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Targeted training: Converging evidence against the transferable benefits of online brain training on cognitive function

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ABSTRACT

There is strong incentive to improve our cognitive abilities, and brain training has emerged as a promising approach for achieving this goal. While the idea that extensive 'training' on computerized tasks will improve general cognitive functioning is appealing, the evidence to support this remains contentious. This is, in part, because of poor criteria for selecting training tasks and outcome measures resulting in inconsistent definitions of what constitutes transferable improvement to cognition. The current study used a targeted training approach to investigate whether training on two different, but related, working memory tasks (across two experiments, with 72 participants) produced transferable benefits to similar (quantified based on cognitive and neural profiles) untrained test tasks. Despite significant improvement on both training tasks, participants did not improve on either test task. In fact, performance on the test tasks after training were nearly identical to a passive control group. These results indicate that, despite maximizing the likelihood of producing transferable benefits, brain training does not generalize, even to very similar tasks. Our study calls into question the benefit of cognitive training beyond practice effects, and provides a new framework for future investigations into the efficacy of brain training.

1. Introduction

The prospect of enhancing our cognitive abilities is alluring, and there is good incentive to want to do so. Performance on measures of different aspects of cognition, such as processing speed, reasoning, and general intelligence have not only been linked to academic and professional success, but also to happiness, and even life expectancy (Calvin et al., 2011). While cognitive abilities tend to remain relatively stable throughout the lifespan, they are not immune to fluctuations; disease (Marinus et al., 2003; Muller et al., 2007), head injuries (Bleiberg et al., 2004), even at a young age (Talavage et al., 2014), and aging can all result in substantial impairments to cognition. However, the trajectory for cognitive change is not always downward; for example, learning through education or practice is clearly one way in which cognition can be enhanced, and have long lasting effects (Ritchie et al., 2013). However, the cognitive benefits associated with education often progress slowly, require significant investment, and unfold over a long period of time. Recently, brain (or cognitive) training has emerged as a potential new approach for improving cognition – one that is easily accessible and can occur on a much shorter time scale. Moreover, the purported benefits of brain training are not limited to improving cognition, but may include therapeutic benefits that slow, or even reverse, cognitive decline across the lifespan (Anguera et al., 2013; Westerberg et al., 2007).

Brain training rests on the assumption that regular and prolonged "training" on computerized tasks (often marketed as "brain games") will result in improvements, not only on the trained task, but also on untrained (and even unrelated) tasks, across different cognitive domains. The focus of many brain training programs is on short-term (working) memory - the ability to hold and manipulate information (Baddeley, 1992) – because short-term (working) memory is considered to be the critical cognitive domain underlying generalizable gains in cognition. This notion rests on two key assumptions: 1) that short-term (working) memory can be improved (Klingberg, 2010), and 2) that short-term (working) memory is closely related to other higher-order cognitive abilities, such as, attention (Klingberg et al., 2005), reasoning, problem solving, executive processes (Kane et al., 2004; McCabe et al., 2010; Süß et al., 2002), multitasking (Redick et al., 2016), and even general intelligence (Engle et al., 1999; Kane and Engle, 2002). The logic is intuitive and appealing; brain training programs that increase short-term (working) memory capacity will lead to performance gains across a variety of other cognitive abilities associated with short-term (working) memory (Klingberg, 2010) including general intelligence (see Redick et al., 2013 for evidence why this logic is limited). The idea

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has also gained some empirical support in recent years.

For example, several studies have claimed to show that training short-term (working) memory produces generalizable improvements in cognition across various untrained tasks, each measuring different aspects of cognition (Jaeggi et al., 2008). The observed benefits range from improvements on variants of the same task (Li et al., 2008), to improvements on similar tasks that rely on overlapping cognitive mechanisms (*near transfer*; Chein and Morrison, 2010; Dahlin et al., 2008; Tulbure and Siberescu, 2013), to performance gains on unrelated cognitive tasks and domains (*far transfer*;(Au et al., 2014; Caeyenberghs et al., 2016; Chein and Morrison, 2010; Jaeggi et al., 2008; Morrison and Chein, 2010). In fact, it has been suggested that cognitive training can have far reaching consequences, including improvements at work and school in activities such as reading (Dahlin, 2011; Swanson and Jerman, 2006) and math proficiency (Bergman-Nutley and Klingberg, 2014). It has also been claimed that brain training can delay aging-related cognitive decline and reduce the effects of cognitive disease (Basak et al., 2008).

However, the efficacy of brain training has recently been called into question (Simons et al., 2016). For example, some attempts to replicate earlier findings showing brain training-related benefits have failed to produce similar effects (Redick et al., 2013; Thompson et al., 2013). Moreover, one large scale meta-analysis that included studies using multiple forms of short-term (working) memory training found no convincing evidence of transfer of benefits (near and far) to untrained tasks (Melby-Lervåg et al., 2016). In fact, difficulties in finding such transfer effects are not limited to short-term (working) memory based training protocols, but extend to training involving inhibitory control (Enge et al., 2014), video game playing (Lee et al., 2012), and decision making (Kable et al., 2017). In one large-scale study involving more than 11,000 participants, Owen et al. (2010) had participants train for six weeks on a variety of tasks based on commercially available brain training games. They found that, while performance improved on every trained task, there were no gains in performance on untrained tests of reasoning, verbal abilities or short-term memory.

A number of reasons have been proposed to account for these failures to reproduce the results of earlier brain-training studies, including participant's expectations (Foroughi et al., 2016), neuroanatomical variability (Simon et al., 2016), and methodological factors, such as, different analysis approaches (Redick et al., 2013). However, a more fundamental issue likely underlying the variability across studies relates to inconsistent and often vague definitions of what constitutes ‘transfer’. The terms ‘near’ and ‘far’ transfer are often used to refer to improvements in closely related and unrelated cognitive tasks, respectively, yet how ‘related’ one task really is to another is often poorly understood. In fact, the degree to which the training tasks differ from the test tasks (and the test tasks from each other) is rarely quantified, and tasks are often selected based on their inferred cognitive properties, rather than some empirical measure of similarity. Without a consistent definition of transfer, and quantifiable measures of similarity between tasks, it is very difficult to make comparisons across studies, and assess the reliability of any observed training related benefits.

To provide a more constrained framework for brain training, the current study focused on two fundamental, but related issues: the nature of the training protocol, and the selection of the tests themselves. Two experiments were conducted that employed a targeted training protocol; in each experiment, participants trained extensively on only one task (unique to each experiment) measuring a single cognitive domain – short-term (working) memory. In addition, quantifiable measures of similarity were used to guide the selection of test tasks. The training and test tasks were taken from the Cambridge Brain Sciences (CBS) battery, an online suite of 12 cognitive assessment tools. One short-term (working) memory task that involved memory for spatial locations was selected for training in experiment 1. Two other tasks were selected to assess the benefits of transfer, one that also involved spatial working memory and one that was procedurally similar, yet involved verbal working memory. These selections were made based on quantifiable measures of similarity using a factor analysis of task performance and underlying neural activity (Hampshire et al., 2012).

To ensure the results were generalizable, in experiment 2, a short-term (working) memory task that has been widely used in brain training studies was selected for training. The dual n-back task shares many of the same cognitive and neural properties as the task that was selected for training in experiment 1 (Owen et al., 2005) and has successfully produced both near and far transfer in previous studies (Au et al., 2016; Jaeggi et al., 2008). In experiment 2, the same two spatial and verbal working memory tasks (that were used in experiment 1) were used to assess the effects of training.

Based on the brain training literature, we predicted that training on a spatial working memory task would produce transferable gains to untrained tasks that were cognitively related (‘near transfer’). As a control, we also expected significant gains in performance on a second spatial short-term memory task that was almost identical to the trained task in terms of cognitive requirements and design. Finally, we hypothesized that the same results would be found when we modified the experimental design to closely mimic that of many successful brain training studies.

2. Methods

2.1. Experiment 1

2.1.1. Participants

Participants were recruited from two research participant pools: 1) locally from the University of Western Ontario, using recruitment flyers, and 2) from Mechanical Turk (MTurk), Amazon's crowdsourcing platform. Participants recruited from MTurk who completed the task were paid $2.00 per session (which lasted approximately 30 min), and were given a $1.00 bonus for every five sessions they completed. Those recruited locally from the University of Western Ontario were paid the same amount for completing the tasks at home, but were given $10/hour to cover transportation costs if they completed the task in the lab. To be included in the analysis, participants had to 1) complete the pre-training test; 2) complete the post-training test; 3) complete at least 16 days of cognitive training with no more than 3 days between training sessions. This amounted to a minimum of approximately 10 h total training. 4) showed evidence of improved performance on the training task based on the slope of a linear fit (mean adjusted R^2). A total of 76 participants signed up for the experiment; of the 76 participants, 56 had completed the pre- and post-test, 48 of those participants had completed at least 16 days of training, and 47 had also improved on the training task. The 47 participants (26 females) between the ages of 20 and 62 (M = 32.89, SD = 8.41) who met all criteria were included in the final analysis. Our final sample size exceeds that of many other studies using different working memory tasks in context of cognitive training that show strong training effects (see Morrison and Chein, 2011). A control group (31 participants; 14 female, ages 22–53; M = 31.35, SD = 6.77) who completed the pre- and post-training 30 days apart, but did not engage in any cognitive training was also included. There were no significant differences in demographic information between the training and control groups. All participants consented to participating, and the study was approved by the Health Sciences Research Ethics Board of the University of Western Ontario.

2.1.2. Procedure

The experiment consisted of three phases: 1) pre-training, 2) training, and 3) post-training, which were completed over the course of 30 days. On the first day of the experiment (the pre-training phase), each participant completed the two test tasks, which served as a baseline measure of their ability on these tasks. The training phase started within three days of completing the pre-training phase. Within three days of finishing the training, participants completed the same test