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Reduced posterior parietal cortex activation after training on a visual search task

Elisenda Bueichekú, Anna Miró-Padilla, María-Ángeles Palomar-García, Noelia Ventura-Campos [1], María-Antonia Parcet, Alfonso Barrós-Loscertales, César Ávila *

Neuropsychology and Functional Neuroimaging Group, Department of Basic Psychology, Clinical Psychology and Psychobiology, University Jaume I, 12071 Castellón, Spain

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ABSTRACT

Gaining experience on a cognitive task improves behavioral performance and is thought to enhance brain efficiency. Despite the body of literature already published on the effects of training on brain activation, less research has been carried out on visual search attention processes under well controlled conditions. Thirty-six healthy adults divided into trained and control groups completed a pre-post letter-based visual search task fMRI study in one day. Twelve letters were used as targets and ten as distractors. The trained group completed a training session (840 trials) with half the targets between scans. The effects of training were studied at the behavioral and brain levels by controlling for repetition effects using both between-subjects (trained *vs.* control groups) and within-subject (trained *vs.* untrained targets) controls. The trained participants reduced their response speed by 31% as a result of training, maintaining their accuracy scores, whereas the control group hardly changed. Neural results revealed that brain changes associated with visual search training were circumscribed to reduced activation in the posterior parietal cortex (PPC) when controlling for group, and they included inferior occipital areas when controlling for targets. The observed behavioral and brain changes are discussed in relation to automatic behavior development. The observed training-related decreases could be associated with increased neural efficiency in specific key regions for task performance.

1. Introduction

Classic psychology paradigms showed that performance improves after completing a training program (Kristofferson, 1972; Neisser et al., 1963; Neisser, 1963; Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977; Prinz, 1979; Rabbit et al., 1979). This behavioral improvement seems to be accompanied by brain activation changes and is observable after training in different cognitive domains (Anguera et al., 2013; Banai and Amitay, 2015; Klingberg, 2010; Waldschmidt and Ashby, 2011). However, few functional magnetic resonance imaging (fMRI) training studies have included control measures in their paradigms; therefore, they have not eliminated the repetition effects from their results, which could bias their interpretations (*e.g.*, Chein and Schneider, 2005; Kübler et al., 2006). Our main objective was to study the behavior and brain changes related to training, but by controlling for repetition effects using both between-subjects (trained *vs.* control groups) and within-subject (trained *vs.* untrained stimuli) controls.

Some decades ago, psychological theories found that training on a task can lead to automaticity. Two-process models distinguished controlled processing from automatic processing. These models argue that when a task has not been trained, it is performed through controlled processes. This processing has been defined as slow and effortful. By contrast, automatic processing has been characterized as being fast and effortless (Posner and Snyder, 1975; Posner, 1978; Schneider and Shiffrin, 1977). Automatic behavior is achievable after completing a number of training trials (600 trials at least) presented under consistent mapping conditions, and it has to produce quantitatively faster responses than controlled processing without obtaining worse accuracy scores (*e.g.*, maintaining or improving them) (Shiffrin and Schneider, 1977).

In relation to brain activity, theoretical predictions hypothesize that gaining experience on a cognitive task, such as a visual search task,

Abbreviations: (d)ACC, (dorsal) anterior cingulate cortex; AC-PC, anterior commissure-posterior commissure; ANOVA, analysis of variance; BA, Brodmann area; BOLD, blood-oxygenation level-dependent; DLPFC, dorsolateral prefrontal cortex; EPI, echo-planar imaging; FG, fusiform gyrus; fMRI, functional Magnetic Resonance Imaging; FWE, family-wise error; FWHM, full-width at half-maximum; HRF, hemodynamic response function; M, mean; MNI, Montreal Neurological Institute; MPRAGE, Magnetization Prepared Rapid Acquisition Gradient Echo; N, number of participants; PPC, posterior parietal cortex; RMS movement, Root Mean Squared movement; ROI(s), region(s) of interest; RT(s), reaction time(s); SD, standard deviation; SMA, supplementary motor area; TE, echo time; TR, repetition time; VLPFC, ventrolateral prefrontal cortex; WAIS, Wechsler Adult Intelligence Scale.

* Corresponding author at: Basic Psychology, Clinical Psychology and Psychobiology, University Jaume I, Avda, Sos Baynat, s/n, E-12071 Castellón, Spain.

E-mail addresses: bueichek@uji.es (E. Bueichekú), amiro@uji.es (A. Miró-Padilla), mpalomar@uji.es (M.-Á. Palomar-García), venturan@uji.es (N. Ventura-Campos), parcet@uji.es (M.-A. Parcet), barros@uji.es (A. Barrós-Loscertales), avila@uji.es (C. Ávila).

[1] Present address: Department of Mathematics Teaching, Faculty of Teacher Training, University of Valencia, 46022, Valencia, Spain.

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could result in the reduced cognitive recruitment of attention-related brain areas (Schneider and Chein, 2003). Early task performance occurs under controlled processing and leads to high activation; then, after reaching a certain level of automaticity, brain activation drops considerably (Chein and Schneider, 2005, 2012). Rather than being fast and effortful, automatic processing has been redefined as efficient and economical in terms of brain activity (Saling and Phillips, 2007).

To date, some functional neuroimaging studies have focused on studying the effects of training on brain functioning. In a meta-analysis carried out with 29 cognitive or motor training studies, reduced activity in diverse cortical areas was the main result reported (Chein and Schneider, 2005). Reductions were found in terms of the extent and magnitude of neural activity, and they involved a consistent brain network: bilateral dorsolateral prefrontal cortex (DLPFC), left ventral prefrontal cortex, anterior cingulate cortex, left insular cortex, bilateral parietal cortex, and occipito-temporal areas, including the fusiform gyri (FG). The authors interpreted that most training-related decreases were located in association areas, whose function is to exert attentional control, regardless of the task or stimuli domain. In particular, these authors claimed that this attention control network was engaged during initial task performance (novice performance), and its involvement dropped as a result of training (Chein and Schneider, 2005). An example of this finding is the fMRI experiment presented along with the meta-analysis results (Chein and Schneider, 2005). A double condition paired-associate task was used in this experiment: words with a low imageability index score and difficult shapes to verbalize. The participants completed a 2-hour training session in each condition with one set of five pairs per condition (80 trials). When the untrained condition was compared to the trained condition, the brain activity results showed that the majority of brain changes involved reduced neural activity, and these reductions generally overlapped the aforementioned meta-analysis results.

In the case of visuospatial search tasks, some fMRI experiments have studied automaticity when task automation has already been established, and fewer studies have examined how the brain implements the automaticity process (Kelly and Garavan, 2005; Raichle et al., 1994). One exception is the study by Kübler et al. (2006), where one objective was to study the establishment of automaticity. The participants completed a training session that lasted 2.5 h (3456 trials). As in Chein and Schneider (2005), the results showed decreased activation in diverse brain areas of the prefrontal, premotor, cingulate and parietal cortices after training. However, other areas typically involved in visuospatial search tasks did not change (*i.e.*, the primary motor, left posterior parietal, temporal and occipital cortices). Main conclusions were that training led to more reduced brain activity in frontal areas than in posterior cerebral areas, and that this reduction indicated less dependence on attentional processes (Kübler et al., 2006).

In summary, training-related fMRI studies have suggested decreased brain activity after training, at least in the attention control system. However, in order to determine whether brain changes are the result of training, two measures should be included in the experimental designs: a control group and an untrained condition. The presence of a statistical comparison between initial and final task performance (at least 10 min of training) was an inclusion criterion in Chein and Schneider's (2005). Twenty-four of the 29 studies included in the meta-analysis were consulted, and none had a control group. In Chein and Schneider (2005), an untrained condition was included in the experimental design, but no control group. Kübler et al. (2006) did not include either of these control measures. Therefore, as far as we know, no experiments carried out in the visual attention domain have reported the objective of studying training-related changes at the brain level with an experimental design that included a control group and an untrained condition, in order to fully characterize the training effects.

Here, we present a pre-post one day fMRI study that included two groups of participants (a trained group and a control group) and two search conditions (trained and untrained targets). We chose to use the visual search task because it has been widely used to study attentional control (Buschman and Kastner, 2015; Bisley, 2011). Searching for letters among letters is a highly demanding task (like searching for objects in a real environment), but it allows the use of familiar stimuli and an experimental set-up (Bueichekú et al., 2015; Shiffrin and Schneider, 1977). We used a letter-based consistent mapping search, which has not been previously used to study training effects on the visual attention system.

We hypothesized that: 1) the participants who completed the training program would produce faster responses to trained targets than those who only repeated it, due to greater automation; 2) after training, the trained participants would produce faster responses to trained targets compared to their responses before training and to untrained targets during the post-training session; 3) automation processes would result in decreased activation of the brain areas already involved in the visual search task; 4) the inclusion of control measures in the experimental paradigm would allow a better understanding of the training effects, and they would be differentiated from repetition effects.

2. Materials and methods

2.1. Participants

Thirty-six healthy undergraduate students from the Universitat Jaume I participated in this study and were paid for their participation. All the participants were right-handed (Oldfield, 1971), had normal or corrected-to-normal vision, and reported no neurological or psychiatric history, or past or current use of any drugs. Participants were randomly assigned to a trained group (N = 18, 9 men; age: M = 20.78 SD = 1.35) or to a control group (N = 18, 9 men; age: M = 20.94, SD = 2.01). A between-groups *t*-test was used to determine that the experimental groups did not differ in age ($t(34) = -0.29$ $p = 0.10$). Intellectual level was evaluated with the Matrix Reasoning Test (WAIS-III-R) (Trained group: M = 21.56 SD = 2.17; Control group: M = 21.83 SD = 1.47). A between-groups *t*-test was used to determine that the experimental groups did not differ in intellectual level ($t(34) = -0.45$ $p = 0.14$). All the participants provided written informed consent prior to scanning. The study was approved by the Ethics Committee of the Universitat Jaume I.

2.2. Stimuli

2.2.1. Search frames

A schematic representation of the stimuli appears in Fig. 1A. The search frames consisted of black ink letters on a white background. Each search frame had six stimuli arranged circularly around a fixation point (visual angle: letters = 0.50°; fixation point = 0.24°; distance between letters and fixation point = 1.32°). Targets and distractors were always letters. Thus, search frames were always "within-category searches". There were two sets of target stimuli: *B C D F G H* and *L M N P Q R*. Distractors were always *J K Ñ S T V W X Y Z*. The role of targets and distractors did not change across tasks (consistent mapping search). Each search frame consisted of the presentation of either six distractors or five distractors and one target. Stimuli locations were randomized in all the conditions. Finally, no stimulus appeared twice in a row in the same location.

2.2.2. Control task

A control task was included in the experimental paradigm to measure a baseline response time and a baseline cerebral response, and it matched the visual array used in the search frames of the visual search conditions. The control task displays consisted of black ink letters on a white background. There were only two types of frames: a six *A-letters* array and a six *X-letters* array. *A's* and *X's* were arranged circularly around a fixation point (visual angle: letters = 0.50°; fixation