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The effectiveness of working memory training – points to consider for future research

***Abstract**: Working memory training (WMT) has recently become one of the most debated issues in the field of cognitive psychology. Since working memory (WM) is considered a strong correlate of IQ, numerous researchers have been trying to increase the latter by training the former. Proven effectiveness of working memory training could lead to its application in the therapy of many cognitive impairments. WMT could be also used as a tool of improving cognitive functioning of healthy subjects. However, almost every publication claiming to provide evidence for achieving one of above mentioned objectives has been criticised, mostly because of methodological shortcomings.*
The aim of my presentation is to extract potential sources of inconsistencies existing between the authors of meta-analysis and reviews of WMT research. For this reason I take a closer look at results and conclusions of several meta-analysis and reviews. As a result I point few indications that should be taken into consideration in future studies on WMT effectiveness.
***Key words**: working memory training, effectiveness of WMT, working memory capacity, near- and far-transfer*

1. Working memory

Working memory (WM) is a core cognitive mechanism responsible for efficient functioning in everyday life. It is a key component of learning, decision making, following instructions, reading, using spoken and written language, reasoning and problem solving (e.g. Engle & Kane, 2004; Jarrold & Towse, 2006; Miyake & Shah, 1999; Unsworth, Redick, Heitz, Broadway, & Engle, 2009; Westerberg & Klingberg, 2007).

The term of working memory was published for the first time in 1974 by Baddeley and Hitch. According to them, working memory consists of a set of mental structures and processes involved in organizing and integrating sensory and other information held in the short-term storage. Along with continuing research on WM there were more attempts to create an decent model as well as a full definition, but so far there is no compromise on this matter (for a review see Baddeley, 2010).

The ability to maintain the activation of memory representations in the face of distraction is termed as working memory capacity (Conway, Cowan, & Bunting, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Oberauer, Lange, & Engle, 2004). Engle (2002) identifies working memory capacity (WMC) with the attentional control. He states that *WM capacity is not directly about memory – it is about using attention to maintain or suppress information. (…) Greater WM capacity does mean that more items can be maintained as active, but this is a result of greater ability to control attention, not a larger memory store.* (p. 20).

Many authors agree on the fact that WMC and reasoning ability are strongly related (Buehner, Krumm, & Pick, 2005; Conway et al., 2002; Engle et al., 1999; Kane, Hambrick, & Conway, 2005; Krumm et al., 2009; Kyllonen & Christal, 1990; Ren, Schweizer, & Xu, 2013; Schweizer & Moosbrugger, 2004; Schweizer, Moosbrugger, & Goldhammer, 2005; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). Working memory capacity is considered the best predictor of general and fluid intellectual abilities. However, so far no one has been able to sufficiently explain the mechanism which underlies this relationship. For instance, disagreement exists on the question whether attentional functions are the exact mediators (Conway et al., 2002; Engle et al., 1999; Ren et al., 2013; Schweizer & Moosbrugger, 2004; Schweizer et al., 2005; but see: Buehner et al., 2005; Chuderski, Taraday, Nęcka, & Smoleń, 2012).

The methods of measuring working memory capacity are usually divided into two groups of tasks. The first group entails complex span tasks (Redick et al., 2012) and the second group entails n-back tasks (Kirchner, 1958) – for a review see Redick and Lindsey, 2013.

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2. Working memory training

2.1. Objectives of working memory trainings

Almost every publication on working memory training (WMT) starts with mentioning the relationship between working memory capacity and higher order cognitive functioning. Since WMC has been proven to be malleable (Dickens & Flynn, 2001; Nisbett et al., 2012) numerous attempts have been undertaken to verify if the intelligence quotient (IQ) can be also increased by WMT. If WMT results in significant improvement of IQ scores, this effect is termed as far-transfer. In contrast, the effect of increasing working memory capacity is called near-transfer and it is basically measured by compex span tasks and/or n-back task.

Improving intelligence is not the only purpose of training working memory. For instance, if WMC is crucial for academic performance (Daneman & Merikle, 1996; Gathercole, Pickering, Knight, & Stegmann, 2004; Tsaparlis, 2005) there is a reason to expect that increasing WMC through WMT would help to compensate the weaknesses of students with lower achievements. High hopes are also placed in training of working memory as a tool of treatment for people with poor cognitive functioning. There is, indeed, broad literature on WMT for ADHD (Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010; Holmes, Gathercole, & Dunning, 2009; Holmes, Gathercole, Place, et al., 2009), amnestic patients and patients with mild cognitive impairment (MCI) (Carretti, Borella, Fostinelli, & Zavagnin, 2013) as well as for elderly (Borella, Carretti, Riboldi, & De Beni, 2010; Borella, Carretti, Zanoni, Zavagnin, & De Beni, 2013; Flak, Hernes, Skranes, & Løhaugen, 2014; Heinzel et al., 2014; Karbach & Verhaeghen, 2014; McAvinue et al., 2013; Mowszowski, Batchelor, & Naismith, 2010; Richmond, Morrison, Chein, & Olson, 2011; Walton, Mowszowski, Lewis, & Naismith, 2014; Xin, Lai, Li, & Maes, 2014).

Interestingly, WMT can be also beneficial for the process of treatment of non-cognitive diseases, such as addiction. In fact, WMT turned out to be helpful in prolonging the period of abstinence from alcohol (Houben, Wiers, & Jansen, 2011) and other psychostimulants (Bickel, Yi, Landes, Hill, & Baxter, 2011).

2.2. Methods of working memory training

2.2.1. Pioneering WMT

The case of S.F. described by Ericsson, Chase and Faloon in 1980 can be classified as a pioneering working memory training. The authors themselves claim that their training was aimed at improving short-term memory (STM), which was at that time considered one of the most important cognitive functions, responsible for example for successful problem solving (Miller, 1956).

The training was administered by Ericsson et al. (1980) systematically during 18-month period and it lasted for a total of 230 hours. Despite of his average intelligence and also average initial level of memory capacity, S.F. was able to memorize and recall up to 79 digits after 18th month of training. However, when the memoranda was replaced by letters, his result dropped down to the initial level of 6 items. This is why Ericsson et al. (1980) concluded that the function, which was actually trained, was not STM, but rather long-term memory (LTM). They claim that S.F. was using some mnemonic strategies that helped him to remember increasing number of digits, but which turned out to be useless in face of another type of stimuli. Even though the Ericsson et al. (1980) described their procedure as the training of short-term memory, there are at least two reasons why it can be actually classified as working memory training.

Firstly, Unsworth and Engle (2007) argued that *simple and complex span tasks largely measure the same basic subcomponent processes (e.g., rehearsal, maintenance, updating, controlled search) but differ in the extent to which these processes operate in a particular task*" (p. 1038). In addition, Shipstead, Redick, and Engle (2010) noted, simple span tasks that exceed the limit of STM through lists that are longer than the capacity of STM require WM components. Consequently, if S.F.'s strategies consisted of storing a string of digits in his memory while simultaneously encoding another sequence, it can be assumed that it was the working memory, rather than the short-term memory, that was engaged in this process.

Secondly, I cannot agree with the argument of Ericsson et al. (1980) according to which the process of encoding performed by S.F. directly reached the long-term memory. Namely, from the neurophysiological point of view, in order to retain some information in the long-term memory, the whole two-phase process of long-term potentiation has to occur, which requires several repetitions in a time period of few hours (Lynch, 2004). Therefore, mnemonic strategies applied by S.F. could not so easily and exclusively pertain LTM system. Moreover, LTM is a component included in every current model of WM (see: Baddeley, 2010), so its active role in S.F.'s training does not exclude, but even confirms our hypothesis.

The above-described training is also a good illustration of the problems that are still being encountered by many researchers, who try to elucidate the question of efficiency of WMT. In particular, the problem of S.F.'s training was the lack of transfer to the ability of memorizing material different from the trained one.

2.2.2. The development of computerised cognitive trainings

It was in the 80s when the first computerised cognitive trainings (CCT) appeared, like for example RehaCom (Fernández et al., 2012) or CogniPlus (Benz, Hatz, Schindler, & Taub, 2014). They were initially designed for cognitive therapy of brain-injured patients.

At the turn of the XXI century, the Cogmed WMT (CWMT) was created by Klingberg's research group. Cogmed, as a commercial platform for cognitive training, was already addressed to a broader range of recipients. Until now, it has become one of the most popular and the most researched CCT. Although, since 2010 Cogmed belongs to Pearson Clinical Assessment Group, Klingberg's scientific activity is still related to the development of CWMT. After the commercial success of CWMT the market of CCT remarkably emerged, which is illustrated by growing number of websites offering on-line games that are constructed analogically to those used in Cogmed.

Nevertheless, the biggest growth of the computerised programs for WMT was seen after the publication of the research paper entitled "Improving fluid intelligence with training on working memory" (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). The claim about the possibility of increasing fluid intelligence by training WMC with *n-back* adaptive task sparked a vivid scientific debate. Consequently, it became another "model training" which structure was implemented in many commercial and non-commercial CCTs (e.g. Brain Workshop, Cogtest, High IQ Pro, MindSparke).

It is important to note that the popularity of WMT was not growing without criticism. Optimistic statements about the potential gains in IQ after WMT included in marketing materials of Cogmed, e.g. *When you improve working memory, you improve fluid IQ (...) you will be better able to pay attention, resist distractions, self-manage, and learn*, were removed from the website after the publication (in October 2014) of the open letter *On The Brain Training Industry from the Scientific Community* (http://longevity3.stanford.edu/blog/2014/10/15/the-consensus-on-the-brain-training-industry-from-the-scientific-community-2/). The letter was signed by 73 researchers from around the world. It was a statement where researchers expressed their disapproval regarding the exaggerated promises of commercial WMT programs: *We object to the claim that brain games offer consumers a scientifically grounded avenue to reduce or reverse cognitive decline when there is no compelling scientific evidence to date that they do.* The same situation applies to many other cognitive trainings. The USA Federal Trade Commission appealed to stop overtly advertise one of the trainings as the one that *could permanently improve a child's focus, memory and school performance and was highly beneficial for children with ADHD* (https://www.ftc.gov/news-events/press-releases/2015/01/makers-jungle-rangers-computer-game-kids-settle-ftc-charges-they). However, two months after the publication of the first open letter, another group of 127 scientists signed another letter (http://www.cognitivetrainingdata.org) refuting the allegations of their colleagues. Even though they agreed on the fact that distributors of some commercial CCTs are improper in their advertising statements, yet they claim that: *There is, in fact, a large and growing body of such evidence. That evidence now includes dozens of randomized, controlled trials published in peer-reviewed journals that document specific benefits of defined types of cognitive training. Many of these studies show improvements that encompass a broad array of cognitive and everyday activities, show gains that persist for a reasonable amount of time, document positive changes in real-life indices of cognitive health, and employ control strategies designed to account for "placebo" effects.*

At this moment most of the popular commercial brain training programs take much care to publish up-to-date research results, and to advertise only these benefits, that can be scientifically justified.

3. Are working memory trainings effective?

The aim of this article is not to adjudicate whether the WMT works or not. A heated discussion around this topic is still present not only in scientific magazines, but it is also observed in form of the above mentioned open letters published online and exchanged between two opponent groups of researchers. Growing number of meta-analysis and reviews demonstrates how much controversy the issue of effectiveness of WMT stirs (Dougherty, Hamovitz, & Tidwell, 2015; Hulme & Melby-Lervåg, 2012; Klingberg, 2010; Melby-Lervåg & Hulme, 2013; Morrison & Chein, 2012; Redick, Shipstead, Wiemers, Melby-Lervåg, & Hulme, 2015; Redick, 2015; Schwaighofer, Fischer, & Bühner, 2015; Shipstead, Hicks, & Engle, 2012a, 2012b; Shipstead, Redick, & Engle, 2012; von Bastian & Oberauer, 2013). There are also publications reviewing the research conducted on clinical groups (Gates, Fiatarone Singh, Sachdev, & Valenzuela, 2013; Weicker & Thöne-otto, 2015). Although most of these meta-analysis are not optimistic, some of the above mentioned authors do not lose hope that the creation of efficient (i.e. having stable both near and far-transfer effects) WMT will be soon possible.

The actual purpose of this paper is to widen the perspective of looking at the effectiveness of WMT and to reflect on potential causes of contradictory results of meta-analysis. It is time to stop asking whether WMT is successful or not, and rather start asking why and under which conditions WMT leads to expected outcomes. Nonetheless, along with asking one more theoretic question about the effectiveness and the extent to which WMT generalizes, one should carefully consider methodological aspects of the planned research. In next paragraphs I will take a closer look at conclusions coming from reviews and meta-analysis of hitherto trainings. I will also resume recommendations made by most of reviewers so that this article can serve as „the map of points to consider" before making any step further in the field of WMT.

3.1. Do we dispose of reliable transfer measures?

One of the most debated issue is the measurement of WMC. On one hand, there are arguments that the near transfer should be tested with a battery of multiple methods assigned to measure the construct termed WMC. Some authors rightly note that when measurement of near transfer is constructed analogically to the methods of training, it is easy to obtain positive results confirming the presence of transfer (Redick et al., 2015; Shipstead, Redick, et al., 2012). On the other hand, there are also arguments saying that we do not dispose of interchangeable and at the same time not similar measures of WMC (Redick & Lindsey, 2013). Thus, is it a good idea to administer two most popular tests, i.e. complex span tasks together with n-back task?

Redick and Lindsey (2013) conducted a meta-analysis of studies analysing the correlation between span tasks and n-back tasks. What they found is that there exist only weak correlation between them. This result is counterintuitive, because, firstly – both types of tests are designed to measure the same theoretic construct, and secondly – both tests tend to correlate stronger with measures of IQ than with each other. The authors conclude explicitly that these tests should not be used interchangeably. Thus, it should not be expected that WMT conducted with the use of one of them will result in transfer on scores of the second one. In fact, hitherto research on WMT were inconsistent in showing such a reciprocal transfer.

Redick and Lindsey (2013) also point to another problem related to the law of diminishing returns (Spearman, 1927) that is observable also in studies on WMC. Namely, the higher level of education characterises a given experimental group, the smaller correlation between methods measuring specific intellectual abilities, including measures of WMC. Therefore, is it possible that when IQ increases as a result of WMT, then the correlation between n-back tasks and complex span tasks decreases? It would be difficult to verify, since similar psychometric problem also concerns the measures of far transfer.

Most of the authors agree on the question that if one wants to prove a positive transfer of WMT on improvement of IQ, one should administer more than a single test designed to measure the intelligence quotient, because Raven Progressive Matrices (RPM) is too weak to capture such a complex construct of intelligence. This remark is justified by early psychometrical studies concerning RPM. Jensen (1998) estimates that 64% of the variance in RPM performance can be explained by Gf.

The discussion around the validity of far transfer measurement was further inspired by the publication of the study conducted by Jaeggi et al. (2008). The authors claim that by shortening the time limit for completing the BOMAT (from 45 min. to 10 min.), they administered a more precise measurement of WMT transfer effects on fluid intelligence improvement. Importantly, Chuderski (2013) showed that along with shortening the time limit for completing RPM, the correlation between WMC and Gf increases. Thus, Moody (2009) accurately remarked that the mode of administration BOMAT test by Jaeggi et al. (2008) makes the BOMAT scores more dependent on WMC comparing to the case where trainees would complete the same test with no time limit. This argumentation is supported by Shipstead, Redick, et al. (2012) who claim that the only conclusion that can be drawn from Jaeggi et al. (2008) is that WMT leads to improvement of performance on tests of Gf only when these tests are administered in conditions that make Gf scores dependent on WMC.

Nevertheless, fluid intelligence is something more than working memory capacity, as was claimed by Kyllonen and Christal (1990) and by Süß et al. (2002). WMC can be illustrated as a mental space, where we can store greater or lesser amount of mental representations. Fluid intelligence, in turn, is claimed to be an ability to abstract reasoning, finding analogies, discovering even remote relationships between stimuli. Working memory, and especially its processing component, can be compared to a tool in intelligence's hands. Without the processing tool the intelligence could not process these representations that are held in the storage component. Therefore, greater WMC enables storage of greater amount of representations as well as computing more operations on these representations. Thus, if one wants to improve the speed of reasoning, WMT may be useful. However, it has not yet been found whether the quality of reasoning (what only intelligence is capable of) also improves as a result of enlargement of one's mental space. Working memory seems to be a necessary but insufficient element of intelligence.

3.2. The most commonly commented weaknesses of WMT

Among the most discussed drawbacks of WMT research is a lack of theory which would propose a good explanation of the mechanism underlying the transfer of training on other non-trained abilities (Redick, 2015; Shipstead, Redick, et al., 2012; von Bastian & Oberauer, 2013). Thus, it is not known whether WMT increases WM capacity or WM efficiency (von Bastian & Oberauer, 2013). The former refers to a number of items that can be stored in memory for a limited period of time. The latter describes the gained skill of reducing/simplifying/reorganising the set of stimuli so that they can be held in temporary memory without increasing WM general capacity.

There is also a controversy over the question of stability of WMT effects. Meta-analysis conducted by Melby-Lervåg and Hulme, (2013) showed that although the near transfer generally occurs on both verbal and visuo-spatial WMC, only effects of visuo-spatial abilities are sustained. However, according to Schwaighofer et al., 2015) transfer effects are significant and stable (i.e. still observable at follow up testing) in case of both verbal and visuo-spatial WMC, but gains in far (verbal and non-verbal) transfer are much more vulnerable (i.e. are not maintained at follow up).

Another mistake commonly made during research on WMT are either a total lack of control groups or inclusion of passive controls (Dougherty et al., 2015; Shipstead et al., 2012a, 2012b). The problem with passive controls is that the advantage in scores of the training group at post-test may reflect the placebo effect instead of the real effectiveness of WMT. More recent reviews also note that the participation of passive controls usually leads to the overestimation of the size effects, because when the Bayesian approach is applied, the data support the null hypothesis (Dougherty et al., 2015; Redick, 2015).

Regarding the reviews of research with clinical patients, Weicker and Thöne-otto (2015) showed that WMT is effective method of cognitive therapy for brain injured patients. Gates et al., (2013) claim in turn that there is no evidence for effectiveness of WMT for 65-year-old patient with Mild Cognitive Impairment (MCI).

Klingberg (2010) claims that Cogmed WMT came out to be efficient tool helping people with low WMC. Without mentioning the possibility of increasing IQ level, he states that WMT improves other WM-related functions such as attention control, which in turn results in better academic achievements. The author also refers to the studies using neuroimaging techniques that show significant training-induced changes at the neural level.

On the other hand, Shipstead, Hicks et al., (2012a) supported by Morrison & Chein (2012) address some critical remarks about Cogmed. Shipstead, Hicks, et al., (2012a) allege that there is no convincing proof that the training results in expected outcomes. They justify their opinion with several arguments. Firstly, according to the authors, the way of measuring transfer effects is not sufficient to claim about the real improvements of WM capacity. (Shipstead, Hicks, et al., 2012a) Shipstead, Hicks, et al., (2012a) criticise negative practices of measuring near-transfer by methods that are very similar to the ones used during the training. Secondly, even when several measures of WMC are administered, the results of such research tend to be inconsistent. There are cases when the near-transfer is present, but without evidence for the presence of far transfer (Seidler, Bernard, Jaeggi, & Jonides, 2010). There are also other cases where the reverse situation occurs (e.g. Jaeggi et al., 2008; Jaeggi et al., 2010).

The critical review of Shipstead, Hicks, et al., (2012a) get the defensive response from (Shinaver, Entwistle, & Söderqvist, 2014). Shinaver et al. (2014) claim that the authors of the critical review draw conclusions (suggesting that CWMT is not effective) that are not adequate to the obtained results of statistical analysis (showing that there actually was significant increase in WMC after WMT). In addition to this, Shinaver et al. (2014) noted that Shipstead, Hicks, et al., (2012a) are not consistent in selecting publications taken into consideration in their meta-analysis. The objection concerns the groundless exclusion of several research showing positive outcomes of WMT, despite of the fact that they meet the criteria of inclusion into the review. Moreover, Shipstead, Hicks, et al., (2012a) included to the same analysis reports of research conducted on groups of different age-range and using incomparable training protocols. This led to high intra-group variances and made reliable inter-group comparisons impossible.

I would also like to comment on a polemic concerning the validity of measures of the transfer effect. Shinaver et al. (2014) argue that the claims of Shipstead, Hicks, et al., (2012a) about the lack of transfer of WMT on attentional stamina is groundless. The critics refers to the post-test results of Stroop task, while Shinaver et al. (2012) note that this test is designed to measure selective attention, which is not in the scope of CWMT objectives. On one hand, it may be true that the result of WMT is rather increased sustained attention, but on the other hand, it is well established that WMC is also related to selective attention and inhibitory control (Schweizer, Moosbrugger, & Goldhammer, 2005). Thus, it would not be inappropriate to expect that WMT will contribute to improvement of these functions as well.

Shinaver et al. (2014) also discuss an important issue of not including these reports of research where transfer effects are measured by subjective methods (e.g. questionnaires filled in by parents and/or teachers). On one hand, this is true that these kinds of questionnaires may lead to an overestimation of positive outcomes, what is well know as the placebo effect, and what may make results difficult to interpret. On the other hand, though, one shall not forget that WMT have also practical objectives, such as improvement of academic performance, reduction of ADHD symptoms or even general improvement of cognitive functioning. Therefore, subjective measures are needed in order to verify whether WMT brings the outcomes expected not only by researchers, but also by trainees, their parents and tutors. The problem of placebo could be simply reduced by the inclusion of active control group and double-blinded protocols of trainings.

It should also be noted that although Shinaver et al. (2014) argue that a significant improvement of school performance should not be expected as a result of sole WMT, the author cite quite a few publications reporting success in this domain. After the WMT students can better cope with those subjects that they previously found problematic (e.g. Beck et al., 2010; Dahlin, 2011; Holmes, Gathercole, & Dunning, 2009).

Besides pointing the weaknesses, some authors also make suggestions on how to conduct more reliable WMT research. For instance, although Morrison and Chein (2012) support critical claims of Shipstead et al., (2012a, 2012b), they express much more optimism regarding future WMT. They are convinced that in the near future WMT studies will be refined enough to bring the expected results. Von Bastian & Oberauer, (2013) make a step further by mentioning few potential moderators that could help to elucidate the source of inconsistencies in hitherto publications. They propose following moderators of the influence of WMT on improvement of higher-order cognitive functions: *type of WMT; intensity and duration of training; whether the training is adaptive or not, active/passive control group; age and initial cognitive capacity, genes, motivation and personality*. However, the authors do not use statistical analysis to verify the actual impact of the postulated factors on the effectiveness of WMT. This was done by Schwaighofer et al. (2015).

Schwaighofer et al. (2015) included 47 studies with 65 group comparisons in their review. The results showed that WMT resulted in both near (verbal & visuo-spatial abilities) as well as far transfer (verbal & non-verbal abilities). However, only the effects of near transfer were sustained at follow-up. From 10 potential moderators, the following turned out to be significantly influential: total duration of training (had effect on visuo-spatial STM); single session duration (effect on verbal STM); supervision (effect on verbal and visuo-spatial WM); place of training (effect on visuo-spatial STM and verbal WM as well as on non-verbal ability); type of control group (effect on mathematical abilities), intervention type (the largest effect of Cogmed on visuo-spatial STM, larger effects of Jungle Memory on verbal WM than of non-commercial trainings, and larger effect of n-back than Cogmed training on non-verbal ability).

The aim of the statistical analysis is usually to find the effect size that is supposed to determine whether there was a significant training-induced gain in scores of tests measuring near- and/or far-transfer. Many of such meta-analysis are focused on the calculation of the pure training effect. This is useful when one wants to have a general image of the training effectiveness. However, it is often difficult to compare two or even more training procedures, as well as to compare different transfer effects, seeing that many researchers apply different training protocols or use diverse transfer measurements. Moreover, so far there is not enough data coming from comparable research so that comparisons taking into account non-cognitive moderators of the effectiveness of the WMT would be possible. Notably, there is more interest in exploring the role of individual differences in the WMT influence on the improvement of cognitive functioning. Amongst these factors are: personality traits and temperament (Studer-Luethi, Jaeggi, Buschkuehl, & Perrig, 2012; Urbánek & Marček, 2015; von Bastian & Oberauer, 2013), need for cognition, or motivational level (Anguera et al., 2012; Jaeggi et al., 2011; Jaeggi et al., 2011; Morrison & Chein, 2011; Oelhafen et al., 2013).

4. Concluding remarks

The short history of WMT research is full of controversies. Although the first publications were rather enthusiastic about the training's outcomes, the enthusiasm was rapidly cooled down by numerous critical reviews and unsuccessful attempts to replicate previously reported positive results. Thanks to this feedback, subsequent studies on effectiveness of WMT became more and more reliable. However, there is still a need to improve both the training protocols, as well as the methodology of WMT research. In the last paragraph of this paper I will present the list of advices for future WMT researchers.

1) Far-transfer as well as near-transfer effects should be administered by a set of multiple tests measuring the abilities of interest.

2) The results of near-transfer measure should be interpreted carefully, since two most popular WMC tests fail to show strong correlation.

3) The golden standard of the training protocols should be agreed. Regardless of the intervention type, there should be an agreement made on the minimal amount of training sessions as well as on the duration of a single session. The training should be conducted in standardised conditions (for example in a laboratory) and should be supervised by a qualified trainer. These suggestions are formulated on the basis of Schwaighofer et al.'s (2015) meta-analysis.

4) It should be decided whether to include subjective measure of WMT effectiveness. In my opinion such measures should be included, as it would allow to verify the ecological validity of WMT.

5) Individual differences in non-cognitive domains should be controlled, especially personality, temperamental and motivational factors, as there is already some evidence of their influence on the effectiveness of WMT.

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