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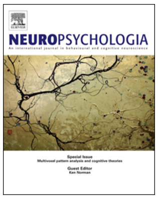

Increased parietal activity after training of interference control

Stephan Oelhafen [a,*], Aki Nikolaidis [a,b], Tullia Padovani [a], Daniela Blaser [a], Thomas Koenig [c], Walter J. Perrig [a,d]

[a] *Institute of Psychology, University of Bern, Switzerland*
[b] *Neuroscience Program, University of Illinois Urbana Champaign, United States*
[c] *Department of Psychiatric Neurophysiology, University Hospital of Psychiatry, University of Bern, Switzerland*
[d] *Center for Cognition, Learning and Memory, University of Bern, Switzerland*

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ABSTRACT

Recent studies suggest that computerized cognitive training leads to improved performance in related but untrained tasks (i.e. transfer effects). However, most study designs prevent disentangling which of the task components are necessary for transfer. In the current study, we examined whether training on two variants of the adaptive dual *n*-back task would affect untrained task performance and the corresponding electrophysiological event-related potentials (ERPs). Forty three healthy young adults were trained for three weeks with a high or low interference training variant of the dual *n*-back task, or they were assigned to a passive control group. While *n*-back training with high interference led to partial improvements in the Attention Network Test (ANT), we did not find transfer to measures of working memory and fluid intelligence. ERP analysis in the *n*-back task and the ANT indicated overlapping processes in the P3 time range. Moreover, in the ANT, we detected increased parietal activity for the interference training group alone. In contrast, we did not find electrophysiological differences between the low interference training and the control group. These findings suggest that training on an interference control task leads to higher electrophysiological activity in the parietal cortex, which may be related to improvements in processing speed, attentional control, or both.

1. Introduction

A fundamental question in the study of learning is whether acquired knowledge or skills transfer to new but similar tasks or situations. Formerly, many researchers agreed that in general, little transfer occurs (Detterman, 1993); recently, the transfer of learning has received more scientific attention due to encouraging approaches to train core mechanisms of working memory (WM). These forms of WM training have improved performance in related but untrained tasks, such as measures of fluid intelligence (gF; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Klingberg et al., 2005). However, inconsistencies in methodology and results have raised questions about the efficacy of WM interventions for the enhancement of fluid intelligence (cf. Morrison & Chein, 2011; Redick et al., 2012). While the factors promoting transfer are still unknown, many have argued that transfer of learning is possible to the degree that the training and transfer tasks involve overlapping neural networks or share cognitive mechanisms (Dahlin, Stigsdotter Neely, Larsson, Bäckman, & Nyberg, 2008; Jonides, 2004; Klingberg, 2010; Perrig, Hollenstein, & Oelhafen, 2009; Persson & Reuter-Lorenz, 2008).

Methodological issues in several WM training studies have presented challenges to the replication and generalization of their findings (cf. Shipstead, Redick, & Engle, 2010). First, since cognitive training studies typically involve complex training paradigms or batteries of training tasks, isolating the cognitive processes critical for transfer proves difficult (Jaeggi et al., 2008; Klingberg et al., 2005; Olesen, Westerberg, & Klingberg, 2004; Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2009). A second, related issue concerns the *adaptive* adjustment of difficulty in many training regimens. Since these are often compared with *non-adaptive* training tasks, the intended differences may be confounded with decreased motivation and training compliance in active control groups. These unintended differences between training and active control groups impair internal validity (cf. Shipstead et al., 2010; Shipstead, Redick, & Engle, 2012). Therefore, contrasting the training intervention with a similar active control group increases the validity of conclusions about the training program. Ideally, researchers should compare training groups that differ only in the demands of critical cognitive processes in order to disentangle relevant components of a training intervention (cf. Schneiders, Opitz, Krick, & Mecklinger, 2011). Likewise, if the training

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[*] Correspondence to: University of Bern, Department of Psychology, Division of Experimental Psychology and Neuropsychology, Fabrikstrasse 8, 3012 Bern, Switzerland. Tel.: +41 316314734.
E-mail address: stephan.oelhafen@psy.unibe.ch (S. Oelhafen).

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and transfer tasks share this critical process, the training is more likely to produce learning transfer.

Previous research has demonstrated that the ability to control interference is critical for WM and gF (Burgess, Gray, Conway, & Braver, 2011; Gray, Chabris, & Braver, 2003; Kane, 2003). Interference control involves the detection and resolution of conflicts that arise when irrelevant stimulus dimensions refer to an incorrect stimulus or response pattern (Carter & van Veen, 2007; Friedman & Miyake, 2004). In the *n*-back task, participants must continuously track a stream of information and decide whether a probe matches the stimulus presented *n*-steps back. In this task, the process of interference control becomes crucial in *lure* trials (Burgess et al., 2011; Gray et al., 2003; Kane, 2003), i.e. non-target trials with a match in non-*n* positions. For instance, in a 2-back task, the probe 'P' in the sequence 'P–T–W–P' is an $n+1$ lure trial, because the actual stimulus only corresponds with the stimulus $n+1$ trials before. Thus, $n+$ lures refer to items presented before the *n*th item, whereas $n-$ lures match with more recent stimuli. These lures induce a familiarity signal which conflicts with explicit recollection of the sequence (Oberauer, 2005; Szmalec, Verbruggen, Vandierendonck, & Kemps, 2011). As a result, the additional demand in interference control leads to increased reaction times and false alarms rates. Specifically, lures that are presented close to the critical lag ($n+1$ or $n-1$) elicit the strongest conflict (Kane, Conway, Miura, & Colflesh, 2007; McCabe & Hartman, 2008; Szmalec et al., 2011). Thus, interference control is a critical process in the *n*-back task, and training of this component may lead to transfer in related cognitive domains.

Similar to isolating cognitive processes necessary for transfer, mapping neural activity allows one not only to test whether trained and untrained tasks overlap in specific brain regions but also to estimate training induced activity changes (Dahlin et al., 2008). A few studies have examined the brain regions that mediate the relationship between working memory, interference control and gF. In a functional magnetic resonance imaging (fMRI) study using a visual 3-back task with $n-1$ and $n+1/+2$ lures, Gray et al. (2003) determined that the blood oxygenation level dependent (BOLD) signal in the left lateral prefrontal and bilateral parietal regions explained 99.9% of the relationship between gF and accuracy in lure trials. In trials with increased demand for interference control, participants with high gF showed increased signal in these regions. In another fMRI study, Burgess et al. (2011) found that BOLD signal in the bilateral dorsolateral prefrontal cortex (middle frontal gyrus) and the inferior parietal cortex mediated the relationship between gF and WM. Thus, regions in the lateral prefrontal and parietal cortices play a crucial role in interference control (cf. Jonides & Nee, 2006; Kane, 2003; Nee, Wager, & Jonides, 2007).

While fMRI allows for assessing the brain regions that contribute to transfer, event-related potentials (ERP) indicate the time frames in which task-critical cognitive processes overlap. ERP research on interference control has often focused on two components. The N2, a fronto-central negative component typically elicited between 200 and 350 ms post-stimulus, is associated with conflict monitoring or the resolution of conflict (Carter & van Veen, 2007; Kopp, Rist, & Mattler, 1996; Silton et al., 2010). The second component, the parietal P3, which typically appears between 300 and 600 ms post-stimulus, is thought to reflect general processes of attentional control, stimulus categorization, and the effort to choose between competing stimuli or responses (Bledowski, Prvulovic, Goebel, Zanella, & Linden, 2004; Neuhaus, Trempler et al., 2010; Neuhaus, Urbanek et al., 2010; Rueda, Posner, Rothbart, & Davis-Stober, 2004).

Based on the relationship between WM, gF, and interference control, the present study was designed to investigate the assumption that transfer effects result from partially shared neural and cognitive mechanisms between the training and transfer tasks. We tested this assumption on a behavioral and electrophysiological level with training and transfer tasks that tax interference control heavily. We used the adaptive dual *n*-back as a training task and manipulated the occurrence of lure trials between training groups. To test for changes in interference control, we used the Attention Network Test (ANT), a cued variant of the flanker task (Fan, McCandliss, Sommer, Raz, & Posner, 2002). Others have used this task (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005), both in healthy children and adults (Fan et al., 2002; Rueda et al., 2004) and patients with various mental disorders (Fernandez-Duque & Black, 2006; Neuhaus et al., 2010a, 2010b). In the ANT, participants must quickly indicate the direction of a central arrow, which is flanked by congruent or incongruent arrows. Distinct cue-flanker combinations allow for assessing the efficiency of three attentional networks. C*onflict resolution* is manipulated by congruent and incongruent flanker arrows, and the efficiency of *alerting* and *orienting* are derived from several types of valid cues (see method section). Since we expected the lure *n*-back training to increase the efficiency of conflict resolution, which is thought to be closely related to interference resolution (cf. Miyake et al., 2000; Szmalec et al., 2011), we focused on this attention network for our theoretical and empirical analysis.

Our primary objective was to test whether training of shared cognitive processes in the training and transfer tasks would lead to improved performance in the ANT and corresponding electrophysiological changes. Researchers have found both increased and decreased activations after task practice, and these changes may arise from either implementing initial strategies more effectively, learning new strategies during training or the reorganization of cognitive functions (Dahlin et al., 2008; Jolles, Grol, Van Buchem, Rombouts, & Crone, 2010). Unfortunately, the heterogeneity of methods and tasks used in the field of cognitive training makes it difficult to predict changes in neuronal activity precisely (cf. Buschkuehl, Jaeggi, & Jonides, 2012). Nevertheless, based on the aforementioned fMRI and ERP studies, we expected ERP effects in the time range of the N2 and P3 components, with activation focused in the fronto-parietal network. Specifically, we predicted that we would detect changes in the time range where the training and transfer tasks overlap in a topographic map of whole brain activity. Additionally, we assessed WM capacity and gF to evaluate transfer effects after training with the *n*-back task (Jaeggi et al., 2008; Jaeggi et al., 2011; Studer-Luethi, Jaeggi, Buschkuehl, & Perrig, 2012). Given the reported relationship between WM, interference control, and gF, we predicted the largest transfer gains after training with lure *n*-back.

2. Methods

2.1. Participants

Forty eight healthy, young adults, were recruited from an academic environment and randomly assigned to the lure training group, the non-lure training group (i.e. the active control), or the passive control group. In each group, one participant dropped out between pre- and post-testing and two dropped out during pretest EEG recording, leaving a final sample of 43 participants (mean age: 25.2 years; $SD=4.1$; range: 18–34). Both training groups consisted of 14 participants (6 female and 1 left-handed each), and 15 people were assigned to the control group (8 female and 2 left-handed). Each individual submitted a written informed consent before the experimental procedure began. After completion of the study, all participants were paid 50 Swiss Francs for participation. The study was of the type approved by the local ethics committee.

2.2. Materials

All training and transfer tasks were conducted with E-prime (Psychology Software Tools, Inc., Pittsburgh, PA). We used a simplified version of the ANT in pre- and post-testing (Fan et al., 2005), and modified the adaptive dual *n*-back task