Psychological Research (2016) 80:877–888
DOI 10.1007/s00426-015-0687-4

ORIGINAL ARTICLE

Investigating the effectiveness of working memory training in the context of Personality Systems Interaction theory

Tomáš Urbánek[1] · Vladimír Marček[1]

Received: 10 January 2015 / Accepted: 6 July 2015 / Published online: 25 July 2015

Abstract Previous research has shown mixed results for the ability of working memory training to improve fluid intelligence. The aims of this study were first to replicate these improvements, and then to explore the moderating role of Personality Systems Interaction (PSI) personality factors. By using three different training methods and an active-contact control group, we examined the effects of 25 days of cognitive training on 142 participants. After examining our results in context of PSI theory, we found that different training methods yielded different IQ gains in participants, depending on their personality styles. In addition, these correlations suggested a meaningful pattern, indicating that PSI theory may be able to account for the different outcomes of cognitive training studies. Our findings may facilitate tailor-made cognitive training interventions in the future, and can contribute to explaining the mechanisms underlying the far transfer of working memory training to fluid intelligence.

This research was supported by the Czech Science Foundation (GACR) project no. 13-36836S.

✉ Vladimír Marček
vlad.marcek@gmail.com

Tomáš Urbánek
tour@psu.cas.cz

[1] Institute of Psychology, Academy of Sciences of the Czech Republic, Veveří 97, 602 00 Brno, Czech Republic

Introduction

Cognitive training (CT) has recently become a primary topic of interest in cognitive psychology, and several lines of research have been producing consistent and encouraging results. CT has been shown to compensate for the natural aging process in healthy adults (Carretti, Borella, Zavagnin & de Beni, 2012; Gates & Valenzuela, 2010; Kueider, Parisi, Gross & Rebok, 2012; Reijnders, van Heugten & van Boxtel, 2012) and benefit individuals with schizophrenia (Subramaniam et al., 2012; Wykes et al., 2011). There are, however, some applications of CT, such as efforts to improve fluid intelligence (Gf) with working memory training (WMT), that have regularly yielded mixed results (discussed below). We hypothesized that such discrepancies may be explained by underlying factors such as personality traits, which influence the effectiveness of WMT in improving Gf.

Working memory (WM) is the cognitive system responsible for actively maintaining and updating task-relevant information. It is related to attention, has a limited overall capacity, and items stored in WM are susceptible to mutual interference. Gf is a factor of general intelligence, which accounts for one's speed and precision of abstract thinking, particularly in novel situations, and can be measured with tests such as analogies or series completions (Mackintosh, 2011). Jaeggi, Buschkuehl, Jonides & Perrig, (2008) claimed to have significantly improved Gf in healthy adults in only one month by administering a WM-taxing exercise (n-back) to participants for 20 min per day. Their findings promptly received both positive (Sternberg, 2008) and negative (Moody, 2009) reviews, and have been scrutinized by the scientific community. Such scrutiny seems justified because, remarkably, there have been a comparable number of methodologically improved studies that have replicated and sometimes extended the original results (Bauernschmidt, Conway & Pisoni, 2009; Colom et al., 2010; Jaeggi, Buschkuehl, Jonides & Shah, 2011; Jaeggi, Buschkuehl, Shah & Jonides, 2014; Jausovec & Jausovec, 2012b; Karbach & Kray, 2009; Schmiedek, Lövdén & Lindenberger, 2010; Stephenson 2010; Wang, Zhou & Shah, 2014), and that have found no Gf improvements in healthy adults after WMT (Baniqued et al., 2013; Brehmer, Westerberg & Bäckman, 2012; Chein & Morrison, 2010; Chooi & Thompson, 2012; Oelhafen et al., 2013; Owen et al., 2010; Pugin et al., 2014; Redick et al., 2012; Salminen, Strobach & Schubert, 2012; Thompson et al., 2013). Meta-analytical studies differ in the conclusion on the presence (Au et al., 2014; Karbach & Verhaeghen, 2014; Schwaighofer, Fischer & Bühner, 2015) or absence of transfer effects (Melby-Lervåg & Hulme, 2013), emphasizing the inconclusiveness of results and the heterogeneity and shortcomings of different methodologies. The main objections concern control groups and measurement processes (Shipstead, Redick & Engle, 2012). Several authors have called for further research to uncover the mechanisms underlying far transfer from WMT to Gf (Jaeggi et al., 2010; Morrison & Chein, 2011; Rabipour & Raz, 2012). In two recent methodologically rigorous studies, Stephenson and Halpern (2013) and Colom et al. (2013) found improvements in several Gf measures following WMT. Despite this, however, these studies have gone on to consider latent factors of Gf or to consider Gf as a construct of the tests administered, respectively, and have led to the interpretation that WMT could improve visual performance rather than Gf. We elaborate on these interpretations in "The nature of cognitive improvements after WMT".

There has also been concern regarding control groups, which show no retest effects. Redick (2015) demonstrated that the mean score of a control group sometimes decreases from pretest to posttest, leading to falsely positive conclusions about the benefits of training in the experimental group. While we agree with this argument, it goes both ways: there is no reason why control groups could not sometimes, by chance, increase in performance when retested, thus leading to falsely negative findings in published studies. In addition, retest effects are not always expected after only one exposure, and their absence is not a problem, but a desired feature reducing confounds in the evaluation of transfer effects (Green, Strobach & Schubert, 2014). Indeed, researchers use parallel versions of IQ tests to eliminate retest effects. In general, when measuring the effects of a few hours of cognitive intervention on general intelligence, one must carefully balance the risk of false positives and false negatives (see Schubert & Strobach, 2012; Green et al., 2014).

The ambiguity of results of WMT effectiveness studies has mostly been explored from the perspectives of training methods and methodology: Does one specific method induce far transfer better than another method? Are some particular methodologies more likely to have positive results? Studer-Luethi, Jaeggi, Buschkuehl, and Perrig (2012) added an individual differences factor into consideration, by noting that "some participants are positively challenged and demonstrate large training gains whereas others feel overwhelmed and hardly improve or even regress" (p. 44). Therefore, the authors decided to investigate the impact of individual differences on WMT and discovered that different training methods led to different IQ gains, depending on participants' neuroticism and conscientiousness. Similarly, Savage (2013) stated that trait Agreeableness (from the HEXACO-60 questionnaire of Ashton & Lee, 2009), negatively modulated improvements after training on a dual n-back task. Jaeggi et al., (2014) observed that intrinsic motivation and the belief that one's intelligence is malleable positively affected the degree of far transfer to a composite score representing five different visuospatial reasoning measures. From a conceptual point of view, if the research on far transfer yields reliably ambiguous results, one plausible explanation is the influence of an independent, randomly distributed factor. Individual differences between participants, such as personality differences, could meet these criteria. Taken together, investigating the role of individual differences on WMT outcomes seems to be of high importance.

Personality Systems Interaction theory

There are many theories that formalize individual differences in psychology. Traditionally, most focus on either personality or cognition, omitting the interplay between the two. In contrast, Personality Systems Interaction (PSI; Kuhl, 2000b) theory integrates insights from cognitive science, motivation science, personality psychology, and neurobiology into a single coherent framework (for more extensive discussion, see Kuhl, 2000c; Kuhl & Koole, 2004). While more traditional theories of personality (e.g., Eysenck's theory; Eysenck 1950) operate with static traits and their content (i.e., traits are a tendency to experience certain affects), PSI theory is more dynamic and process oriented, with traits representing a tendency and capacity to up- or down-regulate certain affects.

PSI theory proposes four major cognitive macrosystems and three broad levels of regulation. At the lowest level, behavior is guided by elementary sensations and intuitive behavior programs. The intuitive behavior system operates on an unconscious automatic level, performing simple behavioral tasks based on context (e.g., stereotyped social interactions). The object recognition system is sensitive to discrepancies between expected and perceived stimuli. At the mid-level, behavior is guided by emotion and coping systems. Here, PSI theory distinguishes between positive and negative affect systems, which regulate approach and avoidance behavior (Kuhl, Kazén & Koole, 2006). At the highest level, behavior is regulated by complex cognitive systems: one focuses on sequential analytical processing and self-control and the other focuses on parallel holistic processing and self-regulation. Intention memory is responsible for sequential storing and processing of conscious intentions; it exercises rule-based thinking and planning. Extension memory, or the self-system, processes information in an unconscious, parallel, and holistic manner. It is congruence oriented, relates to feeling, and plays an important role in intrinsic motivation and the integration of self-related information into a cohesive sense of self.

These four cognitive macrosystems interact with each other in a complex yet well-defined manner (see Kuhl, 2000b), and each of them has been connected to the functioning of distinct neuroanatomical regions (Kuhl, 2000c). In addition, from the 14 possible personality styles of PSI theory, 12 correspond to *DSM-V* personality disorders. PSI theory also provides thorough explanations and testable predictions about human behavior (Kuhl, 2000b; Kazén, Kuhl, Boermans & Koole, 2013). Altogether, this approach suits our research needs by providing measurement concepts, tools, and theoretical explanations of the underlying factors that may affect gain in IQ after WMT.

Methods

We employed a pretest-training-posttest design, including the administration of two non-speeded IQ tests, two personality tests, three different training methods, and an active-contact control group.

Participants

By using printed media ads and public social networks, we recruited 142 participants (62 men, 43.7 %). Their mean age was 25.2 years (SD = 6.47, range 18–50; for details see Table 1). All participants reported no present or previous history of psychiatric illness or medication. Nine participants did not finish the study and were excluded from the final analysis (they either did not meet the required training time or did not attend the posttest session). Participants were required to undergo nearly 3 h of pretesting, 8 h of training in total spread across 25 working days, and 3 h of post-testing. For participation, each received a small financial compensation (ca. €25) and their own test results, including a short interpretation. Our study was approved by the ethics committee of Institute of Psychology, Academy of Sciences of the Czech Republic and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Informed consent was obtained from all participants.

Table 1 Sample characteristics

Group	*N*	% men	Mean age (SD)
Single n-back (SNB)	38	44.7	25.7 (6.2)
Triple n-back (TNB)	36	47.2	24.8 (5.8)
Mental rotations 3D	33	33.3	24.7 (5.8)
Sudoku (control)	35	48.6	24.6 (7.1)

Fluid intelligence measures

We administered Raven's Advanced Progressive Matrices, set II (RAPM; Raven, 1990) with a 40-min time limit. RAPM contains 36 items, each composed of a 3 × 3 grid of pattern elements. One element is always missing, and the participant's task is to choose an option that appropriately fills in the pattern. As a second measure of fluid reasoning, we used the Bochum Matrices Test (BOMAT) devised by Hossiep, Turck & Hasella (1999), with an 80-min time limit. The BOMAT contains 40 items, each of which is composed of 5 × 3 elements. This allows for more pattern relationships and makes the test significantly more difficult than the RAPM, on which some participants performed at ceiling. No participants reached the maximum performance ceiling on the BOMAT.

Personality measures

Personality Styles and Disorders Inventory

The Personality Styles and Disorders Inventory (PSDI), which is based on PSI theory, was developed by Kuhl & Kazén, (1997). It has 140 items and measures 14 scales of non-pathological personality styles. Each scale ranges from a minimal level and extent of the trait to a greater level of severity or intensity [e.g., "assertive/antisocial," "passive/depressive," or "conscientious/compulsive" (for a complete list, see Table 3)]. The 14 scales correspond to the 12 DSM-V personality disorders, with the addition of the optimistic/rhapsodic and unselfish/self-sacrificing scales. This taxonomy of personality styles and disorders is therefore rooted in many decades of clinical observations and research.

State-trait Anxiety Inventory

To measure anxiety, we administered the State-Trait Anxiety Inventory (STAI; Spielberger & Gorsuch, 1983). This is a widely accepted clinical psychometric instrument comprising 40 questions. It measures anxiety both as a current state and as a long-term personality trait.

Training tasks

Adaptive single n-back task (SNB)

The goal of the n-back task is for participants to keep track of regularly appearing stimuli and to respond when a stimulus matches the one presented n trials before. For example, if present $n = 3$, and audio letters were used as stimuli, with the order of "A–A–B–C–D–B," then second occurrence of "B" is a match (because previous B was presented 3 letters ago), and participant should indicate this by pressing the spacebar. For the task to be adaptive, n has to change periodically to match the participant's actual level of performance. In our "single" version of n-back task, participants had to keep track of one stream of stimuli: positions of squares appearing one at a time on a computer screen in a 3×3 grid. For this, we used open-source software (Brain Workshop, v. 4.8.1, http://brainworkshop.sourceforge.net/), configured to match the parameters used by Jaeggi et al. (2008): full-screen mode, no real-time feedback on errors, starting level $n = 2$, each trial consisted of stimulus presentation (500 ms) and break (2500 ms), and 20 trials amounted to one block. If the success rate of any block exceeded 80 %, the level of n increased for next block. If the success rate was lower than 50 % for three blocks altogether, the level of n decreased for next block. Daily training time amounted to 20 min (approximately 15 blocks). We departed from the configuration used by Jaeggi et al. (2008) in that we increased the chance of high-interference ("lure") trials from 0.125 to 0.4. A lure trial involves presenting a stimulus that could seem like a match (e.g., the position of a square presented a few trials previously), but it is actually a non-target because it is being repeated too soon ($n - 1$) or too late ($n + 1$). We increased this parameter, as one's ability to cope with these high-interference trials is significantly correlated with Gf (Gray, Chabris & Braver, 2003; Burgess, Gray, Conway & Braver, 2011). In addition, Jaeggi et al. (2014) used a considerable number of lure trials in their study showing far transfer to visuospatial reasoning.

Adaptive triple n-back task

We also included a "triple" version of the n-back task (TNB), using the same principle, software, and configuration as the "single" version, with the following modifications. Participants were presented with *three* streams of stimuli (positions of squares, colors of squares, and letters presented auditorily). For example, a blue square was presented up and to the left with sound "A," then a green square up and to the right with sound "S," and then a blue square up and to the left with sound "A," and so on. Again, if the current stimulus matched the one presented n trials before (in the same stream), participants had to indicate this by pressing the key assigned to this stream. Considering our example sequence, and present $n = 2$, participants should indicate an auditory and color match in the third trial by pressing two appropriate keys. As this is a highly demanding task, the break time for each trial was increased to 3000 ms to provide participants with more time to react. TNB taxes multiple sensory modalities at once: spatial (positions) and color visual abilities as well as symbolic (letters) auditory processing.

Adaptive mental rotations task

Efforts to improve Gf with CT have thus far focused on training WM. This has been justified because WM has been reliably linked to Gf (Colom, Abad, Quiroga, Shih & Flores-Mendoza, 2008; Kane, Hambrick & Conway, 2005; Oberauer, Süs, Wilhelm & Wittmann, 2008) and has been considered to be improvable with training (Morrison & Chein, 2011; Rafi & Samsudin, 2009). Mental rotation ability (MRA), however, is another cognitive process that meets these criteria and may be an additional pathway to improved Gf. First, MRA strongly correlates with Gf scores (Kaufman, DeYoung, Gray, Brown & Mackintosh, 2009), and Johnson & Bouchard (2005a, b) have even suggested that it is a core component of general intelligence. Second, the outcomes of MRA practice have been considered "dramatic" (Peters et al. 1995), and its trainability has recently been supported by additional studies (Stransky, Wilcox & Dubrowski, 2010; Jausovec & Jausovec 2012a). As the transfer of MRA training to Gf seems reasonable from this perspective, we developed an adaptive 3D mental rotation task. We presented users with a random 3D object and a series of instructions for mentally rotating it along X, Y, and Z axes (Fig. 1a). Participants were then required to select the correct perspective of the object out of six possible alternatives (Fig. 1b). The number of instructions regarding how to rotate the object was adaptively changed based on the previous success rate.

Control group task

We used a non-adaptive, beginner-level Sudoku game as our active-contact control group training task. The goal of Sudoku is to fill each nine-square row, each nine-square column, and each nine-square box with the numbers 1

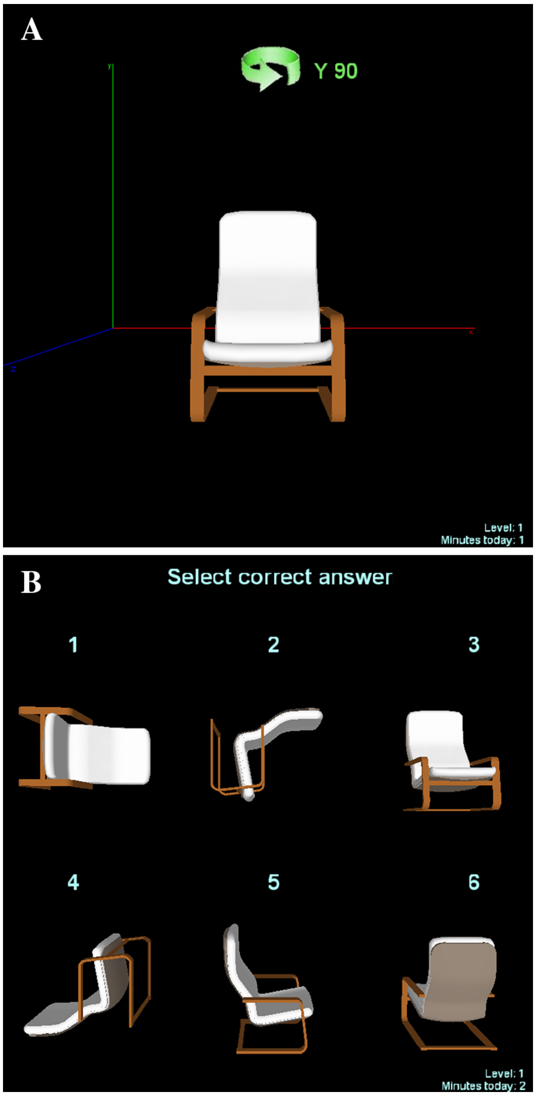

Fig. 1 **a** An example of the instructions for the adaptive mental rotation task. **b** An example of possible response options in the adaptive mental rotation task

through 9, by using each number only once in each. We consider this simple version of Sudoku to be an appropriate control training task for WM training, because at this level, it does not require any significant WM processing, but still involves attention, short-term memory, and some comparing and matching of stimuli.

Procedures

After informing participants on testing and training procedures, each signed a research contract and consent form. All testing sessions were conducted at Masaryk University, Brno, Czech Republic by administering paper-and-pencil based tests to small groups of participants (approximately 15 people). At pretest, we administered the PSDI and the odd- or even-numbered items of the RAPM and BOMAT in half of their standard time limit. One week after pretest, participants started to train individually on auto-timed software that had been distributed to them (Penner et al., 2012) for 20 min per day, across 25 days in total. Data were automatically transmitted to us daily. Posttest took place 1 week after training and consisted of the PSDI and the complementary odd- or even-numbered items of the RAPM and BOMAT. The first version of test (odd or even) was chosen randomly for each participant before the pretest.

Results

Our primary aim was to check for differences in RAPM and BOMAT performance scores from pretest to posttest. We standardized the scores from these different sets by transforming them to *z*-scores (the distance of each user's score from the mean of odd- or even-numbered items of all participants). Pretest/posttest means are summarized in Table 2. For a summary of training performance changes, see Fig. 2a, b. Each training group's mean performance increased with time, suggesting participants' involvement in the WMT.

To investigate possible main effects and interactions between independent variables, time (pretest and posttest) and training group (Sudoku, mental rotations, SNB, and TNB), we conducted a repeated-measures analysis of variance (RM-ANOVA). These tests revealed neither main effects (for RAPM: time $F(1, 138) = 2.858$, $p = 0.093$, $\eta^2 = 0.020$; training group $F(3, 138) = 0.774$, $p = 0.510$, $\eta^2 = 0.017$; for BOMAT: time $F(1,138) = 0.116$, $p = 0.734$, $\eta^2 = 0.001$; training group $F(3, 138) = 0.830$, $p = 0.480$, $\eta^2 = 0.018$), nor their interactions (for RAPM, $F(3, 138) = 0.641$, $p = 0.590$, $\eta^2 = 0.014$; for BOMAT, $F(3, 138) = 0.875$, $p = 0.456$, $\eta^2 = 0.019$) for any of the intelligence measures.

To answer the calls for further research on personality–training interaction (Colquitt, LePine & Noe, 2000; Könen & Karbach 2015), and because there is some evidence that personality could modulate the relationship between CT and IQ (Studer-Luethi et al., 2012; Savage, 2013; Jaeggi et al., 2014), we explored these effects in our data. The study design is not suitable for sophisticated multivariate analyses like structural equation modeling (given $N = 142$, divided into four groups, with 14 PSDI scales and two STAI scales, in a pretest–posttest design). Nevertheless, we agree with Freedman (2010) that assumptions of sophisticated regression models should not be substituted for subject matter knowledge and relevant data. Therefore, we decided to conduct an investigation of the possible relations between personality scales and IQ gain. The patterns

Table 2 Pretest and posttest scores of RAPM, BOMAT, and STAI

		RAPM*		BOMAT[a]		Anxiety as trait		Anxiety as state	
		Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Sudoku	*M*	−0.24	−0.27	−0.13	0.04	35.66	34.12	35.94	36.12
($n = 34$)	SD	1.32	1.07	0.88	1.11	5.57	5.74	4.47	6.23
MRT	*M*	−0.18	0.07	−0.30	−0.02	36.79	37.84	43.00	41.90
($n = 31$)	SD	0.96	0.90	0.76	0.96	9.04	11.04	9.87	9.03
SNB	*M*	0.05	0.10	0.14	0.08	35.97	38.76	41.63	42.14
($n = 37$)	SD	0.99	0.94	0.93	1.17	7.64	7.35	9.00	10.04
TNB	*M*	0.08	0.41	0.00	0.18	35.44	35.55	40.78	40.74
($n = 31$)	SD	0.77	0.84	1.09	1.04	5.56	6.39	7.29	8.49

MRT mental rotations, *SNB* single n-back, *TNB* triple n-back

[a] Figures are in z-scores

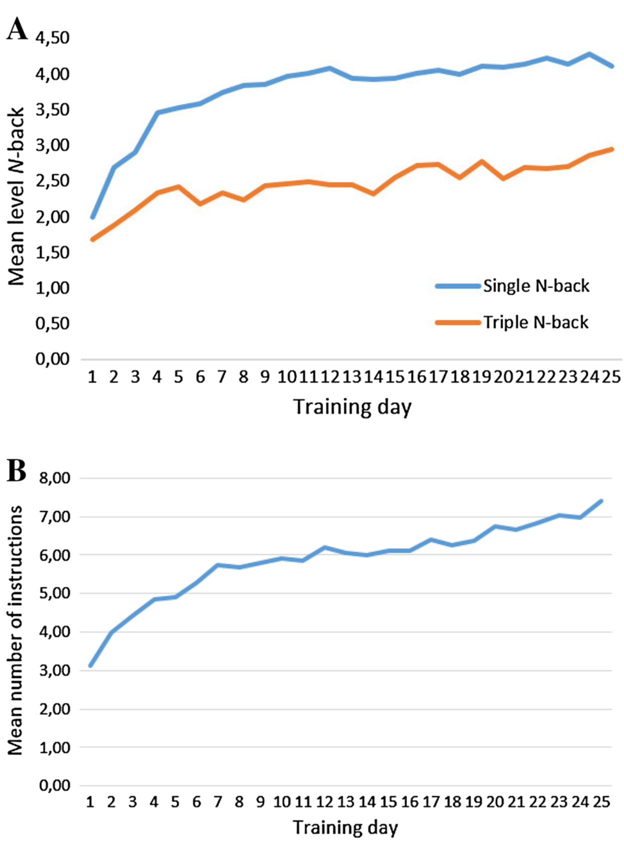

Fig. 2 **a** Group mean values of daily averages in n-back difficulty level as a function of training day. **b** Group mean values of daily averages in mental rotations 3D difficulty level as a function of training day

that emerged in our results seem to justify this analysis—although exploratory, it has the potential to provide interesting and important findings.

Correlations between pretest IQ levels and personality traits are summarized in Table 3. From 14 personality styles, only one was related to both RAPM and BOMAT IQ tests: a negative correlation between test performance and intuitive/schizotypal style (e.g., "I believe telepathy is possible."). Additionally, RAPM scores correlated negatively with situational anxiety, while BOMAT scores correlated negatively with anxiety as a trait.

As RAPM scores were sometimes at ceiling and there were no significant correlations between IQ gains and the PSDI scales, we focused our further analyses only on BOMAT scores. Correlations between changes to IQ as measured by BOMAT score and the different PSI personality styles under different training methods are shown in Table 4. Primarily, there were significant correlations for

Table 3 Correlations between intelligence scores and personality scales in pretest

	RAPM	BOMAT
RAPM	1	0.49
BOMAT	0.49	1
Anxiety state	−0.21*	−0.1
Anxiety trait	−0.08	−0.17*
Assertive (antisocial)	−0.12	0
Willful (paranoid)	−0.05	0.02
Reserved (schizoid)	0.15[†]	0.04
'Self-critical (avoidant)	−0.15[†]	−0.11
Conscientious (compulsive)	0.2*	0.05
Intuitive (schizotypal)	−0.24*	−0.24**
Optimistic (rhapsodic)	−0.04	0.04
Ambitious (narcissistic)	−0.13	0.01
Critical (negativistic)	−0.05	−0.02
Loyal (dependent)	−0.05	−0.01
Spontaneous (borderline)	−0.16[†]	−0.15[†]
Charming (histrionic)	−0.2*	−0.14
Passive (depressive)	−0.06	−0.14
Unselfish (self-sacrificing)	0.02	−0.02

$N = 132$; ** $p < 0.01$, * $p < 0.05$, † $p < 0.10$

both SNB and TNB training, sometimes mirroring each other (e.g., changes in BOMAT scores due to SNB training and pretest cautious personality style: $r(36) = 0.51$, $p < 0.01$; changes in BOMAT scores due to TNB training and pretest cautious personality style: $r(31) = -0.31$, $p = 0.09$). Posttest personality traits correlated with the different versions of n-back in a very similar fashion, and sometimes the mirroring was even more pronounced. For example, the correlation between the changes in BOMAT scores due to SNB training and posttest optimistic personality style [$r(36) = -0.36$, $p = 0.03$] was nearly the opposite of the correlation due to TNB training [$r(31) = 0.40$, $p = 0.03$]. Similarly, the correlations between BOMAT score changes and posttest depressive personality style scores were nearly opposite for SNB training [$r(36) = 0.40$, $p = 0.02$] and TNB training [$r(31) = -0.36$, $p = 0.05$].

Discussion

In this study, we investigated whether WMT would cause any statistically significant changes in intellectual performance from pretest to posttest (as measured by RAPM and BOMAT), and whether these potential changes would correlate with different personality traits. Using RM-ANOVA, we found no main effects nor interactions reaching statistical significance (although pretest–posttest effect was approaching it). While failures to replicate and null results are scientific contributions that are generally desirable in psychology research (Makel, Plucker & Hegarty, 2012), and publishing them is important to combat the “file-drawer” problem (Redick et al., 2012; Shipstead et al., 2012), the ambiguity of CT outcomes has become an important issue requiring further explanation.

Moderating role of PSI personality factors in CT outcomes

We started by correlating baseline IQ scores of participants with their scores on 14 PSDI personality trait scales. Some weak correlations appeared (see Table 3), which are consistent with the notion that ability traits (e.g., IQ) and non-ability traits (e.g., the “big five” personality dimensions) are relatively independent (Demetriou, Kyriakides & Avraamidou, 2003; Farsides & Woodfield, 2003; Soubelet & Salthouse, 2011). We then correlated PSI personality profiles with the IQ gains from the multiple CT methods, and with the pooled sample of training as a whole (not differentiating between training methods; see Table 4).

Table 4 Correlational analyses of pretest PSDI scales and IQ score changes (BOMAT) for each of the possible cognitive training methods (see legend for description)

PSDI and STAI scores	All training groups		Control (Sudoku)		MR		SNB		TNB	
	r_G	r_{part}	r_G	r_{part}	r_G	r_{part}	r_G	r_{part}	r_G	r_{part}
Self-determined (dissocial)	0.12	0.13	−0.22	−0.20	0.25	0.33†	0.19	0.19	−0.17	−0.19
Cautious (paranoid)	0.13	0.16	0.01	−0.02	0.17	0.20	0.51**	0.50**	−0.31†	−0.22
Reserved (schizoid)	0.08	0.08	−0.09	−0.02	−0.2	−0.17	0.52**	0.49**	−0.23	−0.12
Self-critical (self-insecure)	−0.14	−0.17†	0.25	0.14	−0.17	−0.20	−0.01	−0.02	−0.32†	−0.39*
Conscientious (compulsive)	0.13	0.17†	0.09	0.12	−0.05	−0.06	0.17	0.23	0.32†	0.34†
Intuitive (schizotypal)	0.03	−0.08	0	−0.12	0.07	−0.02	−0.30†	−0.37*	0.28	0.16
Optimistic (rhapsodic)	−0.01	0.02	−0.11	−0.10	0.18	0.25	−0.37*	−0.33†	0.19	0.11
Ambitious (narcissistic)	−0.07	−0.01	0.06	−0.07	−0.12	0.04	−0.09	−0.05	0	0.03
Critical (negativistic)	0.18†	0.19†	−0.1	−0.14	0.13	0.28	0.41*	0.40*	−0.11	−0.12
Loyal (dependent)	−0.09	−0.04	0.30†	0.14	−0.21	−0.04	−0.06	0.00	0.01	−0.07
Spontaneous (borderline)	−0.06	−0.13	0.12	−0.02	0.02	−0.04	0.06	−0.02	−0.32†	−0.29
Charming (histrionic)	0.12	0.06	−0.16	−0.22	0.18	0.18	−0.15	−0.16	0.29	0.16
Calm (depressive)	0.01	−0.06	0.22	0.15	−0.14	−0.21	0.30†	0.23	−0.22	−0.24
Helpful (self-sacrificing)	−0.08	−0.07	0.12	0.06	−0.27	−0.14	0.03	0.02	0.02	−0.05
State anxiety	−0.05	−0.09	0.01	−0.09	−0.19	−0.21	0.07	0.01	−0.02	0.02
Trait anxiety	0.09	0.00	0.08	0.03	−0.13	−0.10	0.38*	0.33†	0	−0.20

SNB single n-back, *TNB* triple n-back, r_G correlation (zero-order) of the pretest personality scale with IQ gain, r_{part} partial correlation of the pretest personality scale with the posttest IQ (pretest IQ partialled out)

$N_{\text{all-training}} = 97$, $N_{\text{sudoku}} = 34$, $N_{\text{MR}} = 31$, $N_{\text{SNB}} = 36$, $N_{\text{TNB}} = 31$; ** $p < 0.01$, * $p < 0.05$, † $p < 0.10$

There was no significant relationship with any of the PSDI scales, which suggests that there is no effective way to predict if and how much a person will gain from CT based on their personality scores. However, when we split our sample according to the type of training method, substantially different results appeared. Specifically, in the SNB training group, gains in BOMAT scores correlated positively with negativistic, paranoid, and schizoid PSDI scales, while at the same time, correlated negatively with schizotypal and rhapsodic PSDI scales (see Table 4). Looking at the STAR model proposed by Kuhl (2000a; Fig. 3), the PSDI scales that are positively associated with BOMAT scores are situated exactly opposite those PSDI scales that are negatively associated with BOMAT scores.

According to PSI theory, the two pairs of styles correlating with IQ gain positively (distrustful and reserved) and those correlating with IQ gain negatively (intuitive and optimistic) are fundamentally different from each other. They are not, however, reduced to opposite poles of one common continuum (e.g., introversion-extroversion). They differ in terms of their sensitivity to rewards and punishments and in the dominance of cognitive macrosystems as described by PSI theory. While both distrustful and reserved styles are dominated by analytical thinking and planning (and include low sensitivity to both rewards and punishments), intuitive and optimistic PSI styles are dominated by intuitive behavior control and are characterized by high sensitivity to rewards and punishments (see Kuhl, 2000a). Accordingly, this perspective suggests that the effects of SNB exercise (utilizing only one sensory modality, presenting only one stimulus every 3 s, and requiring greater delays in WM processing as higher levels of n are reached) correlates positively with personality styles that typically engage in time-planning and that are less dependent on rewards or punishments. On the other hand, the substantially different training method of TNB (which requires more immediate processing and presents participants with diverse, multimodal stimuli) favors persons with intuitive and action-oriented personality styles (although evidence for this is based on our small sample of 31 and correlations with IQ gain that were marginally significant at $p < 0.10$; see Table 4). This finding could further suggest that the influence of processing style (analytical vs. intuitive-holistic) plays a greater role in modulating training gains than does emotional sensitivity (to punishments and rewards).

The complexity of PSI theory allows us to elaborate further on our results. It is evident that opposing PSI personality styles influence the effectiveness of CT differently, and the fact that opposing correlations in our data both reached

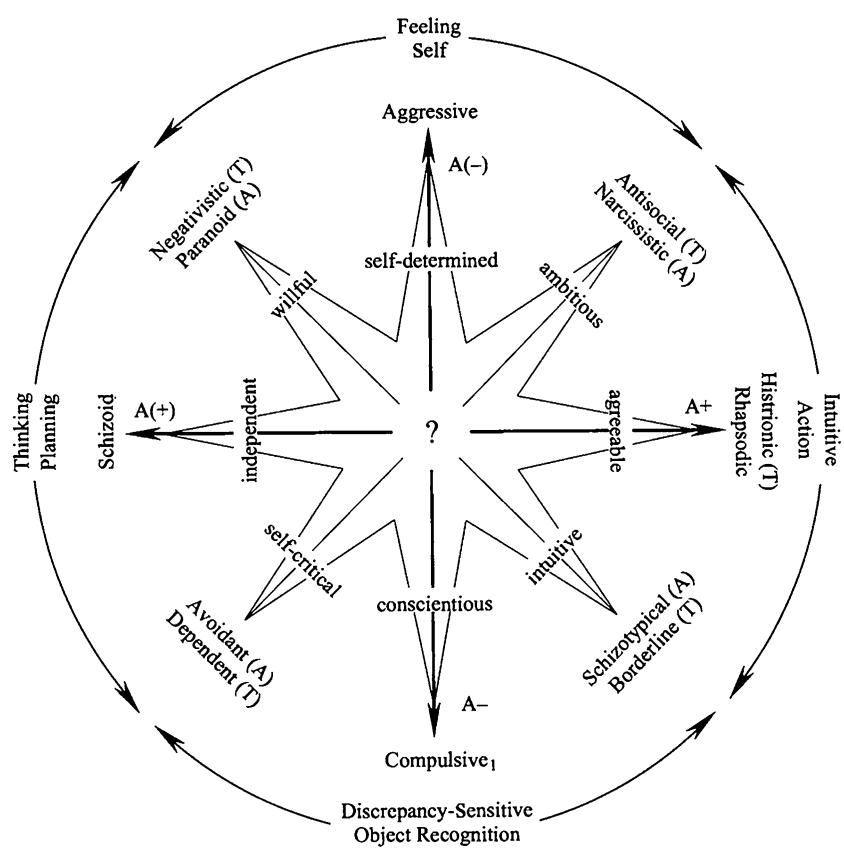

Fig. 3 The STAR model of personality dimensions by Kuhl and Kazén (1997)

statistical significance further supports the emerging correlation pattern that fits the PSI model. In addition, this pattern repeats itself in retest sessions and seems to be mirrored in independent groups training on either of the considerably different TNB and SNB training methods. The pattern of correlations present in our data fits well with PSI theory, and we suggest that this explanation of ambiguous WMT results is the most important finding of our study.

We did not find this pattern in the RAPM. One possible reason for this could be that RAPM was much more influenced by a ceiling effect. No participants scored perfectly in the BOMAT, but 23 % of participants did in the RAPM.

To explore the directionality of significant correlations between pre- and posttest personality and cognition, we conducted cross-lagged panel analyses. In several cases, pretest personality traits significantly added to the prediction of the posttest IQ score (but not vice versa, see Table 4). Caution is always advised when interpreting causality, but there is some evidence suggesting that posttest IQ score changes are influenced by pretest personality traits, rather than posttest personality traits being influenced by pretest IQ scores (Granger, 1969).

Moderating role of anxiety in WMT outcomes

Studer-Luethi et al. (2012) have also documented the influence of personality traits on WMT outcomes. In their study, individuals scoring high in neuroticism benefitted more from SNB and individuals scoring low in neuroticism benefitted more from dual n-back training. The authors hypothesized that anxiety could be a moderating factor: individuals high in neuroticism are overwhelmed sooner by more complex, multimodal n-back exercises (i.e., the dual n-back), and this anxiety in turn blocks the process of cognitive gain. In our experiment, we tested this hypothesis, by measuring both state and trait anxiety using the STAI. We found a positive correlation of anxiety as a long-term personality trait (which presumably influenced participants WMT continuously, as opposed to the transient state of anxiety during the test-taking situation), with BOMAT gain for the SNB training group (see Table 4). This "high-anxiety–gain after SNB" correlation is in concordance with the hypothesis proposed by Studer-Luethi et al. (2012). In addition, there seems to be certain phenomenological closeness in all of the personality traits thus far found to correlate positively with cognitive gain after SNB (anxiety, neuroticism, and critical, reserved, and cautious personality style).

The nature of cognitive improvements after WMT

Improvements in tests of fluid intelligence after WMT have recently been interpreted as improvements not of Gf, but rather of "visual performance" (Colom et al., 2013; Stephenson & Halpern, 2013). We have several conceptual objections to this interpretation. First, this general kind of "visual performance" may very well be what one actually aims to improve with WMT, considering that several theories of intelligence recognize visuospatial abilities as an essential component of general intelligence (Wechsler, 2008; Johnson and Bouchard, 2005b). More importantly, visual performance (e.g., the Gv factor of Cattell–Horn–Carroll theory; Carroll 1993) is measured by administering visually complex stimuli (e.g., noise-obscured objects, complex patterns, fields of letters) and one task operation (e.g., change size, rotate, search for something visually). In contrast, matrix tests (such as the RAPM and BOMAT used in this study) use items consisting of visually simple stimuli, meant only to be carriers of an underlying reasoning problems containing complex transformations that must be discovered and interpreted during the task. Finally, tests of visual performance increase their difficulty by increasing the visual complexity of stimuli, whereas matrix tests increase their difficulty by increasing the number of possible and necessary logical relationships, regardless of visual complexity (indeed, some of the hardest RAPM or BOMAT items look visually simpler than the easiest ones—it is the number of potential logical relationships one has to discover and test that makes them difficult). Taken together, visually performing a search for an object partially obscured by visual noise is substantially different from the inductive reasoning required to find the logical relationships of the RAPM and BOMAT. In addition, Jaeggi et al. (2014) documented far transfer from an auditory n-back task to visuospatial reasoning, indicating improvements to modality-independent cognitive abilities.

Limitations

Some inherent limitations of our study include the problem of psychometric precision and difficulty identifying small inter-group differences (one or two points of raw score from pretest to posttest), against noticeable intra-group differences caused by unavoidable differences in level of difficulty between the odd- and even-numbered IQ subtests (RAPM: $t = 7.50$, $p < 0.001$; BOMAT: $t = 3.13$, $p = 0.002$). We consider total training time (approximately 8 h) to be another constraint to examining the effects of CT to Gf thoroughly. Stronger effects may have been observed with additional training. Another limitation may be the relatively high pretest scores of our sample (RAPM mean = 14.78 out of 18, SD = 2.6, corresponding to about the 90th percentile; BOMAT mean = 13.38 out of 20, SD = 2.34, corresponding to about the 70th percentile). In addition, our control group task (basic-level Sudoku) was perceived as quite demanding by several training subjects retrospectively, which could result in type-II errors of negative bias in favor of the null hypothesis. We are also aware of the potential risk of some statistical tests being significant by chance due to our multiple comparisons (analyzing several personality factors in each group). Nevertheless, the emerging pattern of correlations does not seem random, but rather, it seems to fit logically into the PSI personality model.

Conclusions

Our study echoes the findings of several previous studies suggesting that ability and non-ability traits can emerge in any combination in a person, with a loose relationship between the two at best. Nevertheless, we presented some evidence that changing or training an already established, complex ability trait (e.g., fluid intelligence) requires an understanding of non-ability traits (e.g., PSI personality styles). Intuitively, the opposite seems to be plausible as well: if one seeks to modify personality traits (e.g., in psychotherapy), this may depend in part on levels of ability traits such as intelligence. Of course, any investigation into the interplay of two large areas in psychology (intelligence and personality) is bound to be incomplete. Still, we believe our findings can contribute to the efficacy of tailor-made CT interventions and inspire further research in this exciting area.

Acknowledgments Our study took place with the financial support of the Czech Science Foundation, project no. GAČR13-36836S, awarded to Tomáš Urbánek. This funding source had no involvement in study design; in the collection, analysis, and interpretation of data; in the writing of the report; or in the decision to submit the article for publication.

References

Ashton, M. C., & Lee, K. (2009). The HEXACO-60: A short measure of the major dimensions of personality. *Journal of Personality Assessment, 91*(4), 340–345.

Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2014). Improving fluid intelligence with training on working memory: A meta-analysis. *Psychonomic Bulletin & Review*,. doi:10.3758/s13423-014-0699-x.

Baniqued, P. L., Kranz, M. B., Voss, M. W., Lee, H., Cosman, J. D., Severson, J., et al. (2013). Cognitive training with casual video games: Points to consider. *Frontiers in Psychology*,. doi:10.3389/fpsyg.2013.01010.

Bauernschmidt, A., Conway, C. M., & Pisoni, D. B. (2009). *Working memory training and implicit learning*. Report: Research on Spoken Language Processing Progress. **29**.

Brehmer, Y., Westerberg, H., & Bäckman, L. (2012). Working-memory training in younger and older adults: Training gains, transfer, and maintenance. *Frontiers in Human Neuroscience*,. doi:10.3389/fnhum.2012.00063.

Burgess, G. C., Gray, J. R., Conway, A. R. A., & Braver, T. S. (2011). Neural mechanisms of interference control underlie the relationship between fluid intelligence and working memory span. *Journal of Experimental Psychology: General, 140*(4), 674–692.

Carretti, B., Borella, E., Zavagnin, M., & de Beni, R. (2012). Gains in language comprehension relating to working memory training in healthy older adults. *International Journal of Geriatric Psychiatry, 28*(5), 539–546.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. New York: Cambridge University Press.

Chein, J. M., & Morrison, A. B. (2010). Expanding the mind's workspace: Training and transfer effects with a complex working memory span task. *Psychonomic Bulletin Review, 17*(2), 193–199.

Chooi, W.-T., & Thompson, L. A. (2012). Working memory training does not improve intelligence in healthy young adults. *Intelligence, 40*(6), 531–542.

Colom, R., Abad, F. J., Quiroga, M. Á., Shih, P. C., & Flores-Mendoza, C. (2008). Working memory and intelligence are highly related constructs, but why? *Intelligence, 36*(6), 584–606.

Colom, R., Quiroga, M. Á., Shih, P. C., Martinez, K., Burgaleta, M., Martinez-Molina, A., et al. (2010). Improvement in working memory is not related to increased intelligence scores. *Intelligence, 38*(5), 497–505.

Colom, R., Román, F. J., Abad, F. J., Shih, P. C., Privado, J., Froufe, M., et al. (2013). Adaptive n-back training does not improve fluid intelligence at the construct level: gains on individual tests suggest that training may enhance visuospatial processing. *Intelligence, 41*(5), 712–727.

Colquitt, J. A., LePine, J. A., & Noe, R. (2000). Toward an integrative theory of training motivation: A meta-analytic path of analysis of 20 years of research. *Journal of Applied Psychology, 85*(5), 678–707.

Demetriou, A., Kyriakides, L., & Avraamidou, C. (2003). The missing link in the relations between intelligence and personality. *Journal of Research in Personality, 37*(6), 547–581.

Eysenck, H. J. (1950). *Dimensions of personality* (Vol. 5). New Brunswick: Transaction Publishers.

Farsides, T., & Woodfield, R. (2003). Individual differences and undergraduate academic success: The roles of personality, intelligence, and application. *Personality and Individual Differences, 34*(7), 1225–1243.

Freedman, D. A. (2010). *Statistical models and causal inference: A dialogue with the social sciences*. New York: Cambridge University Press.

Gates, N., & Valenzuela, M. (2010). Cognitive exercise and its role in cognitive function in older adults. *Current Psychiatry Reports, 12*(1), 20–27.

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: Journal of the Econometric Society*, 37(3), 424–438.

Gray, J. R., Chabris, C. F., & Braver, T. S. (2003). Neural mechanisms of general fluid intelligence. *Nature Neuroscience, 6*, 316–322.

Green, C. S., Strobach, T., & Schubert, T. (2014). On methodological standards in training and transfer experiments. *Psychological Research, 78*(6), 756–772.

Hossiep, R., Turck, D., & Hasella, M. (1999). *Bochumer Matrizentest (BOMAT) advanced*. Göttingen: Hogrefe.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences, 105*(19), 6829.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Shah, P. (2011). Short- and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences, 108*(25), 10081–10086.

Jaeggi, S. M., Buschkuehl, M., Shah, P., & Jonides, J. (2014). The role of individual differences in cognitive training and transfer. *Memory & Cognition, 42*(3), 464–480.

Jaeggi, S. M., Studer-Luethi, B., Buschkuehl, M., Su, Y.-F., Jonides, J., & Perrig, W. J. (2010). The relationship between n-back performance and matrix reasoning — implications for training and transfer. *Intelligence, 38*(6), 625–635.

Jausovec, N., & Jausovec, K. (2012a). Sex differences in mental rotation and cortical activation patterns: Can training change them? *Intelligence, 40*(2), 151–162.

Jausovec, N., & Jausovec, K. (2012b). Working memory training: improving intelligence-changing brain activity. *Brain and Cognition, 79*(2), 96–106.

Johnson, W., & Bouchard, T. J. (2005a). Constructive replication of the visual-perceptual-image rotation model in Thurstone's (1941) battery of 60 tests of mental ability. *Intelligence, 33*(4), 417–430.

Johnson, W., & Bouchard, T. J. (2005b). The structure of human intelligence: It is verbal, perceptual, and image rotation (VPR), not fluid and crystallized. *Intelligence, 33*(4), 393–416.

Kane, M. J., Hambrick, D. Z., & Conway, A. R. A. (2005). Working memory capacity and fluid intelligence are strongly related constructs: Comment on Ackerman, Beier, and Boyle (2005). *Psychological Bulletin, 131*(1), 66–71.

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science, 12*(6), 978–990.

Karbach, J., & Verhaeghen, P. (2014). Making working memory work: A meta-analysis of executive-control and working memory training in older adults. *Psychological Science, 25*(11), 2027–2037.

Kaufman, S. B., DeYoung, C. G., Gray, J. R., Brown, J., & Mackintosh, N. (2009). Associative learning predicts intelligence above and beyond working memory and processing speed. *Intelligence, 37*(4), 374–382.

Kazén, M., Kuhl, J., Boermans, S., & Koole, S. L. (2013). Excelling at selling: The charming personality style predicts occupational activities, sales performance, and persuasive competence. *PsyCh Journal, 2*(2), 86–100.

Könen, T., & Karbach, J. (2015). The benefits of looking at intraindividual dynamics in cognitive training data. *Frontiers in Psychology,*. doi:10.3389/fpsyg.2015.00615.

Kueider, A. M., Parisi, J. M., Gross, A. L., & Rebok, G. W. (2012). Computerized cognitive training with older adults: a systematic review. *PLoS One, 7*(7), e40588.

Kuhl, J. (2000a). A theory of self-development: affective fixation and the STAR model of personality disorders and related styles. In J. Heckhausen (Ed.), *Motivational psychology of human development: developing motivation and motivating development*. Oxford: Elsevier.

Kuhl, J. (2000b). The volitional basis of personality systems interaction theory: Applications in learning and treatment contexts. *International Journal of Educational Research, 33*(7), 665–703.

Kuhl, J. (2000c). A functional-design approach to motivation and volition: The dynamics of personality systems interactions. In M. Boekaerts, P. R. Pintrich, M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 111–169). New York: Academic Press.

Kuhl, J., & Kazén, M. (1997). *Persönlichkeits-Stil-und-Störungs-Inventar (PSSI) [The Personality-Styles-and-Disorder-Inventory (PSDI): Manual]*. Göttingen: Hogrefe.

Kuhl, J., Kazén, M., & Koole, S. L. (2006). Putting self-regulation theory into practice: A user's manual. *Applied Psychology, 55*(3), 408–418.

Kuhl, J., & Koole, S. L. (2004). Workings of the will: A functional approach. In J. Greenberg, S. L., Koole, & T. Pyszczynski (Eds.), *Handbook of experimental existential psychology* (pp. 411–430). New York: Guilford.

Mackintosh, N. (2011). *IQ and human intelligence*. New York: Oxford University Press.

Makel, M. C., Plucker, J. A., & Hegarty, B. (2012). Replications in psychology research: how often do they really occur? *Perspectives on Psychological Science, 7*(6), 537–542.

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? *A meta-analytic review. Developmental Psychology, 49*(2), 270.

Moody, D. E. (2009). Can intelligence be increased by training on a task of working memory? *Intelligence, 37*(4), 327–328.

Morrison, A. B., & Chein, J. M. (2011). Does working memory training work? The promise and challenges of enhancing cognition by training working memory. *Psychonomic Bulletin & Review, 18*(1), 46–60.

Oberauer, K., Süs, H. M., Wilhelm, O., & Wittmann, W. W. (2008). Which working memory functions predict intelligence? *Intelligence, 36*(6), 641–652.

Oelhafen, S., Nikolaidis, A., Padovani, T., Blaser, D., Koenig, T., & Perrig, W. J. (2013). Increased parietal activity after training of interference control. *Neuropsychologia, 51*(13), 2781–2790.

Owen, A. M., Hampshire, A., Grahn, J. A., Stenton, R., Dajani, S., Burns, A. S., et al. (2010). Putting brain training to the test. *Nature, 465*(7299), 775–778.

Penner, I.-K., Vogt, A., Stöcklin, M., Gschwind, L., Opwis, K., & Calabrese, P. (2012). Computerised working memory training in healthy adults: a comparison of two different training schedules. *Neuropsychological Rehabilitation, 22*(5), 716–733.

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn Vandenberg and Kuse mental rotations test-different versions and factors that affect performance. *Brain and Cognition, 28*(1), 39–58.

Pugin, F., Metz, A. J., Stauffer, M., Wolf, M., Jenni, O. G., & Huber, R. (2014). Working memory training shows immediate and long-term effects on cognitive performance in children and adolescents. *F1000Research*, 3, 82.

Rabipour, S., & Raz, A. (2012). Training the brain: Fact and fad in cognitive and behavioral remediation. *Brain and Cognition, 79*(2), 159–179.

Rafi, A., & Samsudin, K. (2009). Practising mental rotation using interactive desktop mental rotation trainer (iDeMRT). *British Journal of Educational Technology, 40*(5), 889–900.

Raven, J. C. (1990). *Advanced Progressive Matrices. Sets I, II.* Oxford: Oxford University Press.

Redick, T. S. (2015). Working memory training and interpreting interactions in intelligence interventions. *Intelligence, 50*, 14–20.

Redick, T. S., Shipstead, Z., Harrison, T. L., Hicks, K. L., Fried, D. E., Hambrick, D. Z., et al. (2012). No evidence of intelligence improvement after working memory training: A randomized, placebo-controlled study. *Journal of Experimental Psychology: General, 142*(2), 359–379.

Reijnders, J., van Heugten, C., & van Boxtel, M. (2012). Cognitive interventions in healthy older adults and people with mild cognitive impairment: A systematic review. *Ageing Research Reviews, 12*(1), 263–275.

Salminen, T., Strobach, T., & Schubert, T. (2012). On the impacts of working memory training on executive functioning. *Frontiers in Human Neuroscience, 6*, 166.

Savage, L. (2013). *Near and far transfer of working memory training related gains in healthy adults (Unpublished doctoral dissertation), Department of Clinical Psychology*. Alberta: University of Calgary.

Schmiedek, F., Lövdén, M., & Lindenberger, U. (2010). Hundred days of cognitive training enhance broad cognitive abilities in adulthood: Findings from the COGITO study. *Frontiers in Aging Neuroscience, 2*, 27.

Schubert, T., & Strobach, T. (2012). Video game experience and optimized executive control skills—On false positives and false negatives: Reply to Boot and Simons (2012). *Acta Psychologica, 141*(2), 278–280.

Schwaighofer, M., Fischer, F., & Bühner, M. (2015). Does Working Memory Training Transfer? A Meta-Analysis Including Training Conditions as Moderators. *Educational Psychologist, 50*(2), 138–166.

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? *Psychological Bulletin, 138*(4), 628–654. doi:10.1037/a0027473.

Soubelet, A., & Salthouse, T. A. (2011). Personality–cognition relations across adulthood. *Developmental Psychology, 47*(2), 303.

Spielberger, C. D., & Gorsuch, R. L. (1983). *State-trait anxiety inventory for adults: Sampler set: manual, test, scoring key*. Menlo Park: Mind Garden.

Stephenson, C. (2010). *Does training to increase working memory capacity improve fluid intelligence?* (Doctoral dissertation). UMI Dissertation Publishing (number: 3417011). Claremont Graduate University, Ann Arbor, Michigan.

Stephenson, C. L., & Halpern, D. F. (2013). Improved matrix reasoning is limited to training on tasks with a visuospatial component. *Intelligence, 41*(5), 341–357.

Sternberg, R. J. (2008). Increasing fluid intelligence is possible after all. *Proceedings of the National Academy of Sciences, 105*(19), 6791–6792.

Stransky, D., Wilcox, L. M., & Dubrowski, A. (2010). Mental rotation: cross-task training and generalization. *Journal of Experimental Psychology: Applied, 16*(4), 349.

Studer-Luethi, B., Jaeggi, S. M., Buschkuehl, M., & Perrig, W. J. (2012). Influence of neuroticism and conscientiousness on working memory training outcome. *Personality and Individual Differences, 53*(1), 44–49.

Subramaniam, K., Luks, T. L., Fisher, M., Simpson, G. V., Nagarajan, S., & Vinogradov, S. (2012). Computerized cognitive training restores neural activity within the reality monitoring network in schizophrenia. *Neuron, 73*(4), 842–853.

Thompson, T. W., Waskom, M. L., Garel, K.-L. A., Cardenas-Iniguez, C., Reynolds, G. O., Winter, R., et al. (2013). Failure of working memory training to enhance cognition or intelligence. *PLoS One, 8*(5), e63614.

Wang, Z., Zhou, R., & Shah, P. (2014). Spaced cognitive training promotes training transfer. *Frontiers in Human Neuroscience, 8*, 217.

Wechsler, D. (2008). *Wechsler adult intelligence scale–Fourth Edition (WAIS–IV)*. San Antonio: NCS Pearson.

Wykes, T., Reeder, C., Landau, S., Everitt, B., Knapp, M., Patel, A., & Romeo, R. (2007). Cognitive remediation therapy in schizophrenia: Randomised controlled trial. *The British Journal of Psychiatry, 190*(5), 421–427.