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Formation of abstract task representations: Exploring dosage and mechanisms of working memory training effects

Nitzan Shahar[a,*], Maayan Pereg[a], Andrei R. Teodorescu[b], Rani Moran[c,d], Anat Karmon-Presser[a], Nachshon Meiran[a]

[a] Psychology Department and Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 8410501, Israel
[b] Psychology Department, University of Haifa, 199 Aba Khoushy Ave. Mount Carmel, Haifa, Israel
[c] Max Planck UCL Centre for Computational Psychiatry and Ageing Research, University College London, 10-12 Russell Square, London WC1B 5EH, UK
[d] Wellcome Centre for Human Neuroimaging, University College London, London WC1N 3BG, United Kingdom

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ABSTRACT

Working memory is strongly involved in human reasoning, abstract thinking and decision making. Past studies have shown that working memory training generalizes to untrained working memory tasks with similar structure (near-transfer effect). Here, we focused on two questions: First, we ask how much training might be required in order to find a reliable near-transfer effect? Second, we ask which choice- mechanism might underlie training benefits? Participants were allocated to one of three groups: working-memory training (combined set-shifting and N-back task), active-control (visual search) and no-contact control. During pre/post testing, all participants completed tests tapping procedural and declarative working memory as well as reasoning. We found improved performance only in the procedural working-memory transfer tasks, a transfer task that shared a similar structure to that of the training task. Intermediate testing throughout the training period suggest that this effect emerged as soon as after 2 training sessions. We applied evidence accumulation modeling to investigate the choice process responsible for this near-transfer effect and found that trained participants, compared with active-controls had quicker retrieval of the action rules, and more efficient classification of the target. We conclude that participants were able to form abstract representations of the task procedure (i.e., stimulus-response rules) that was then ~applied to novel stimuli and responses.

1. Introduction

Working memory is an attentional-cognitive control system that is considered to play a major role in goal-directed behavior and decision-making (Kane & Engle, 2002; Oberauer, 2009). It allows the agent to hold, update and manipulate relevant information in mind, while resisting interference from irrelevant information (Carruthers, 2013; Kane & Engle, 2002; Oberauer, 2009). Working memory is involved in abstract thinking, planning and reasoning (Baddeley, 2003; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). Moreover, working memory deficits were reported in clinical conditions including; attention-deficit disorders (Andreou et al., 2007; Shahar, Teodorescu, Karmon-Presser, Anholt, & Meiran, 2016) and low intelligence (Schmiedek, Oberauer, Wilhelm, Süß, & Wittmann, 2007; Wilhelm & Oberauer, 2006). Understanding the underlying mechanisms might therefore be of value to those conditions, especially given the potential to improve working memory via computerized training, for example.

Computerized working memory training has gained much interest over the last decade, with many studies exploring whether training can be used as a remedy for psychopathology and/or enhance human performance in healthy individuals (Klingberg, 2010; Melby-Lervåg & Hulme, 2013). An early training theory pertained a muscle-like assumption, claiming that by repeatedly loading a certain cognitive process, one might enhance the overall resources dedicated to that process. Under this assumption, improvement in a working memory demanding training task should generalize (at least in part) to other situations where working memory load is also demanding. This should be true when the amount of shared features between the training and transfer task is high (i.e., near transfer), or even when it is low (i.e., far transfer) (Constantinidis & Klingberg, 2016; Lindenberger, Wenger, & Lövdén, 2017; Melby-Lervåg, Redick, & Hulme, 2016). Early optimistic reports in support of the muscle-like assumption (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008) were later shadowed by studies claiming that far-transfer findings are mostly due to the type of control group used

* Corresponding author at: Department of Psychology, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel.
E-mail address: nitzans@post.bgu.ac.il (N. Shahar).

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(Redick et al., 2013; Shipstead, Redick, & Engle, 2012). A current meta-analysis found a close to zero effect-size for far transfer effects (Melby-Lervåg et al., 2016), and recent studies using Bayesian statistics, also claim for evidence in favor of the null hypothesis (Clark, Lawlor-Savage, & Goghari, 2017).

Despite the strong negative evidence regarding far-transfer effects for working memory training, the majority of studies have shown that training in a working memory demanding task generalizes to other working memory tasks with a similar structure. Current meta-analyses suggested that the near-transfer effect is reliable and replicable (Melby-Lervåg & Hulme, 2013; Melby-Lervåg et al., 2016; Soveri, Antfolk, Karlsson, Salo, & Laine, 2017), with some showing near transfer effects for working memory training holding for as much as a few months post-training (Shahar & Meiran, 2015). Although the tiny (or even absent) far transfer effects might be discouraging at first sight, we believe that the reliable near transfer effects hold promise, and understanding their nature might enhance them and even extend transfer breadth. For example, pertinent questions are how much training does one need to generate near transfer effects? And what mechanisms might allow participants to show improved performance in a novel, never-before performed task? This study tries to shed light on these questions.

For this aim, we trained participants on a working memory demanding task for 12 weeks. In the training task, participants were asked to randomly switch between two choice-Reaction Time (RT) tasks, classifying either the spatial-location or the content of a target, using one of two manual responses. Importantly, on each training session, we frequently changed the task-set (target stimuli, response keys and mapping thereof), requiring participants to adapt and perform a new task-set after only a few trials. To ensure high working memory load as well as wider coverage of the various WM functions, the current task-switching task was combined with an N-back procedure, asking participants to also act according to information that was presented N trials beforehand (N was adapted according to the participants' performance; Jaeggi et al., 2008).

The notion behind the combination of rapid changes in task material (stimuli and response keys), N-back and task-switching was to increase demands for the maintenance and updating of action rules in working memory. The task-switching component was introduced to obligate participants to form task-sets which are hierarchical mental constructs that hold together information related to a specific task (e.g., task-cues, targets, response-keys and their relationships). The fact that task information kept changing between blocks (new stimuli and response keys on every block), assured that the information that participants were using to construct the task-sets was working memory demanding, and not based on long-term representations. Finally, the N-back component assured that across trials, the information required for task performance was held in mind for a brief moment and then immediately replaced by new information. Therefore, this task was designed to require participants to be able to repeatedly form, maintain and update task-sets based on novel information held in working memory.

Our hope was that rapid changes in the task-set (stimuli and response-keys), combined with high control demands (due to the task-switching and N-back combination) would encourage participants to form an abstract representation of the overall task structure. This representation could comprise of interlinked slots for holding stimuli and their associated responses. Theoretically, such abstract stimulus-response rules should allow participants to flexibly allocate novel targets and response-keys to a well-trained abstract stimulus-response association. This theoretical assumption is not restricted to procedural training tasks (it can explain for example stimulus-stimulus associations) and can explain, at least in part, how participants gain expertise in a specific task structure regardless of any specific task-set. The notion of forming abstract task representations can therefore account for the so–called near transfer effect, where participants show improvement on a novel task that is very similar to the training task (e.g., same instructions and trial sequence but with different response keys and stimuli). However, our theoretical assumption also suggests that the transfer effect should be very limited, and should affect only tasks that directly use the abstract representations that have been formed.

In designing our study, we considered Oberauer (2009) who suggested a distinction between procedural and declarative working memory processing. Declarative working memory was suggested to hold representations relevant to knowledge and facts (based on stimulus-stimulus associations), while procedural working memory was proposed to hold action rules (Oberauer, Souza, Druey, & Gade, 2013; Souza, da, Oberauer, Gade, & Druey, 2012; but see Barrouillet, Corbin, Dagry, & Camos, 2014 for different results). Training studies have mainly explored declarative working memory processing (e.g., N-back, Span tasks), where participants are asked to memorized the presentation order of a stimulus set (i.e., stimulus-location associations). These studies have shown near transfer effects to similar declarative working memory measures with novel stimuli (Melby-Lervåg & Hulme, 2013). Here, we did not aim to explore whether declarative and procedural representations are held in two different sub-components of the working memory system (an issue that is still debated). Instead, we aimed to explore whether working memory training is specific and general at the same time – in the sense that it allows participants to form highly abstract (general) representations, of the (very specific) procedure they are training at.

Our main assumption was that working memory training would lead participants to form highly abstract task representations (stimulus-response abstract slots) which would allow them to subsequently show better performance on unpracticed procedural choice-RT tasks. On the other hand, such abstract representations should not benefit participants when performing declarative working memory or reasoning tests that also demand working memory resources but do not tap the same representational structure. Some evidence for the fact that the procedural choice-RT tasks and declarative working memory tasks tap different processes/representations in this specific data set was reported in a previous study that performed correlational analysis using only pre-test data from the current study (Meiran, Pereg, Givon, Danieli, & Shahar, 2016). In that study, it was found that a factor explaining the shared variance among the procedural working memory tasks was weakly related ($r = 0.12$, ns) to a factor explaining the variance among the declarative working memory tasks.

In the current study, we compared the effect of procedural working memory training with an active control training (visual search task, where participants were asked to find a target in an array of distractors, tapping relatively early perceptual processes) and passive control (no training). Importantly, in both working memory and active-control training tasks participants were required on each trial to report a decision between two alternatives using a manual key response (i.e., 2-alternative forced choice). However, stimulus-response associations were unchanged across the entire training in the visual search group, while for the working memory training group, participants had to adapt to frequent changes in the task-set across blocks (i.e., new stimuli and response keys) and trials (task-switching). Therefore, we assumed that if needed, participants can form abstract stimulus-response associations and this might be more strongly encouraged in the working memory training task. To assess training benefits, we measured performance in three types of working memory demanding transfer tasks: (1) reasoning, (2) declarative working memory, and (3) procedural working memory, assuming that procedural working memory training would benefit participants only in the latter. To assess dosage effects we also administered procedural working memory transfer tasks in three additional time points in the study (after 2, 5 and 9 training sessions). Finally, we applied a mechanistic-based modeling approach to explore the choice mechanism that might underlie the observed transfer effects.