the numbers in sequential order, followed by the letters in alphabetical order.

Digit Span Task: The digit span task, a simple span subtest of the Wechsler Adult Intelligence Scale, includes a forward and backward digit span task. For the forward digit span (FDS) task, a measure of short-term recall, participants repeated a string of numbers that the examiner read aloud; in the backward digit span (BDS) task, an index of WM capacity and incomplete effort (Axelrod, Fichtenberg, Millis, & Wertheimer, 2006), participants recited the string of numbers in the reverse order.

Controlled Oral-Word Association Test (COWAT) and Animal Naming Test: The COWAT measures letter fluency (LF) or knowledge (i.e., letter-sound associations) and requires the generation of words that begin with a given letter within 60 seconds (Lanting, Haugrud, & Crossley, 2009). In the present study, participants were asked to name as many words as possible that begin with the letter “C”, then “F”, and finally “L”, or “P”, then “R”, and finally “W” at baseline and following tDCS, in counterbalanced order. The animal-naming test, administered immediately after the COWAT, is a measure of semantic fluency (SF) that requires participants to name as many animals as possible in 60 seconds. In the present study, scores represent the total number of admissible words reported.

Feedback on Perceived Experience

Immediately following the stimulation procedure, we asked participants to report on their experience. On a scale from 1-7 (1 = “very strongly disagree,” 2 = “strongly disagree,” 3 = “disagree,” 4 = neutral/“neither agree nor disagree,” 5 = “agree,” 6 = “strongly agree,” 7 = “very strongly agree”), participants rated the degree to which they found the experience: i) enjoyable; ii) challenging; iii) frustrating; iv) engaging; v) boring; vi) motivating; and vii) satisfying.

Statistical Analysis

Using G*Power version 3.1, we determined that a total sample of 84 participants would detect a moderate effect size at an alpha level of .05 with 80% power.

Primary outcomes were analysed using repeated-measures analysis of variance (ANOVA), as well as univariate ANOVA and multivariate ANOVA (MANOVA), with within-between factors interactions to evaluate the outcome measures described, at an alpha level of 0.05. For our online WM task, we analysed the proportion of correct trials (i.e., hits and correct rejections) and of false alarms (i.e., incorrect clicks as a proportion of total incorrect trials). For our transfer measures, we combined the behavioural outcome measures a priori into a single standardized "executive function" score at baseline and following stimulation. We used the mean and standard deviation from baseline scores to compute the composite for both baseline and post-stimulation scores. As a more conservative approach, we initially opted to analyse our results with condensed composite scores comprised of only the LNS, BDS, and LF total scores, which have been shown to correlate more strongly with executive function (e.g., see: Crowe, 2000; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Redick & Lindsey, 2013; St Clair-Thompson, 2010). Based on feedback from a reviewer, we report results from both analyses (i.e., with the complete composite scores and the condensed composite scores). We employed Pearson correlations and Principal Components Analysis (PCA) of baseline scores to verify the relatedness of these outcomes in our sample. Where applicable, we used the Holm-Bonferroni correction for multiple comparisons and Greenhouse-Geisser correction for sphericity. We performed analyses using IBM SPSS Statistics, Inc. version 23 and R version 3.1.1.

Results

Expectation ratings and measures of performance did not significantly differ based on blinding (i.e., single vs. double). We therefore report results from both recruitment phases together.

How do people perceive non-invasive brain stimulation?

Based on their prior knowledge and perceptions of NIBS, participants were largely uncertain of the effectiveness of NIBS (Fig. 2). Responses were significantly above neutral only for "memory" in participants assigned to receive low expectation priming and sham tDCS (M = 4.57, SD = 0.788, $t_{[22]}$ = 3.44, p = 0.002, Cohen's d = 1.47; Fig. 2d) after correcting for multiple comparisons in a series of single-sample t-tests comparing each of the baseline ratings to the neutral point (rating of "4"). Because participants had not yet received the priming messages, this significant group difference in the baseline expectation ratings may represent a chance finding unrelated to our experimental protocol.

We performed repeated measures ANOVA examining expectation ratings on each of the cognitive domains ("general cognitive function", "memory", "distractibility", "reasoning ability", "multitasking ability", "performance in everyday activities") across time (baseline, before simulation, and following stimulation) based on priming (high vs. low) and stimulation condition (active vs. sham). This analysis revealed a significant effect of time ($F_{[1.5,73.66]}$ = 7.81, p = .002, η_p^2 = .137), of our priming conditions ($F_{[1,49]}$ = 10.562, p = .002, η_p^2 = .177) and of cognitive domain ($F_{[4.09,200.2]}$ = 3.745, p = .005, η_p^2 = .071) on expectation ratings, a significant interaction between time and priming condition ($F_{[2, 73.66]}$ = 10.147, p < .0001, η_p^2 = .172), and a three-way interaction between time, cognitive domain, and priming condition ($F_{[10,490]}$ = 1.997, p = .032, η_p^2 = .039; Fig. 2).

Follow-up repeated measures ANOVA comparing ratings based on each priming condition across time revealed a significant effect of time ($F_{[1.4,35]}$ = 7.022, p = .002, η_p^2 = .219) and of domain ($F_{[3.6,91.19]}$ = 4.566, p = .003, η_p^2 = .154) as well as an interaction between time and domain ($F_{[10,250]}$ = 2.108, p = .024, η_p^2 = .078) in participants who received high expectation priming. In participants who received low expectation priming, we found only a significant effect of time ($F_{[1.6,38.16]} = 10.917$, $p < .0001$, $\eta_p^2 = .313$). Overall, our pattern of results suggests that expectations increased before stimulation (i.e., after receiving the priming information) and decreased following stimulation in participants who received high expectation priming; conversely, in participants who received low expectation priming, expectations decreased relative to baseline before stimulation and remained low after stimulation (see Supplementary Table S1 for expectation ratings across domain, within each group).

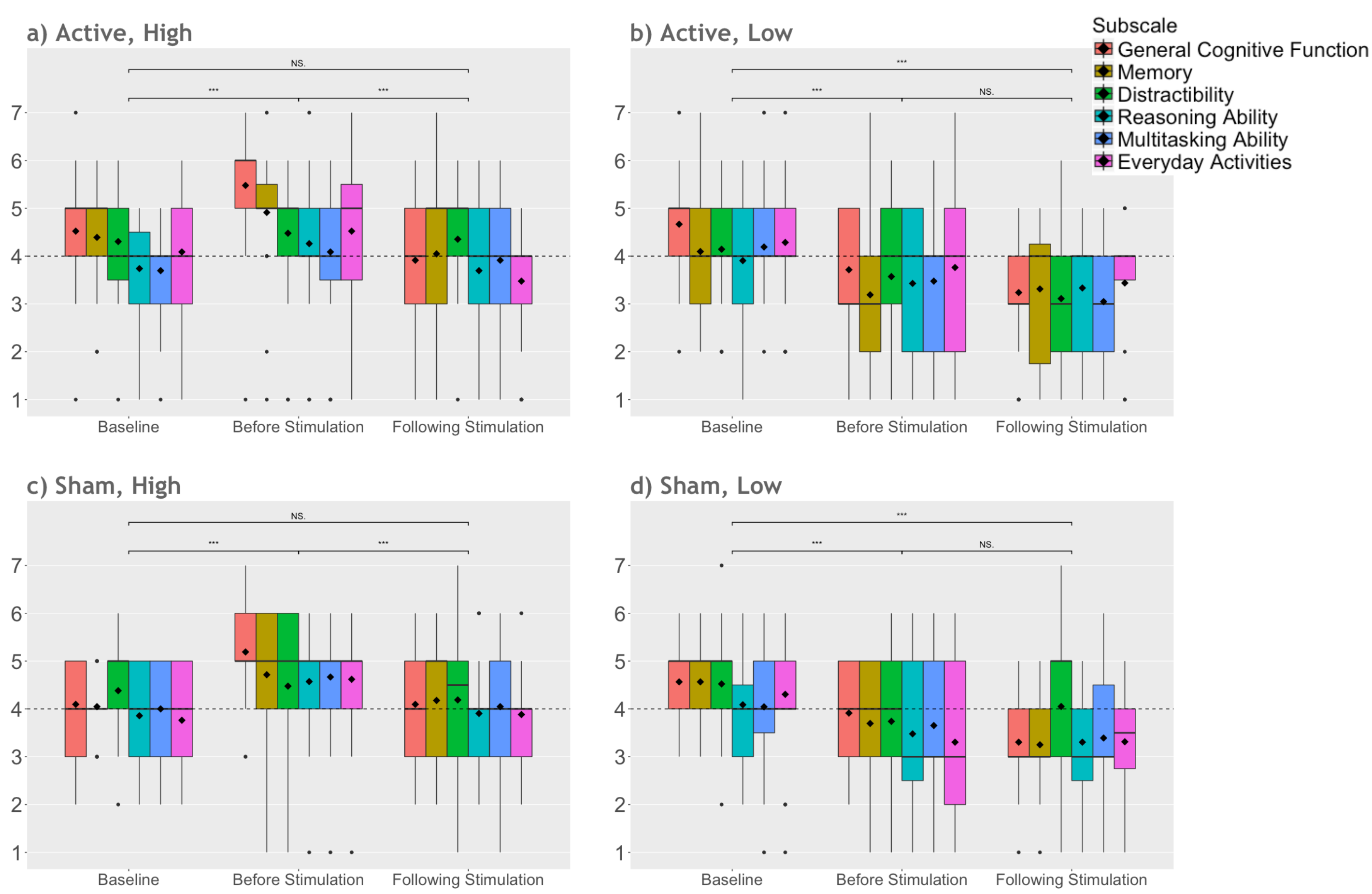


Fig. 2. Mean group ratings of expected tDCS effectiveness for improving performance in participants who received a) active stimulation and high expectation priming, b) active stimulation and low expectation priming, c) sham stimulation and high expectation priming, and d) sham stimulation and low expectation priming. The upper and lower whiskers represent 1.5 x the inter-quartile range. Dashed lines indicate a neutral score (rating of “4”); bold lines indicate group medians; diamonds indicate group means. *$p < .05$. **$p < .01$. ***$p < .001$.

Does expectation priming interact with stimulation effects on cognitive performance?

Online Working Memory Task

Participants in all groups completed approximately four trial blocks in total during stimulation ($M = 4.11$, $SD = 1.68$; *ns*). For sessions where trial blocks were randomized across the three types of n-back, the number of trial blocks completed in each type of n-back did not differ between groups (Table 2a).

Table 2. a) Mean number of n-back trial blocks completed during stimulation and b) proportion of correct responses, based on n-back type, for participants who received all three types of n-back.

a)	**Letter-Number n-back**	**Image n-back**	**Spatial n-back**
Active, High	1.27 ± 1.44	.26 ± .46	1.07 ± 1.39
Active, Low	1.29 ± 1.44	.36 ± .50	.93 ± .92
Sham, High	1.56 ± 1.50	.19 ± .40	1.31 ± 1.25
Sham, Low	1.61 ± 1.72	.33 ± .49	.78 ± 1.00
b)			
Active, High	.92 ± .07	.96 ± .08	.95 ± .06
Active, Low	.89 ± .09	.92 ± .06	.91 ± .07
Sham, High	.87 ± .10	.97 ± .40	.89 ± .09
Sham, Low	.92 ± .08	.94 ± .49	.93 ± .08

ANOVA examining n-back performance[1] across expectation priming (high vs. low priming) and stimulation condition (active vs. sham) revealed a significant interaction between expectation and stimulation on correct trials (i.e., hits and correct rejections; $F_{[1, 68]} = 9.002$, $p = .004$, $\eta_p^2 = .117$; Fig. 4). Specifically, participants who received low expectation priming and active tDCS had significantly fewer correct trials (i.e., correct identification of targets and correct rejection of distractors) compared to their counterparts who received high expectation priming and active tDCS ($t_{(20.28)} = 2.754$, $p = .012$; $M_{diff} = .085$, $CI = .02$-$.149$; Cohen's $d = 1$; Fig. 3a). These differences remained significant after accounting for baseline expectations and performance on neuropsychological tests, as well as anticipated and experienced side effects. We

[1] Because we erred in not distinguishing between hits and correct rejections in programming our database, we were unable to analyse n-back performance as a function of hits vs. false alarms. We did, however, distinguish false alarms from misses in incorrect trials. Therefore, we were unable to perform sensitivity and bias analyses.

found a comparable, albeit non-significant, pattern for false alarms (i.e., incorrect identification of distractors as targets as a proportion of incorrect trials; Fig. 3b). However, we found no main effect of expectation priming ($F_{[1, 68]} = 3.819$, $p = .055$) or stimulation condition ($F_{[1, 68]} = .107$, $p = .744$) on n-back performance.

For participants who completed all three types of n-back, we included n-back type as a within-subjects variable in a separate ANOVA of performance, as measured by correct responses. We found a significant main effect of n-back type ($F_{[1.63, 96.04]} = 3.752$, $p = .035$, $\eta_p^2 = .06$), but no interaction between n-back type and expectation ($F_{[1.63, 96.04]} = 1.065$, $p = .348$) or stimulation condition ($F_{[1.63, 96.04]} = .679$, $p = .48$), and no three-way interaction between these variable ($F_{[1.63, 96.04]} = .008$, $p = .697$). Following up on the effect of n-back type revealed that performance was significantly higher on the image n-back compared to the letter-number n-back ($t_{(63)} = 2.38$, $p = .02$; $M_{diff} = .046$, $CI = .007$-$.085$; Cohen's $d = .60$; Table 2b). As in our previous analysis, we also found a significant interaction between expectation priming and stimulation condition ($F_{[1,59]} = 7.38$, $p = .009$, $\eta_p^2 = .11$), wherein participants who received low expectation priming and active tDCS had significantly fewer correct trials compared to those who received high expectation priming and active tDCS ($t_{(27)} = 2.553$, $p = .017$; $M_{diff} = .058$, $CI = .023$-$.105$; Cohen's $d = .98$).

Executive Function Transfer Tasks

Pearson correlations demonstrated significant positive correlations between most executive function scores ($r \geq .261$, $p < .014$), with the exception of BDS and SF ($r=.192$, *ns*). PCA indicated that all scores loaded onto a single component, explaining 53.56% of the sample variance.

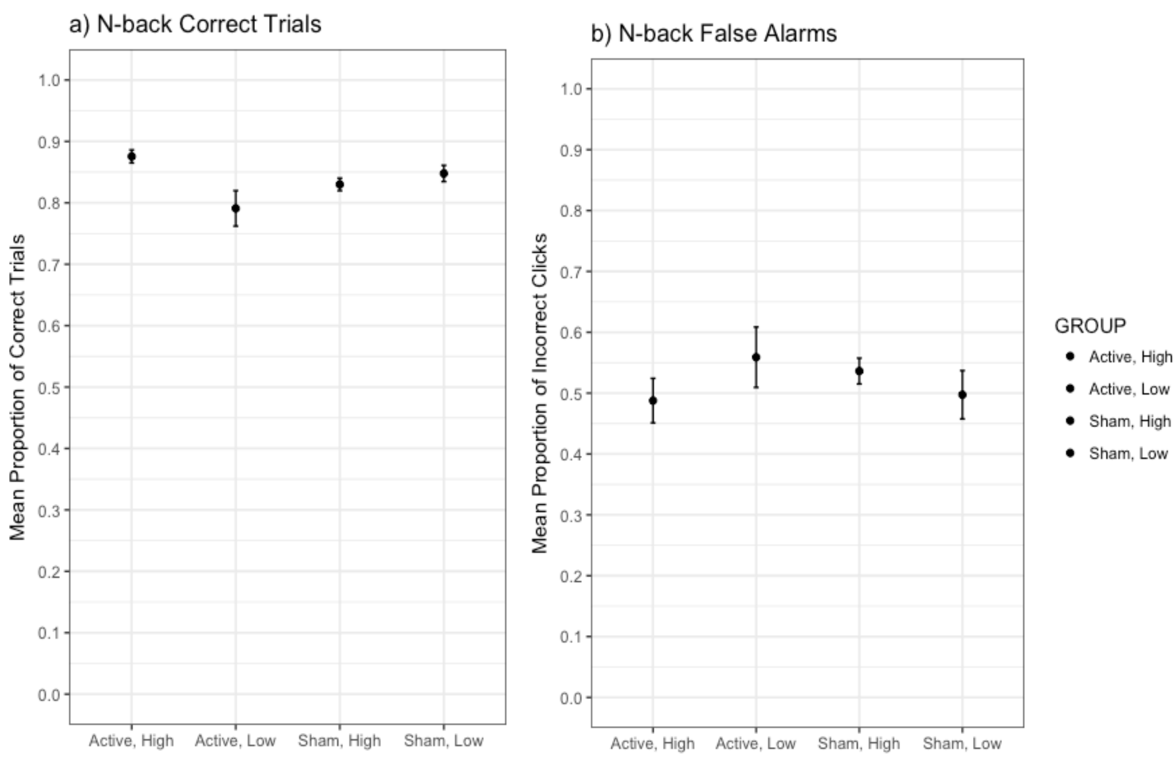


Fig. 3. Performance on n-back task represented as a) correct trials (i.e., correct identification of targets and rejection of distractors) and b) false alarm rate (i.e., incorrect identification of distractors as targets, as a proportion of incorrect trials). Results indicate that, among participants who received active tDCS, the proportion of correct trials was significantly higher in participants who received high expectation priming compared to those who received low expectation priming. Despite greater variability in scores of participants who received active stimulation and low expectation priming, these results are not driven by outliers. Error bars represent standard error of the mean. Due to technical issues with task programming, we were unable to separate hits and correct rejections.

Repeated measures ANOVA of priming (high vs. low) and stimulation (active vs. sham) condition across time (i.e., before and after the stimulation procedure) revealed a significant effect of time ($F_{[1, 84]} = 64.12$, $p < .0001$, $\eta_p^2 = .433$), of expectation priming ($F_{[1,84]} = 4.169$, $p = .044$, $\eta_p^2 = .047$), and an interaction between time and expectation priming ($F_{[1, 84]} = 4.468$, $p = 0.037$, $\eta_p^2 = .051$) on the standardized executive function composite score (Fig. 4). Closer examination of the interaction between time and expectation priming revealed greater improvement in participants who received high expectation priming, compared to those assigned to low expectation priming; although performance was not significantly different between the two priming conditions at baseline ($t_{(86)} = 1.559$, $p = .123$; $M_{diff} = .237$, $CI = .065\text{-}.54$), participants in the high expectation condition performed better than those in the low expectation condition following stimulation ($t_{(86)} = 2.459$, $p = .016$; $M_{diff} = .394$, $CI = .076\text{-}.713$; Cohen's $d = .53$). We did not find a main effect of stimulation ($F_{[1,84]} = .001$, $p = .973$), interactions between time and stimulation ($F_{[1,84]} = .001$, $p = .977$) or expectation priming and stimulation ($F_{[1,84]} = .167$, $p = .684$), or a three-way interaction between time, priming, and stimulation ($F_{[1,84]} = 1.975$, $p = .164$).

We re-analyzed these results in an ANCOVA, with the inclusion of baseline ratings on all 6 cognitive domains as covariates. We found the same general pattern of results, with the following differences: a smaller effect of time ($F_{[1, 78]} = 6.24$, $p = .015$, $\eta_p^2 = .074$) and marginal effect of priming ($F_{[1, 78]} = 6.24$, $p = .06$), but larger interaction between time and priming ($F_{[1, 78]} = 5.27$, $p = .024$, $\eta_p^2 = .063$).

Performing the ANOVA on the condensed executive function composite score (i.e., including only the LNS, BDS, and LF scores) demonstrated a significant effect of time ($F_{[1, 84]} = 46.345$, $p < .0001$, $\eta_p^2 = .355$) and a subtle interaction between time and expectation priming ($F_{[1, 84]} = 3.905$, $p = 0.051$, $\eta_p^2 = .044$). Closer examination of the interaction revealed greater improvement in participants who received high expectation priming, compared to those assigned to low expectation priming. Specifically, although baseline performance did not significantly differ between the two priming conditions ($t_{(86)} = 1.231$, $p = .222$; $M_{diff} = .199$, $CI = .122\text{-}.519$), following stimulation participants in the high expectation condition performed better than those in the low expectation condition ($t_{(86)} = 2.294$, $p = .024$; $M_{diff} = .387$, $CI = .052\text{-}.722$; Cohen's $d = .49$). We did not find a main effect of expectation priming ($F_{[1,84]} = 3.394$, $p = .069$), of stimulation ($F_{[1,84]} = .113$, $p = .737$), interactions between time and stimulation ($F_{[1,84]} = .191$, $p =$

.663) or expectation priming and stimulation ($F_{[1,84]} = .620$, $p = .433$), or a three-way interaction between time, priming, and stimulation ($F_{[1,84]} = 1.057$, $p = .307$).

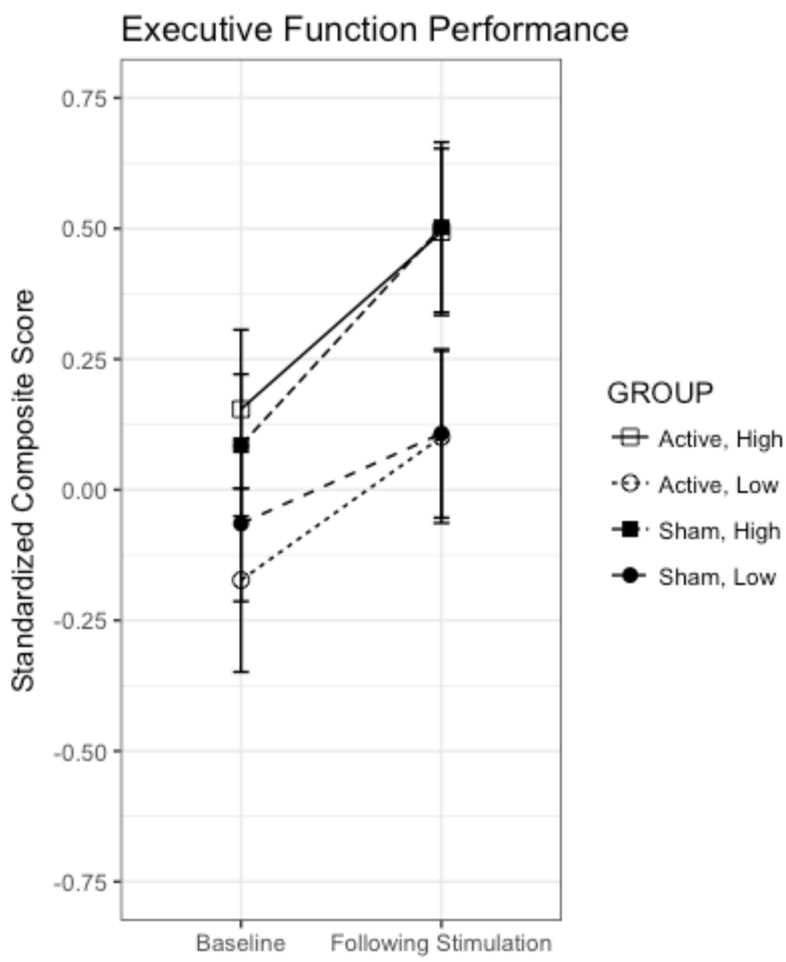


Fig. 4. Executive function performance represented as standardized composite scores of all transfer tests at baseline and following stimulation. Results indicate a significant interaction between time, expectation priming, and stimulation condition. Bars represent standard error of the mean.

Does perceived application of non-invasive brain stimulation influence cognitive performance?

Following the stimulation procedure, we asked all participants if they believed their brain was genuinely stimulated during the course of the study. The majority of participants in each of the experimental conditions (67-81%) believed their brains were stimulated during the study;

these proportions did not significantly differ between the experimental conditions. Moreover, repeating our analyses based on this perceived application of stimulation (i.e., "belief") revealed no significant effect of belief on neuropsychological or WM performance. Similarly, repeated measures ANOVA examining expectation ratings in the different cognitive domains did not reveal significant differences at baseline, after receiving the priming message, or following stimulation based on belief.

Do expectations or performance influence subjective experience?

In addition to asking about perceived nature of stimulation, we asked participants to rate their experience with the brain stimulation program. MANOVA across expectation priming and stimulation conditions revealed a significant effect of expectation priming on subjective experience ($F_{[7,78]} = 2.263$, $p = .038$, $\eta_p^2 = .169$).

After correcting for multiple comparisons, we found that participants who received high expectation priming reported higher levels of enjoyment ($F_{[1,84]} = 9.737$, $p = .002$, $\eta_p^2 = .104$), engagement ($F_{[1,84]} = 7.183$, $p = .009$, $\eta_p^2 = .079$), motivation ($F_{[1,84]} = 8.146$, $p = .005$, $\eta_p^2 = .088$), and satisfaction ($F_{[1,84]} = 8.169$, $p = .005$, $\eta_p^2 = .089$), compared to participants in the low expectation priming condition. Subjective experience did not differ based on stimulation condition, and did not significantly influence cognitive performance or expectation ratings at baseline. In an exploratory analysis of these feedback ratings, we did not find differences between participants who believed they received stimulation vs. those who did not.

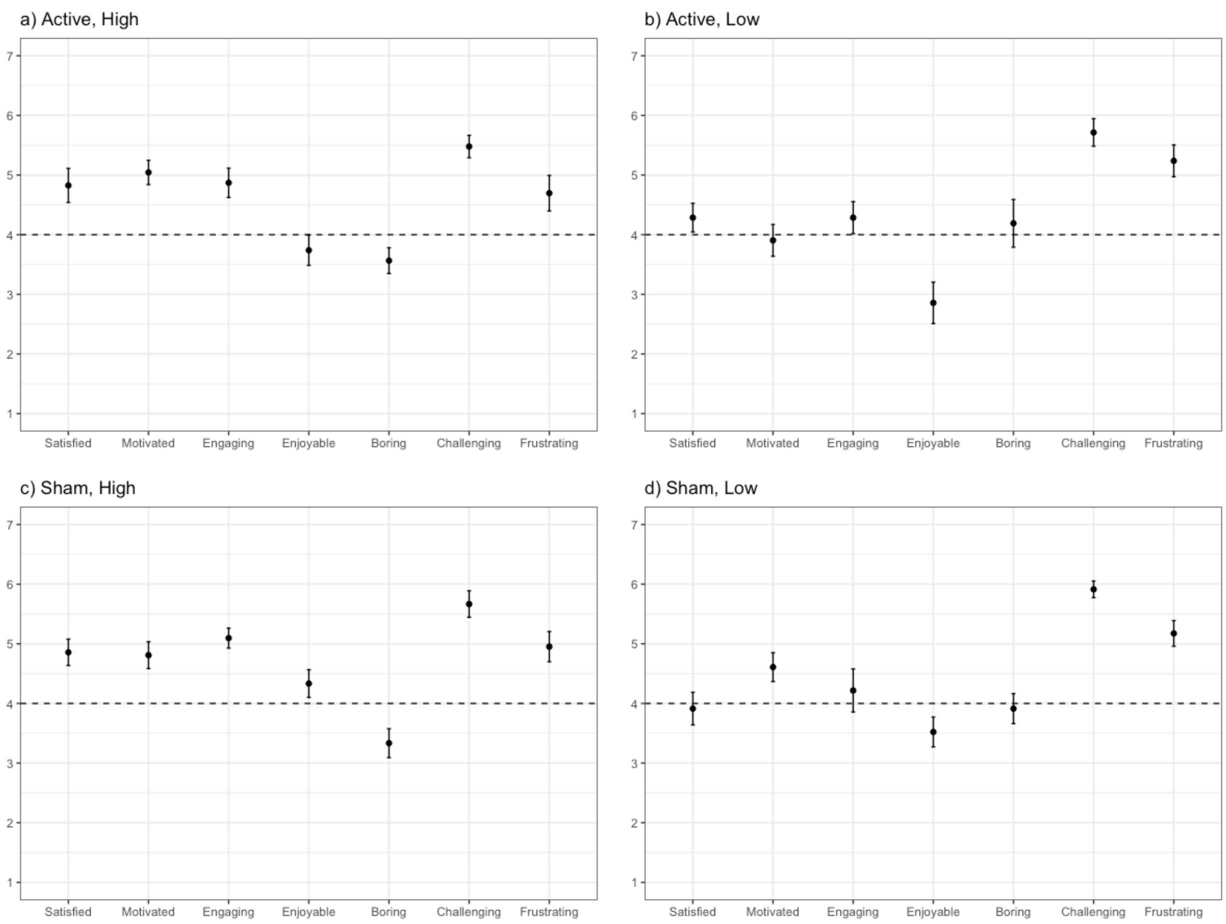


Fig. 5. Feedback on perceived experience.

Are any individual factors associated with expectations or performance?

Based on our previous studies (Rabipour et al., 2017; Rabipour & Davidson, 2015), we examined whether prior knowledge of or experience with brain stimulation might influence expectations or cognitive performance. About one third of participants (30%) had previously heard of brain stimulation, and 20% had prior exposure to media reports about cognitive stimulation, but only 6% had any prior experience with brain stimulation. These proportions did not differ between experimental groups. Conversely, most participants (57%) reported having online gaming experience; the proportion was highest in people assigned to receive high expectation priming and active stimulation (21/24 = 88%; $X^2 = 12.924$, $p = .005$). Neither expectations nor cognitive performance differed based on these individual factors.

We further explored whether gender might have an effect on our outcomes. Including gender as a variable in the repeated measures ANOVA for expectations ratings revealed no difference between women and men. However, adding gender as a variable in the ANOVA examining executive function composite scores across time revealed a significant main effect of gender ($F_{[1,80]} = 4.143$, $p = .045$, $\eta_p^2 = .049$) and significant three-way interaction between time, stimulation condition, and gender ($F_{[1,80]} = 4.631$, $p = .034$, $\eta_p^2 = .055$). Breaking down executive function scores across gender in each stimulation condition revealed a significant main effect of gender in participants who received sham stimulation ($F_{[1,39]} = 7.714$, $p = .008$, $\eta_p^2 = .165$), with higher scores in men both at baseline ($t_{(41)} = 2.55$, $p = .015$; $M_{diff} = .51$, $CI = .105$-$.905$; Cohen's d = 0.78) and following stimulation ($t_{(41)} = 2.797$, $p = .008$; $M_{diff} = .654$, $CI = .182$-1.126; Cohen's $d = 0.84$); we did not find an effect of gender in participants who received active tDCS ($F_{[1,41]} = .123$, $p = .728$). We did not find significant gender differences on n-back performance when adding gender as a factor to the ANOVA examining correct responses and false alarm rate across stimulation and priming conditions.

We did not find any group differences in reported levels of computer exposure, programming experience, or concern over declining cognitive functions (Table 3).

Table 3. Individual characteristics of participants across experimental conditions. Numbers represent the largest reported proportion per category.

	Computer Exposure: >2h per day	**Programming Experience: None**	**Concern over Cognitive Functions: None**
Active, High	21/23 (91%)	14/23 (61%)	21/23 (91%)
Active, Low	13/21 (62%)	14/21 (67%)	18/21 (86%)
Sham, High	16/21 (76%)	13/21 (62%)	20/21 (95%)
Sham, Low	17/23 (74%)	16/23 (70%)	20/23 (87%)

Did anticipated or experienced side effects interact with expectations or performance?

We asked participants about anticipated and experienced side effects before and after the stimulation procedure, respectively (Table 4). In each group, about half of participants or fewer (≤54%) anticipated experiencing side effects. After experiencing the stimulation procedure, however, the majority of participants in all groups (≥82%) – notably, all participants who received low expectation priming and active stimulation – reported experiencing at least one side effect. Similarly, the reported intensity was mild in the majority of participants in each group who reported experiencing side effects (≥67%), except for participants who received low expectation priming and active stimulation, who reported "considerable" intensity (35%), followed by "moderate" (29%), "mild" (24%) and "strong" (12%); this difference was significant compared to people who received high expectation priming and active stimulation ($X^2 = 8.316$, $p = 0.04$). Moreover, we found a significant difference in reports of itchiness in people who received active stimulation, wherein a larger proportion of people who received low expectation priming reported experiencing itchiness, compared to those who received high expectation priming ($X^2 = 10.286$, $p = 0.001$). Similarly, of people who received active stimulation, a larger proportion of people who received low (compared to high) expectation priming reported experiencing warmth or heat ($X^2 = 6.747$, $p = 0.009$). The anticipation or overall experience of side effects did not significantly differ between groups, and did not significantly correlate with differences in expectation ratings, executive function scores, or WM performance.

Table 4. Proportion of participants who reported anticipating and experiencing side effects.

	Anticipated Side Effects	**Experienced: Itchiness**	**Experienced: Warmth / heat**	**Experienced: Pinching**	**Experienced: Pain**	**Experienced: Iron taste**	**Experienced: Fatigue**
Active, High	12/23 (52%)	8/22 (36%)	7/22 (32%)	5/22 (23%)	2/22 (9%)	0/22 (0%)	2/22 (9%)
Active, Low	7/21 (33%)	17/20 (85%)	15/21 (71%)	7/21 (33%)	7/21 (33%)	1/21 (5%)	4/21 (19%)
Sham, High	5/20 (25%)	13/20 (65%)	8/20 (40%)	3/20 (15%)	2/20 (10%)	1/20 (5%)	2/20 (10%)
Sham, Low	7/23 (30%)	9/22 (41%)	10/23 (44%)	10/23 (44%)	5/23 (22%)	1/23 (4%)	1/23 (4%)

For clarity, we summarize our most pertinent findings in Table 5; see above for greater detail on each finding.

Table 5. Summary of results per experimental condition, with respect to: a) expectation ratings; b) composite Z scores on the executive function transfer tasks, with all scores normalized to baseline; c) proportion of correct trials (i.e., correct identification of targets and rejection of distractors) and false alarms (i.e., incorrect identification of distractors as targets, as a proportion of incorrect trials) on the WM task; and d) feedback ratings of subjective experience.

		Main Finding
a)	**Expectations of Outcomes**	• Ratings largely ”neutral” at baseline • Ratings increase after high expectation priming and decrease after low expectation priming • Following stimulation, ratings decrease across all groups
b)	**N-back performance**	• Number of correct trials lowest in people who received active stimulation and low expectation priming • Number of false alarms comparable across all groups
c)	**Executive Function Scores**	• Performance similar between groups at baseline • Following stimulation, improvement greater after receiving high (vs. low) expectation priming • No difference in performance based on stimulation
d)	**Subjective experience**	• Greater perceived enjoyment, engagement, motivation, and overall satisfaction in participants who received high (vs. low) expectation priming • No group differences in perceived challenge, frustration, or boredom with the tasks

Discussion

Attitudes towards an intervention may greatly impact outcomes through placebo-like effects (Benedetti, Carlino, & Pollo, 2011). Factors such as expectation and satisfaction have potentially important implications for intervention adoption and adherence: for example, high expectations of positive outcomes may lead people to select and invest more time and resources in one program over another, and enhance their responsiveness to treatment. Conversely, low expectations may deter people from pursuing or adhering to an intervention. Given the current uncertainties surrounding tDCS mechanisms and the inconsistent findings in this field, understanding the potential interactions between expectations and stimulation is crucial.

Here we found that healthy subjects are generally uncertain about the effectiveness of NIBS in improving cognitive performance based on prior knowledge or familiarity with the concept. These neutral baseline ratings replicate our previous findings from people who completed our expectation scale as part of an online survey (Rabipour et al., 2017), suggesting that uncertainty about NIBS effectiveness extends to people who are willing to participate in such studies. Baseline ratings of perceived brain stimulation effectiveness did not appear to be influenced by exposure to advertisements and other media reports claiming that brain stimulation can improve cognitive function. Notably, very few participants reported having any prior experience with NIBS.

Our results further suggest that expectations of NIBS are malleable in response to simple written messages, even with a single exposure. Specifically, we demonstrate that reading information supporting the effectiveness of brain stimulation may induce higher expectations of improved cognitive performance, as well as improvements on objective measures of cognitive function. Conversely, reading information criticizing brain stimulation appears to decrease people's expectations of brain stimulation effectiveness, and may subtly interfere with interventions aimed at improving cognitive performance. These patterns appear irrespective of whether the tDCS is genuinely applied throughout the session (i.e., active versus sham stimulation), and may be particularly pronounced in people who receive active stimulation.

Expectations of outcomes may influence cognitive performance. We found a subtle interaction between expectation priming and stimulation condition on both the neuropsychological transfer tests and the WM task performed concurrently with stimulation. Performance was greatest in people who received high, compared to low, expectation priming, irrespective of stimulation condition, suggesting a possible benefit of high expectations over stimulation. Conversely, participants randomly assigned to receive low expectation priming and active stimulation had the lowest performance scores on the WM task, suggesting that stimulation may have interfered with performance. Moreover, we found no evidence of improvement on the neuropsychological tests in participants assigned to receive low expectation priming, irrespective of active or sham stimulation. These effects are unlikely to result from knowledge of assignment to experimental condition (i.e., inadequate blinding), with the majority of participants believing that current was genuinely applied throughout the stimulation procedure.

Although differences in baseline performance on the neuropsychological tests were not statistically significant, a potential consideration is that participants randomly assigned to receive high expectation priming had slightly higher baseline scores than those assigned to the low expectation priming condition. Differences in baseline performance may explain why the interaction between time and expectation priming became marginal when examining performance on executive function transfer tests using a more conservative approach (i.e., with the condensed composite scores). Only future work will clarify this.

Notably, we found no evidence for an effect of stimulation condition on either the online WM task or the transfer measures of executive function. Coupled with the possible influence of expectations on outcomes, these findings put into the question the nature of reported stimulation effects in other studies examining tDCS and cognitive function.

Importantly, we found that people who received high expectation priming reported having a more positive experience, including greater enjoyment, engagement with the program, motivation to perform well, and satisfaction with the program. These findings have important potential implications for multi-session studies, which are becoming increasingly common: higher expectations of outcomes, either based on prior knowledge or delivered through researchers and clinicians – directly, via information provided, or indirectly, based on their attitudes and perceptions – may lead participants to be more enthusiastic after the first session and indirectly influence other outcomes.

Reports of anticipated and experienced side effects did not significantly differ across most conditions, although reports were greatest among participants assigned to receive low expectation priming and active stimulation. This may reflect a larger degree of surprise regarding the experience of sensations as well as greater allocation of attention to the sensations during task performance in these participants, who may have expected to receive sham stimulation based on their priming message. However, although side effects may have contributed to differences in performance and perceived experience, they are unlikely to have been the sole contributor to the group differences we found.

Despite the overarching uncertainty about NIBS outcomes at the outset of the tDCS procedure, and the malleability of expectations following expectation priming with the High and Low expectation messages, we found that all participants reported lower expectations of effectiveness following the stimulation procedure. This finding may reflect perceived difficulty of the WM task completed concurrently with tDCS, as the majority of participants expressed low confidence in their performance, as well as discomfort based on experienced side effects. However, factors such as perceived frustration and motivation did not account for differences in cognitive performance following tDCS in our sample. Taken together, our results suggest that expectations of NIBS may shape cognitive function independently of perceived performance.

Limitations

Due to the subjective nature of surveys, we cannot rule out the possibility that our participants simply provided the responses they believed we wanted (i.e., "demand characteristics"). However, differences in cognitive performance outcomes following our balanced-placebo protocol offer evidence of a potential causal influence of expectations on cognitive performance following tDCS. Moreover, although our selected outcome measures (n-back task of WM and transfer tests of executive function) are commonly used in studies of cognitive function and NIBS, they may have been too coarse to detect subtle differences based on our experimental conditions. Our use of a single-task paradigm, rather than dual task, may explain why our results did not replicate those of Martin et al. (2014). Similarly, other methods of priming may be more powerful in creating an effect on stimulation outcomes. Finally, our sample of undergraduate students was relatively uniform, with few differences in background characteristics that may play a role in expectations of brain stimulation (e.g., education level, education type, culture, computer exposure, etc.). Thus, findings of this study are not necessarily representative of the general population. Related to the issue of sample composition is the issue of sample size. Although we determined sample size based on a priori power analyses, as with any study it is possible that a larger sample would have helped make our results easier to interpret. For example, in earlier analyses we included data on correct n-back trials from a participant who only had partial data available (i.e., no data on false alarm rate). The addition of this single data point made our results more pronounced, leading to a significant effect of expectation priming and larger interaction effect between expectation priming and stimulation condition on n-back performance. We ultimately decided to omit such data from our final analyses for a more conservative approach (see Materials and Methods), yielding the reported results. This example highlights issues regarding statistical power endemic to tDCS research.

Significance for real-world trials

Our findings highlight the urgent need to consider the potential long-term effects of people's beliefs in clinical trials and protocols. Here we were able to shape healthy subjects' expectations with a simple, brief message, in just one lab session. These effects might be even greater in real-world situations, particularly for programs or treatments that require long-term compliance in patients seeking treatment for their condition. Trials may succeed or fail due to people's pre-existing beliefs regarding the effectiveness of treatment received. In addition to a possible direct influence on outcomes, satisfaction with a program (or lack thereof) can potentially amplify results by positively or negatively affecting attrition rates and participant persistence over the course of treatment. Without evaluating the potential influence of such factors, the therapeutic viability of tDCS and optimal treatment parameters will remain unclear.

Conclusions

The present study is the first, to our knowledge, to directly examine expectations of NIBS outcomes in the lab setting. Our overt attempt to prime expectations revealed subtle evidence for a potential causal influence of expectations on cognitive performance following tDCS. Notably, we found no group differences on the basis of stimulation. Results from our cognitive tasks suggest that positive priming may have beneficial effects on intervention experience and subsequent performance, whereas low expectations might be counterproductive in some cases (e.g., during administration of tDCS).

Replications of this study should examine the conditions under which expectations and stimulation meaningfully interact. Similarly, long-term investigations involving multiple sessions would further help elucidate the sustainability and potential additive effects of NIBS and expectations on cognitive performance. As such NIBS approaches become more common, people may form expectations that could interact with other intervention outcomes.

Here we show the importance of assessing participant expectations as a possible influence on the outcomes of cognitive interventions, and examining potential interactions between expectations and NIBS or related approaches to cognitive enhancement. Given the widespread appeal of NIBS as an affordable and accessible intervention in both healthy and clinical populations, understanding the potential impact of expectations is imperative to intervention design and for assessing the practical value of specific techniques.

Acknowledgements

We thank Anita Popescu and Vilma Bezerra Alves for help with data processing, as well as Sima Sadeghinejad, Shreya Sreekantaswamy, and members of the Neuromodulation Lab at UCLA for help with data collection. We also thank Dr. Walter Dunn for helpful feedback on study design. For generous support the authors also wish to thank the Brain Mapping Medical Research Organization, Brain Mapping Support Foundation, Pierson-Lovelace Foundation, The Ahmanson Foundation, William M. and Linda R. Dietel Philanthropic Fund at the Northern Piedmont Community Foundation, Tamkin Foundation, Jennifer Jones-Simon Foundation, Capital Group Companies Charitable Foundation, Robson Family and Northstar Fund, as well as the Natural Sciences and Engineering Research Council (NSERC, Discovery Grant), Ontario Graduate Scholarships, and Fonds de Recherche Québec – Santé.

References

Au, J., Katz, B., Buschkuehl, M., Bunarjo, K., Senger, T., Zabel, C., . . . Jonides, J. (2016). Enhancing Working Memory Training with Transcranial Direct Current Stimulation. *Journal of Cognitive Neuroscience, 28*(9), 1419-1432. doi: 10.1162/jocn_a_00979

Axelrod, B. N., Fichtenberg, N. L., Millis, S. R., & Wertheimer, J. C. (2006). Detecting incomplete effort with digit span from the Wechsler Adult Intelligence Scale - Third edition. *Clinical Neuropsychologist, 20*(3), 513-523. doi: Doi 10.1080/13854040590967117

Benedetti, F., Carlino, E., & Pollo, A. (2011). How Placebos Change the Patient's Brain. *Neuropsychopharmacology, 36*(1), 339-354. doi: Doi 10.1038/Npp.2010.81

Bennabi, D., Pedron, S., Haffen, E., Monnin, J., Peterschmitt, Y., & Van Waes, V. (2014). Transcranial direct current stimulation for memory enhancement: from clinical research to animal models. *Front Syst Neurosci, 8*, 159. doi: 10.3389/fnsys.2014.00159

Berlim, M. T., Van den Eynde, F., & Daskalakis, Z. J. (2013). Clinical utility of transcranial direct current stimulation (tDCS) for treating major depression: A systematic review and meta-analysis of randomized, double-blind and sham-controlled trials. *Journal of Psychiatric Research, 47*(1), 1-7. doi: 10.1016/j.jpsychires.2012.09.025

Bikson, M., Grossman, P., Thomas, C., Zannou, A. L., Jiang, J., Adnan, T., . . . Woods, A. J. (2016). Safety of Transcranial Direct Current Stimulation: Evidence Based Update 2016. *Brain Stimul, 9*(5), 641-661. doi: 10.1016/j.brs.2016.06.004

Chew, T., Ho, K. A., & Loo, C. K. (2015). Inter- and Intra-individual Variability in Response to Transcranial Direct Current Stimulation (tDCS) at Varying Current Intensities. *Brain Stimulation, 8*(6), 1130-1137. doi: 10.1016/j.brs.2015.07.031

Coffman, B. A., Clark, V. P., & Parasuraman, R. (2014). Battery powered thought: Enhancement of attention, learning, and memory in healthy adults using transcranial direct current stimulation. *Neuroimage, 85*, 895-908. doi: 10.1016/j.neuroimage.2013.07.083

Crowe, S. F. (2000). Does the letter number sequencing task measure anything more than digit span? *Assessment, 7*(2), 113-117. doi: Doi 10.1177/107319110000700202

Dockery, C. A., Hueckel-Weng, R., Birbaumer, N., & Plewnia, C. (2009). Enhancement of Planning Ability by Transcranial Direct Current Stimulation. *Journal of Neuroscience, 29*(22), 7271-7277. doi: Doi 10.1523/Jneurosci.0065-09.2009

Farah, M. J. (2015). The unknowns of cognitive enhancement. *Science, 350*(6259), 379-380. doi: 10.1126/science.5893

Filmer, H. L., Dux, P. E., & Mattingley, J. B. (2014). Applications of transcranial direct current stimulation for understanding brain function. *Trends Neurosci, 37*(12), 742-753. doi: 10.1016/j.tins.2014.08.003

Foroughi, C. K., Monfort, S. S., Paczynski, M., McKnight, P. E., & Greenwood, P. M. (2016). Placebo effects in cognitive training. *Proc Natl Acad Sci U S A, 113*(27), 7470-7474. doi: 10.1073/pnas.1601243113

Freitas, C., Mondragon-Llorca, H., & Pascual-Leone, A. (2011). Noninvasive brain stimulation in Alzheimer's disease: Systematic review and perspectives for the future. *Experimental Gerontology, 46*(8), 611-627. doi: 10.1016/j.exger.2011.04.001

Gandiga, P. C., Hummel, F. C., & Cohen, L. G. (2006). Transcranial DC stimulation (OCS): A tool for double-blind sham-controlled clinical studies in brain stimulation. *Clinical Neurophysiology, 117*(4), 845-850. doi: Doi 10.1016/J.Clinph.2005.12.003

Iyer, M. B., Mattu, U., Grafman, J., Lomarev, M., Sato, S., & Wassermann, E. M. (2005). Safety and cognitive effect of frontal DC brain polarization in healthy individuals. *Neurology, 64*(5), 872-875. doi: 10.1212/01.WNL.0000152986.07469.E9

Jones, K. T., Gozenman, F., & Berryhill, M. E. (2015). The strategy and motivational influences on the beneficial effect of neurostimulation: A tDCS and fNIRS study. *Neuroimage, 105*, 238-247. doi: 10.1016/j.neuroimage.2014.11.012

Kekic, M., Boysen, E., Campbell, I. C., & Schmidt, U. (2016). A systematic review of the clinical efficacy of transcranial direct current stimulation (tDCS) in psychiatric disorders. *Journal of Psychiatric Research, 74*, 70-86. doi: 10.1016/j.jpsychires.2015.12.018

Kincses, T. Z., Antal, A., Nitsche, M. A., Bartfai, O., & Paulus, W. (2004). Facilitation of probabilistic classification learning by transcranial direct current stimulation of the prefrontal cortex in the human. *Neuropsychologia, 42*(1), 113-117. doi: Doi 10.1016/S0028-3932(03)00124-6

Lanting, S., Haugrud, N., & Crossley, M. (2009). The effect of age and sex on clustering and switching during speeded verbal fluency tasks. *Journal of the International Neuropsychological Society, 15*(2), 196-204. doi: Doi 10.1017/S1355617709090237

Li, L. M., Uehara, K., & Hanakawa, T. (2015). The contribution of interindividual factors to variability of response in transcranial direct current stimulation studies. *Frontiers in Cellular Neuroscience, 9*. doi: ARTN 181
10.3389/fncel.2015.00181

Lopez-Alonso, V., Cheeran, B., Rio-Rodriguez, D., & Fernandez-del-Olmo, M. (2014). Inter-individual Variability in Response to Non-invasive Brain Stimulation Paradigms. *Brain Stimulation, 7*(3), 372-380. doi: 10.1016/j.brs.2014.02.004

Luber, B., & Lisanby, S. H. (2014). Enhancement of human cognitive performance using transcranial magnetic stimulation (TMS). *Neuroimage, 85*, 961-970. doi: 10.1016/j.neuroimage.2013.06.007

Martin, D. M., Liu, R., Alonzo, A., Green, M., & Loo, C. K. (2014). Use of transcranial direct current stimulation (tDCS) to enhance cognitive training: effect of timing of stimulation. *Experimental Brain Research, 232*(10), 3345-3351. doi: Doi 10.1007/S00221-014-4022-X

McCabe, D. P., Roediger, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The Relationship Between Working Memory Capacity and Executive Functioning: Evidence for a Common Executive Attention Construct. *Neuropsychology, 24*(2), 222-243. doi: 10.1037/a0017619

McCambridge, J., Witton, J., & Elbourne, D. R. (2014). Systematic review of the Hawthorne effect: New concepts are needed to study research participation effects. *Journal of Clinical Epidemiology, 67*(3), 267-277. doi: Doi 10.1016/J.Jclinepi.2013.08.015

McIntire, L. K., McKinley, R. A., Goodyear, C., & Nelson, J. (2014). A Comparison of the Effects of Transcranial Direct Current Stimulation and Caffeine on Vigilance and Cognitive Performance During Extended Wakefulness. *Brain Stimulation, 7*(4), 499-507. doi: 10.1016/j.brs.2014.04.008

Medina, J., & Cason, S. (2017). No evidential value in samples of transcranial direct current stimulation (tDCS) studies of cognition and working memory in healthy populations. *Cortex, 94*, 131-141. doi: 10.1016/j.cortex.2017.06.021

Monti, A., Ferrucci, R., Fumagalli, M., Mameli, F., Cogiamanian, F., Ardolino, G., & Priori, A. (2013). Transcranial direct current stimulation (tDCS) and language. *Journal of*

Neurology Neurosurgery and Psychiatry, 84(8), 832-842. doi: Doi 10.1136/Jnnp-2012-302825

Nitsche, M. A., Cohen, L. G., Wassermann, E. M., Priori, A., Lang, N., Antal, A., . . . Pascual-Leone, A. (2008). Transcranial direct current stimulation: State of the art 2008. *Brain Stimul, 1*(3), 206-223. doi: 10.1016/j.brs.2008.06.004

Penolazzi, B., Pastore, M., & Mondini, S. (2013). Electrode montage dependent effects of transcranial direct current stimulation on semantic fluency. *Behavioural Brain Research, 248*, 129-135. doi: 10.1016/j.bbr.2013.04.007

Poreisz, C., Boros, K., Antal, A., & Paulus, W. (2007). Safety aspects of transcranial direct current stimulation concerning healthy subjects and patients. *Brain Res Bull, 72*(4-6), 208-214. doi: 10.1016/j.brainresbull.2007.01.004

Rabipour, S., Andringa, R., Boot, W. R., & Davidson, P. S. R. (2017). What Do People Expect of Cognitive Enhancement? *Journal of Cognitive Enhancement*, 1-8. doi: 10.1007/s41465-017-0050-3

Rabipour, S., & Davidson, P. S. R. (2015). Do you believe in brain training? A questionnaire about expectations of computerised cognitive training. *Behavioural Brain Research, 295*, 64-70. doi: 10.1016/j.bbr.2015.01.002

Rabipour, S., Davidson, P. S. R., & Kristjansson, E. (2018). Measuring Expectations of Cognitive Enhancement: Item Response Analysis of the Expectation Assessment Scale. *Journal of Cognitive Enhancement*. doi: 10.1007/s41465-018-0073-4

Redick, T. S., & Lindsey, D. R. B. (2013). Complex span and n-back measures of working memory: A meta-analysis. *Psychonomic Bulletin & Review, 20*(6), 1102-1113. doi: 10.3758/s13423-013-0453-9

Riggall, K., Forlini, C., Carter, A., Hall, W., Weier, M., Partridge, B., & Meinzer, M. (2015). Researchers' perspectives on scientific and ethical issues with transcranial direct current stimulation: An international survey. *Scientific Reports, 5*. doi: ARTN 10618
10.1038/srep10618

Ruf, S. P., Fallgatter, A. J., & Plewnia, C. (2017). Augmentation of working memory training by transcranial direct current stimulation (tDCS). *Scientific Reports, 7*. doi: ARTN 876
10.1038/s41598-017-01055-1

Sandrini, M., Brambilla, M., Manenti, R., Rosini, S., Cohen, L. G., & Cotelli, M. (2014). Noninvasive stimulation of prefrontal cortex strengthens existing episodic memories and reduces forgetting in the elderly. *Frontiers in Aging Neuroscience, 6*(289), 1-9. doi: 10.3389/fnagi.2014.00289

Sarkar, A., Dowker, A., & Cohen Kadosh, R. (2014). Cognitive enhancement or cognitive cost: trait-specific outcomes of brain stimulation in the case of mathematics anxiety. *J Neurosci, 34*(50), 16605-16610. doi: 10.1523/JNEUROSCI.3129-14.2014

Scheldrup, M., Greenwood, P. M., McKendrick, R., Strohl, J., Bikson, M., Alam, M., . . . Parasuraman, R. (2014). Transcranial direct current stimulation facilitates cognitive multi-task performance differentially depending on anode location and subtask. *Front Hum Neurosci, 8*, 665. doi: 10.3389/fnhum.2014.00665

Schwarz, K. A., Pfister, R., & Buchel, C. (2016). Rethinking Explicit Expectations: Connecting Placebos, Social Cognition, and Contextual Perception. *Trends in Cognitive Sciences, 20*(6), 469-480. doi: 10.1016/j.tics.2016.04.001

Shiozawa, P., Duailibi, M. S., da Silva, M. E., & Cordeiro, Q. (2014). Trigeminal nerve stimulation (TNS) protocol for treating major depression: An open-label proof-of-concept trial. *Epilepsy Behav, 39*, 6-9. doi: 10.1016/j.yebeh.2014.07.021

St Clair-Thompson, H. L. (2010). Backwards digit recall: A measure of short-term memory or working memory? *European Journal of Cognitive Psychology, 22*(2). doi: 10.1080/09541440902771299

Underwood, E. (2016). Cadaver study casts doubts on how zapping brain may boost mood, relieve pain. *Science*. Retrieved from doi:**10.1126/science.aaf9938**

Voroslakos, M., Takeuchi, Y., Brinyiczki, K., Zombori, T., Oliva, A., Fernandez-Ruiz, A., . . . Berenyi, A. (2018). Direct effects of transcranial electric stimulation on brain circuits in rats and humans. *Nat Commun, 9*(1), 483. doi: 10.1038/s41467-018-02928-3

Walsh, V. Q. (2013). Ethics and Social Risks in Brain Stimulation. *Brain Stimulation, 6*(5), 715-717. doi: 10.1016/J.Brs.2013.08.001

Zhao, H. C., Qiao, L., Fan, D. Q., Zhang, S. Y., Turel, O., Li, Y. H., . . . He, Q. H. (2017). Modulation of Brain Activity with Noninvasive Transcranial Direct Current Stimulation (tDCS): Clinical Applications and Safety Concerns. *Frontiers in Psychology, 8*. doi: 10.3389/fpsyg.2017.00685