Intelligence 41 (2013) 638–663

Contents lists available at ScienceDirect

Intelligence

Training working memory: Limits of transfer

Amber M. Sprenger [a], Sharona M. Atkins [a], Donald J. Bolger [c], J. Isaiah Harbison [b], Jared M. Novick [b], Jeffrey S. Chrabaszcz [a], Scott A. Weems [b], Vanessa Smith [a], Steven Bobb [a], Michael F. Bunting [b,*], Michael R. Dougherty [a,**]

[a] Department of Psychology, University of Maryland, USA
[b] Center for Advanced Study of Language, University of Maryland, USA
[c] Department of Human Development & Quantitative Methodology, University of Maryland, USA

ARTICLE INFO

Article history:
Received 17 October 2011
Received in revised form 12 July 2013
Accepted 15 July 2013
Available online xxxx

Keywords:
Working memory training
Fluid intelligence
Inhibition
Verbal abilities

ABSTRACT

In two experiments (totaling 253 adult participants), we examined the extent to which intensive working memory training led to improvements on untrained measures of cognitive ability. Although participants showed improvement on the trained task and on tasks that either shared task characteristics or stimuli, we found no evidence that training led to general improvements in working memory. Using Bayes Factor analysis, we show that the data generally support the hypothesis that working memory training was ineffective at improving general cognitive ability. This conclusion held even after controlling for a number of individual differences, including need for cognition, beliefs in the malleability of intelligence, and age.

1. Introduction

Working-memory (WM) processes, which support the purposeful, active maintenance of goals and information, are among the most important and widely studied components of human cognition, and for good reason. WM processes have been implicated in a variety of cognitive processes, such as visual and auditory attention, language learning and comprehension, problem solving, and fluid intelligence (see Conway, Jarrold, Kane, Miyake, & Towse, 2008). Simply put, WM is important for everyday activities, and poor WM is often associated with poor performance inside as well as outside the laboratory (Bull, Espy, & Wiebe, 2008; Gathercole, Alloway, Willis, & Adam, 2006; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007). In light of its importance, it is unsurprising that there is extensive interest in developing procedures to enhance WM. Improving WM even by a small amount could have enormous practical implications across a wide variety of contexts, ranging from educational to mental health contexts.

The very notion that WM in adults is changeable stands in stark contrast to the traditional view that most cognitive abilities (as opposed to acquired skills) reflect a *stable* individual trait (Neisser et al., 1996). Implicit in this view is the notion that cognitive abilities are fixed by early adulthood and immutable to positive change thereafter. Indeed, some studies have even suggested that WM has a strong genetic component (Friedman et al., 2008). Genetics aside, recent research challenges the traditional view that fluid cognitive abilities lack the capability to improve (Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Jaeggi, Buschkuel, Jonides, & Perrig, 2008), and that the neural systems underlying WM processes remain plastic throughout the lifespan and can be enhanced through intensive cognitive training (Klingberg et al., 2005; Mahncke, Connor, et al., 2006; but see Owen et al., 2010, for a contrasting view). Several studies have purported that targeted training of WM abilities leads to both behavioral (Chein & Morrison, 2010; Jaeggi et al., 2008; Klingberg et al., 2005;

* Correspondence to: M.F. Bunting, Center for Advanced Study of Language, University of Maryland, 7005 52nd Ave., College Park, MD 20742, USA.
** Correspondence to: M.R. Dougherty, Department of Psychology, University of Maryland, College Park, MD 20742, USA.
E-mail addresses: mbunting@casl.umd.edu (M.F. Bunting), mdougher@umd.edu (M.R. Dougherty).

0160-2896/$ – see front matter © 2013 Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.intell.2013.07.013

Mahncke, Connor, et al., 2006; Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2009) and neurophysiological changes (McNab et al., 2009; Olesen, Westerberg, & Klingberg, 2004; Westerberg & Klingberg, 2007).

The evidence supporting the efficacy of WM training is enticing but not perfectly robust. Jaeggi et al. (2008) reported transfer from n-back training to a matrix reasoning test that is presumed to tap general fluid intelligence, but not to verbal WM, as measured by the reading span task (see also Jaeggi et al., 2010, 2011). By contrast, Owen et al. (2010) examined whether a variant of popular training tasks would improve cognitive performance, and concluded that training on these tasks did not transfer to other, untrained tasks. Although the Owen et al. study calls into question the validity of cognitive training altogether, the results of Jaeggi et al. (2008) suggest that transfer from one particular type of training, using dual-task n-back, may yield fairly narrow transfer effects. Indeed, a recent review of the cognitive training literature by Klingberg (2010) suggests that transfer effects in cognitive training studies are frequently narrow in scope. That is, training-related transfer effects typically are limited to improvements on one or a couple of transfer tasks, rather than a broad spectrum of tasks. At the same time, most of the studies reviewed by Klingberg (2010) used narrowly defined training regimens consisting of one or a few tasks. For example, in studies by Jaeggi et al. (2008, 2011), participants trained only on an adaptive version of the n-back task. Likewise, in Klingberg, Forssberg, and Westerberg (2002), Klingberg et al. (2005) and also Olesen et al. (2004), participants trained on only three different tasks. Moreover, the bulk of the studies reviewed by Klingberg (2010) showed improvements only on tasks that were closely related to the trained abilities with respect to processing demands.

These studies suggest two important properties of cognitive training: First, cognitive training may be process-specific (cf. Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008); and second, narrow training yields narrow transfer. The implication of these two assertions is that the breadth of transfer effects should reflect the breadth of training. Training a narrowly defined set of cognitive processes should yield improvement on transfer tasks only to the extent that the transfer tasks share the same underlying cognitive processes with the training tasks. We refer to this as *process-specific* transfer. We prefer to use the terms process-specific and non-process-specific transfer as opposed to the terms 'near' and 'far' transfer, which appear elsewhere in the training literature and are unclear in our opinion. Far-transfer typically refers to improved performance on an assessment task that is ostensibly quite different from the training task(s) completed during the intervention regimen. However, one obviously expects transfer only when the underlying cognitive processes (and possibly the neuroanatomical systems that support them) are common across training and transfer tasks. Thus, the term 'far' may be a misnomer in view of the shared processes.

The possibility that training related effects might lead to generalizable transfer is both exciting and provocative, yet as discussed above the available evidence is hotly debated. If cognitive training can yield broad improvements in cognitive ability, beyond the trained tasks, it could be of enormous benefit for domains such as education and cognitive and neural remediation. However, some researchers have expressed skepticism that cognitive training works. For example, Shipstead, Redick, and Engle (2012) (see also Redick et al., 2013; Melby-Lervåg & Hulme, 2012) have argued that the majority of the empirical studies purported to show benefits of cognitive training were fundamentally flawed in ways that prevent drawing straightforward interpretations, for example, by lacking a proper control condition or a failure to keep both the participants and the experimenters blind to condition. In addition, several recent studies that have included so-called active control conditions have failed to demonstrate any advantage of cognitive training. Redick et al. (2013; see also Chooi and Thompson (2012) and Thompson et al. (2013), for example, failed to replicate findings reported by Jaeggi et al. (2008) using n-back training. Finally, using meta-analytic techniques, Melby-Lervåg and Hulme (2012) concluded that there was no evidence that WM training was effective at improving reasoning, intelligence, or Stroop performance. Yet, one shortcoming of these studies is the reliance on traditional null hypothesis significance testing (NHST) methodology. Obviously, claims made about the ineffectiveness of training imply that the null hypothesis is true, or approximately so. NHST methods are not well suited for quantifying the degree to which the data support the null, versus the alterative.

The present paper addresses some of the shortcomings in prior studies. First, rather than focusing on a single training task, we evaluated the impact of training on a battery of training tasks. Our goal was to test the hypothesis that broad training yields broad transfer. In Experiment 1, participants trained on eight different cognitive tasks, and in Experiment 2, we manipulated the process-specificity versus -generality of the training by manipulating the number and type of training tasks.

Second, in both of the studies reported herein, we included proper control conditions. In Experiment 1, we utilized a double-blind no-contact control where both the experimenter and the participant were blind to group-assignment: The experimenter did not know which participants had been assigned to training versus control, and participants were not informed about the nature of the comparison condition (or that one even existed, for that matter). In Experiment 2, we included an active control condition in which participants trained on tasks that resembled some of the training tasks, but which did not require much effortful processing beyond sustained attention.

Third, we utilized Bayesian methods to evaluate the strength of the evidence for and against the null hypothesis. Given that much of the debate regarding WM focuses on whether the existing data support the claim that training is effective or not, it is particularly important to evaluate the hypothesis that cognitive abilities are *invariant* to WM training. Indeed, the relevant question in our mind is the degree to which the evidence actually supports the hypothesis that WM training works (the alternative hypothesis) versus that it does not work (the null hypothesis). In what follows, we present data that are, by and large, consistent with the hypothesis that WM training, as implemented in our experiments, does not improve cognitive abilities unless the assessments share task or stimulus characteristics with the trained task.

2. Experiment 1

The purpose of Experiment 1 was to address two potential implications of cognitive training, within the context of