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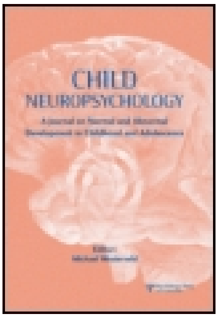

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Adaptive working-memory training benefits reading, but not mathematics in middle childhood

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Working memory (WM) capacity is highly correlated with general cognitive ability and has proven to be an excellent predictor for academic success. Given that WM can be improved by training, our aim was to test whether WM training benefited academic abilities in elementary-school children. We examined 28 participants (mean age = 8.3 years, *SD* = 0.4) in a pretest-training-posttest-follow-up design. Over 14 training sessions, children either performed adaptive WM training (training group, *n* = 14) or nonadaptive low-level training (active control group, *n* = 14) on the same tasks. Pretest, posttest, and follow-up at 3 months after posttest included a neurocognitive test battery (WM, task switching, inhibition) and standardized tests for math and reading abilities. Adaptive WM training resulted in larger training gains than nonadaptive low-level training. The benefits induced by the adaptive training transferred to an untrained WM task and a standardized test for reading ability, but not to task switching, inhibition, or performance on a standardized math test. Transfer to the untrained WM task was maintained over 3 months. The analysis of individual differences revealed compensatory effects with larger gains in children with lower WM and reading scores at pretest. These training and transfer effects are discussed against the background of cognitive processing resulting from WM span training and the nature of the intervention.

***Keywords*:** Working memory training; Academic achievement; Childhood; Cognitive plasticity.

Working memory (WM) is a cognitive system allowing us to temporarily store and manipulate information (Kane & Engle, 2002) and it is essential for mastering the demands of our daily lives. We use it, for instance, every time we need to keep track of things that unfold over time, to make sense of any linguistic information, or to mentally relate pieces of information to derive a general principle or see novel relations between concepts (e.g., Diamond, 2012).

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Both authors, Julia Karbach and Tilo Strobach, contributed equally to this publication and share the first authorship

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It is therefore not surprising that research repeatedly confirmed WM as an important prerequisite for the general ability to acquire knowledge and new skills (e.g., Lu, Weber, Spinath, & Shi, 2011; Pickering, 2006; St. Clair-Thompson & Gathercole, 2006). WM is not only related to higher level cognitive abilities contributing to academic success, such as executive control and problem solving (e.g., Miyake et al., 2000), but also to performance in the classroom (e.g., Alloway & Alloway, 2010; Gathercole, Pickering, Knight, & Stegmann, 2004; Pickering, 2006). In fact, WM has been shown to explain at least as much variance in academic achievement as intelligence (e.g., Alloway, Bibile, & Lau, 2013; Andersson, 2008; Lu et al., 2011; Swanson, 2004), which is usually considered the most powerful predictor of academic success (e.g., Gottfredson, 2002; cf. Gustafsson & Undheim, 1996).

Studies investigating the contribution of WM to scholastic achievement have often focused on the domains of language and mathematics (for a review, see Titz & Karbach, 2014). Their results showed that WM is directly associated with math ability (e.g., DeSmedt et al., 2009; DeStefano & LeFevre, 2004; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Zheng, Swanson, & Marcoulides, 2011) as well as with reading, writing, and language comprehension (e.g., Alloway et al., 2005; Engel de Abreu, Gathercole, & Martin, 2011; Gathercole et al., 2004; Landerl & Wimmer, 2008; Montgomery, Magimairaj, & O'Malley, 2008; Swanson & Berninger, 1995, 1996). The strong relationship between WM and academic attainment is further supported by findings showing that children with learning disabilities often suffer from specific WM deficits, suggesting that WM deficits are risk factors for poor academic performance and development (Alloway, 2009; Gathercole, Alloway, Willis, & Adams, 2006; Schuchardt, Maehler, & Hasselhorn, 2008). Thus, considering this strong relation between WM and academic achievement, it seems reasonable to assume that increases in the capacity of WM may improve children's academic performance.

Quite a number of studies have shown that WM can be improved by training and that these training-related improvements generalized to structurally similar, untrained WM tasks in childhood (for reviews, see Buschkuehl, Jaeggi, & Jonides, 2012; Jolles & Crone, 2012). However, the findings on the transfer to structurally dissimilar tasks were less consistent and have been the focus of recent debates (for reviews, see Melby-Lervåg & Hulme, 2013; Redick et al., 2013; Shipstead, Redick, & Engle, 2012). Yet, a number of developmental studies have indicated that training-related benefits also transferred to new, structurally different tasks: WM training, for instance, benefitted inhibitory control and fluid intelligence in children suffering from attention deficit/hyperactivity disorder (ADHD; e.g., Klingberg et al., 2005) as well as attention in healthy children (e.g., Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009).

Still, surprisingly few WM training studies have included transfer tasks from the domain of academic abilities and most of these studies focused on children with special educational needs, such as attentional problems or learning difficulties (Titz & Karbach, 2014). Some of these studies reported evidence for positive effects of WM training on language (Alloway et al., 2013; Dahlin, 2011) and math abilities (Alloway, 2012; Dahlin, 2013), while others found no transfer of WM training to academic performance and classroom activities (e.g., Dunning, Holmes, & Gathercole, 2013; Holmes, Gathercole, & Dunning, 2009).

The few existing studies including healthy children did not provide a clear pattern of results: St. Clair-Thompson, Stevens, Hunt, and Bolder (2010) examined the effects of

WM strategy training in middle childhood (5–8 years of age). Participants performed 12–16 sessions of training and were compared to a passive control group. Although the training group showed improvements in the ability to remember and to follow classroom instructions, there were no improvements in standardized tests of reading, arithmetic, or mathematics, neither immediately following training nor 5 months later. More recently, Loosli, Buschkuehl, Perrig, and Jaeggi (2012) applied a training that was based on complex process-based WM span tasks and tested for transfer to reading ability in a sample of children between the ages of 9 and 11. Compared to a passive control condition, 10 sessions of WM training benefitted text reading. Yet, these findings are inconclusive because both studies lacked an active control condition (cf. Green, Strobach, & Schubert, 2013; Shipstead et al., 2012).

To summarize, recent findings indicated that cognitive training may indeed support specific aspects of school-related abilities and academic performance in childhood. However, previous studies were mostly restricted to clinical subgroups (Alloway, 2012; Alloway et al., 2013; Dahlin, 2011, 2013; Dunning et al., 2013; Holmes et al., 2009) and it is unknown whether their findings generalize to healthy children. In addition, some prior work, including the few studies on healthy children (Loosli et al., 2012; St. Clair-Thompson et al., 2010), lacked active control conditions and often also the assessment of maintenance effects. Both features are important in intervention studies, because they allow controlling for the influence of various external factors, such as task instructions, stimulus-response mappings, test familiarity, expectations, or computer use, as well as identifying the mechanisms mediating transfer of training. Moreover, the longevity of training-induced changes is considered a key measure for the value of a training program. Finally, previous studies often did not analyze individual differences in the amount of training-related benefits (but see Dahlin, 2013; Loosli et al., 2012), even though that information seems to be of high relevance for the understanding of the mechanisms mediating training-induced performance changes as well as for the adaptation of training interventions to individuals with specific needs.

Therefore, the present study was designed to extend previous findings by testing the effects of adaptive training with a complex WM span task on academic abilities in the domains of math and reading in a sample of healthy elementary-school children. To investigate the range of transfer after WM training on a functional level, we additionally included transfer tests tapping trained and untrained domains of executive control functions. According to Miyake's model of executive control, multiple domains contribute to behavioral control (Miyake et al., 2000). He assumed that the abilities to update relevant information in WM (i.e., Updating), to switch between different tasks (i.e., Shifting), and to inhibit irrelevant information (i.e., Inhibition) are key domains of executive functioning that are moderately correlated but clearly separable (Miyake et al., 2000). In keeping with Miyake's framework, WM span tasks such as the training tasks applied in this study are well-established measures of WM capacity, which is closely related to the WM Updating domain (Schmiedek, Hildebrandt, Lövdén, Wilhelm, & Lindenberger, 2009). We therefore included an untrained WM span task in the transfer test battery to test the task and material independence (i.e., transfer) of training gains within the Updating domain. In addition, we added a switching task and an inhibition task to the test battery to investigate whether training on the WM Updating domain also benefited the other domains of executive control (Shifting, Inhibition). We assumed that transfer effects were most likely to occur on the WM transfer task since the underlying cognitive functions strongly overlapped with the training tasks.

In sum, we investigated (a) whether adaptive WM training yielded larger training benefits than nonadaptive low-level WM training (cf. Holmes et al., 2009; Klingberg et al., 2005). In order to assess the scope of transfer, we tested (b) whether training-related benefits transferred to new, untrained executive control tasks and (c) to academic performance on standardized measures of reading and math. Finally, we examined (d) individual differences in the amount of training and transfer benefits and (e) maintenance over 3 months.

METHOD

Participants

Twenty-eight elementary school students (mean age = 8;4, *SD* = 0.07; age range = 7;2–9;7; 50% female; 93% right-handed) participated in the study (see Table 1). They were German native speakers recruited from the university subject database (which included families that had volunteered to participate in academic studies) as well as via flyers in the community's primary schools and were randomly assigned to the training or the control group. The children received 100€ as compensation for their participation in the 17 sessions of the study. Parents provided written consent and reported no neurological, psychiatric, or developmental disorders. Participants were screened for normal or corrected-to-normal vision and hearing. Two participants in the control group dropped out of the study at follow-up and had to be excluded from the analyses of maintenance effects.

Between-group comparisons (*t*-tests) showed no baseline differences between the training group and the control group in terms of age, speed of processing (digit-symbol substitution test; Wechsler, 1981), WM, reading, or math ability at pretest (see Table 1).

Material and Procedure

Training and control group performed 14 training sessions that were preceded by a pretest and followed by a posttest and a 3-month follow-up assessment (see Figure 1). In the first and the last training sessions, participants in the training and the control groups

Table 1 Characteristics of the Effective Sample.

	Training group	Control group	*t*-test for between-group differences (*p*)
n (female)	14 (7)	14 (7)	–
	M (*SD*)	*M* (*SD*)	
Days between pretest and posttest	64.1 (8.2)	68.0 (12.7)	.34
Days between pretest and follow-up	155.6 (17.3)	163.0 (13.6)	.24
Age (months)	99.3 (5.9)	101.4 (4.7)	.30
Speed of processing (*N* correct)	28.8 (3.6)	28.4 (5.0)	.80
WM (set size)	4.5 (0.56)	4.7 (0.63)	.32
Reading ability (*N* correct)	80.0 (3.74)	84.8 (2.59)	.30
Math ability (% correct)	60.8 (4.26)	59.4 (5.20)	.84

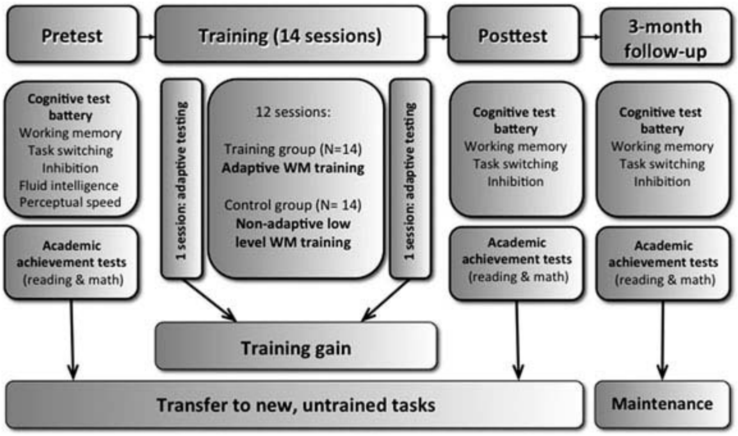

Figure 1 Illustration of the study design for the adaptive WM training group (Training group) and the nonadaptive training group (Control group).

performed an adaptive version of the training tasks that allowed testing for between-group differences in training-related benefits. In the 12 sessions in between, the training group performed adaptive training and the control group performed a nonadaptive low-level version of the same tasks and materials. In both the training and control groups, the following transfer tests were applied at pretest, posttest, and follow-up: Standardized tests of mathematical and reading ability and tests of WM, task switching, inhibition, and perceptual speed (detailed descriptions of the tests are provided below).

Training Tasks

The two WM span tasks applied during training were drawn from the “Braintwister” WM training battery (*farm task* and *safari task*; Buschkuehl, Jaeggi, Kobel, & Perrig, 2008). Trials consisted of two parts: At the encoding stage, a sequence of animal pictures was presented either upright or upside-down in the center of the screen and participants indicated the orientation of each picture by pressing the left or right mouse button. In case their responses were too slow (>3000 ms) or erroneous, five monkeys appeared in the upper part of the computer screen. At the recall stage (i.e., the second trial part), the four animal pictures were presented in the upper half of the screen. Participants reproduced the animal sequence seen at the encoding stage in the correct order by subsequently clicking on the appropriate pictures.

Importantly, the tasks in the training group were adaptive, that is, task difficulty was adapted to the individual level of performance: If the performance on both the encoding and the recall task was correct, the number of to-be-remembered items (set size) was increased by one in the next trial. If the performance on the encoding task was erroneous but correct on the recall task, the set size did not change. If participants committed any errors on the recall task, the set size was reduced by one.

In each training session, the task started with a set size of two animals and lasted for 40 minutes. The dependent variable was the set size. Participants performed the “safari” version of the task in the first training session and both versions were altered from session to session afterwards.

The training procedure in the control group was identical to the training group with the following exceptions: Training was not adaptive and set size was fixed to two. Thus, both groups performed the same tasks for the same amount of time, with increasingly higher demands on WM in the training group and constant low-level WM demands in the control group.

In the first and last training session, both groups performed an adaptive version of the task (30 trials in the first and 60 trials in the last session) allowing to test for training-related improvements (cf. Holmes et al., 2009).

Transfer Tasks

Reading Ability. The standardized test for reading skills (Knuspels Reading Tasks; Marx, 1998) was designed for the assessment of reading ability in Grades 1–4 and included two parallel test versions. We applied these different versions at pretest (Form A) and at posttest/follow-up (Form B) to reduce retest effects. The reading test included a total of 109 items (assessing listening and reading comprehension, recoding, decoding). The total *reading test score* indicated the general level of reading ability (max. score = 109).

Mathematical Ability. Mathematical skills were assessed with a standardized curriculum-based math test (German Mathematics Test; Krajewski, Liehm, & Schneider, 2004; Roick, Gölitz, & Hasselhorn, 2004). The test also included two parallel test versions that were applied at pretest (Form A) and at posttest/follow-up (Form B) to reduce retest effects. The total *math test score* (% correct) indicated the general level of math ability.

Wm. The WM transfer test was an untrained WM-span task (Buschkuehl et al., 2008). Four colored squares appeared in a row in the middle of the screen and then disappeared and reappeared in random order. Participants memorized this sequence and reproduced it at the end of each trial. The set size was adaptive: It increased by one after correct sequence reproduction and decreased by one after incorrect reproductions. Participants started with a set size = 2 and performed 30 trials at pre- and posttest/follow-up.

Task Switching. The task-switching paradigm (Karbach & Kray, 2009) included performance in single-task (Task A/B only) and mixed-task blocks (switching between both tasks on every second trial). Task A required participants to decide whether a picture showed a fruit or a vegetable and Task B whether a picture was small or large. Participants performed two single-task practice blocks (17 trials) followed by eight experimental blocks (four single-task and four mixed-task blocks; 17 trials each). We calculated two types of task-switching costs: General switch costs (the difference in performance between single-task and mixed-task blocks) referred to the ability to maintain and select two task sets. Specific switch costs (the difference in performance between stay-and-switch trials within mixed-task blocks) were considered a measure for the ability to flexibly switch between tasks on trial-to-trial transitions.

Inhibitory Control. Inhibitory control skills were measured with the Stroop task. Participants saw words (e.g., “RED”, “TREE”) presented in red, blue, green, or yellow font and indicated the font color as quickly as possible by pressing one of four response buttons on a computer keyboard. Stroop interference was defined as the difference in performance between incongruent trials (e.g., “RED” in blue font) and congruent trials (e.g., “RED” in red font). Participants performed one practice block (24 trials) and four experimental blocks (24 trials each). Stimuli were presented for 2000 ms or until the participants responded.

RESULTS

Means and standard errors for all experimental conditions are provided in Table 2. We report the analyses for (a) training-related improvements on the training task, (b) training-induced transfer at posttest, (c) the maintenance of transfer at follow-up, and (d) individual differences in transfer gains. For significant training and transfer effects, we calculated Cohen’s *d* (1977), or the standardized mean difference in performance between pretest and posttest. That is, the pretest-posttest difference was divided by the pooled standard deviation for both test occasions for each of the groups. We then corrected all *d* values for small sample bias using the Hedges and Olkin (1985) correction factor (*d’*). A pretest-posttest effect size *d*’ = 1, for instance, indicates that the mean difference between

Table 2 Means (Standard Errors) of Training and Transfer Tests as a Function of Session (Pretest, Posttest, Follow-Up) and Group (Training, Control).

	Training group			Control group		
	Pretest	Posttest	Follow-up	Pretest	Posttest	Follow-up
WM training task span (set size)	3.4 (0.2)	4.0 (0.2)	—	3.1 (0.2)	3.1 (0.2)	—
WM transfer task span (set size)	4.5 (0.2)	4.9 (0.2)	5.0 (0.2)	4.6 (0.2)	4.5 (0.2)	4.4 (0.3)
Reading ability (*N* correct)	80.0 (3.2)	93.2 (2.8)	93.9 (4.1)	84.7 (3.2)	89.6 (2.8)	91.8 (4.4)
Mathematical ability (% correct)	60.8 (4.8)	66.4 (4.5)	70.0 (4.4)	59.4 (4.8)	69.8 (4.5)	70.5 (4.7)
Task switching (RTs)						
Switch (ms)	1665.6 (116.2)	1546.0 (95.5)	1486.1 (79.8)	1713.8 (116.2)	1534.0 (95.5)	1398.6 (86.2)
Stay (ms)	1317.0 (102.2)	1201.7 (84.1)	1109.7 (75.9)	1349.9 (102.2)	1207.4 (84.1)	1141.2 (81.9)
Single (ms)	1246.8 (85.9)	1152.3 (79.2)	962.7 (42.1)	1246.5 (84.5)	1089.8 (82.5)	1062.6 (95.2)
Inhibition (RTs)						
Incongruent (ms)	925.6 (41.4)	953.2 (36.7)	943.5 (35.5)	964.5 (41.4)	953.1 (36.7)	932.4 (38.3)
Neutral (ms)	919.2 (40.9)	923.6 (36.4)	937.1 (36.7)	955.4 (40.9)	944.9 (36.4)	953.6 (39.6)
Congruent (ms)	887.1 (40.2)	927.0 (36.8)	922.0 (36.9)	931.5 (40.2)	940.5 (36.8)	892.2 (39.8)

pretest and posttest corresponds to one standard deviation of the pooled pretest and posttest data.

Training-Related WM Improvements

Training-related benefits in WM capacity were analyzed with a repeated-measures analysis of variance (ANOVA) including the between-subjects factor Group (training, control) and the within-subjects factor Session (first training session, last training session). A main effect of Group, $F(1, 26) = 6.081$, $p < .05$, $\eta_p^2 = .19$, indicated an increased set size in the training compared to the control group. The main effect for Session was not significant ($p = .08$), but we found an interaction between Session and Group, $F(1, 26) = 5.742$, $p < .05$, $\eta_p^2 = .18$, indicating that the training group, but not the control group, showed a significant pretest-posttest increase of set size, $t(13) = 4.361$, $p < .001$, $d' = 0.75$.

Transfer of WM Training

To test for transfer of adaptive WM training to an untrained WM task and performance on standardized academic tests, we ran ANOVAs with the factors Group (training, control) and Session (pretest, posttest).

Wm. Neither the main effect for Group ($p = .40$) nor Session ($p = .66$) reached significance. However, an interaction between Group and Session, $F(1, 26) = 6.695$, $p < .05$, $\eta_p^2 = .21$, revealed pretest-posttest improvements in the training group, $t(13) = 2.245$, $p < .05$, $d' = 0.65$, but not in the control group ($p = .09$), demonstrating transfer of adaptive WM training to an untrained WM task.

Reading Ability. The analysis of the reading test score revealed a main effect of Session, $F(1, 26) = 25.932$, $p < .001$, $\eta_p^2 = .50$, indicating an increase in performance from pretest to posttest. The main effect for Group was not significant ($p = .88$). Importantly, we found an interaction between Session and Group, $F(1, 26) = 5.546$, $p < .05$, $\eta_p^2 = .18$: The training group showed a significant pretest-posttest increase in the number of correct responses, $t(13) = 5.826$, $p < .001$, $d' = 1.08$, while there was no such increase in the control group ($p = .10$), pointing to transfer of adaptive WM training to reading ability.[1]

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[1] Given that the sample consisted of second and third graders, we performed an additional control analysis in order to check for class grade differences in training-induced transfer in terms of reading. An ANOVA with the between-subjects factor Grade (2nd, 3rd) and Group (training, control) and the within-subjects factor Session (pretest, posttest) revealed better performance at posttest than at pretest, $F(1, 24) = 18.887$, $p < .001$, $\eta_p^2 = .44$, but no significant main effect or interactions with the factor Grade. Thus, the transfer gain was not modulated by Grade (Grade × Group × Session: $p = .26$).

Furthermore, the different abilities assessed by the reading test (e.g., listening and reading comprehension, recoding, decoding) benefitted equally from adaptive WM training. This was indicated by a nonsignificant main effect of Group (training, control) on the difference score between pretest and posttest in a multivariate analysis of variance (MANOVA, Pillai's Trace), $F(4, 23) = 1.855$, $p > .15$, $\eta_p^2 = .24$.

Mathematical Ability. The analysis of performance on the math test (% correct) showed a main effect of Session, $F(1, 26) = 25.302$, $p < .001$, $\eta_p^2 = .50$, indicating an increase in performance from pretest to posttest. Neither the main effect for Group ($p = .88$) nor the interaction between Session and Group ($p = .15$) were significant.

Task Switching. We ran an ANOVA with the factors Group (training, control), Session (pretest, posttest), and Trial Type (single, stay, switch) on mean latencies and excluded trials with incorrect responses and trials with reaction times (RTs) < 200 and > 5000 ms. General and specific switch costs were specified as orthogonal a priori contrasts on the factor Trial Type (general costs: 2–1–1; specific costs: 0 1–1). Results revealed a main effect for Session, showing that participants responded faster at posttest than at pretest, $F(1, 26) = 4.604$, $p < .05$, $\eta_p^2 = .15$. We also found a main effect for Trial Type, $F(2, 26) = 98.007$, $p < .001$ $\eta_p^2 = .79$, and significant general switch costs, $F(1, 26) = 103.632$, $p < .001$, $\eta_p^2 = .80$, as well as specific switch costs, $F(1, 26) = 91.98$, $p < .001$, $\eta_p^2 =.78$; no other effects reached significance (all *p*s > .11).

Inhibition. We performed an ANOVA with the factors Group (training, control), Session (pretest, posttest), and Trial Type (congruent, neutral, incongruent) on mean latencies and excluded trials with erroneous responses and RTs < 200 ms. The interference effect was analyzed by means of an a priori contrast comparing performance on congruent and incongruent trials (1 0 −1). We found a main effect of Trial Type, $F(2, 52) = 3.740$, $p < .05$, $\eta_p^2 = .13$, and a significant interference effect, $F(1, 26) = 5.836$, $p < .05$, $\eta_p^2 = .18$. No other effects reached significance (all *p*s > .37).

Maintenance of Transfer Effects

To test for maintenance of transfer, we compared the performances at pretest and at follow-up. Because of the drop outs ($n = 2$), we analyzed maintenance effects in a separate set of analyses. The ANOVAs for each one of the measures were identical to those reported above with the exception that the factor Session now included the two levels pretest and follow-up.

Wm. None of the main effects reached significance (Session: $p = .69$; Group: $p = .63$). However, an interaction between Group and Session, $F(1, 26) = 5.244$, $p < .05$, $\eta_p^2 = .18$, showed that performance improvements were larger in the training group ($d' = 0.63$) than in the control group.

We performed the respective analyses for each one of the transfer tasks, but none of the interactions between Group and Session were significant.

Individual Differences in Training-Induced Transfer

To analyze individual differences in training-induced transfer in the adaptive training group, we correlated baseline performance at pretest with transfer gains in WM and reading ability. WM performance at baseline and transfer gains at posttest/follow-up were significantly correlated ($r = -.39$, $p < .05$ and $r = -.41$, $p < .05$, respectively). Reading ability at baseline and transfer gains at posttest were also significantly related, $r = -.54$,

$p < .01$. Thus, poorer performance at pretest was consistently associated with larger transfer gains. Furthermore, we tested for a direct association between WM training gain and transfer gains at posttest and found a significant positive correlation between WM training gain and WM transfer gain ($r = .39$, $p < .05$) and a similar but insignificant correlation between WM training gain and reading transfer gain ($r = .24$, $p = .23$).

DISCUSSION

We investigated the effects of WM training on the performance of untrained cognitive tasks and academic tests in reading and mathematics. With respect to improvements on the training task, our data showed an advantage of adaptive over nonadaptive low-level WM training, which is consistent with previous findings in groups of children suffering from ADHD (Klingberg et al., 2005) and low WM capacity (Dunning et al., 2013; Holmes et al., 2009) as well as healthy adult populations (e.g., Brehmer, Westerberg, & Bäckman, 2012) and extends these findings to healthy children.

Regarding the transfer effects, our data showed that adaptive training resulted in transfer to an untrained WM task that was still significant after 3 months. This transfer to another WM task is consistent with prior evidence (e.g., Dunning et al., 2013; Holmes et al., 2009; Klingberg et al., 2005). It indicates that the adaptive training-induced WM improvements were neither task nor material specific and benefited performance on another task tapping the Updating domain (Miyake et al., 2000). Moreover, the training-induced long-term benefits were large in Cohen's terms ($d' = 0.65$ at posttest and $d' = 0.63$ at follow-up), thus highlighting the great potential of WM training for cognitive plasticity in childhood.

In contrast, we found no evidence for transfer of WM training to task switching and inhibition. This lack of transfer may be explained by the fact that the training tasks in the current study did not include strong demands on these control domains, even though they are moderately correlated on the latent level (Miyake et al., 2000) and rely on the recruitment of common neural networks in the frontal and parietal lobe (Adleman et al., 2002; Klingberg, Forssberg, & Westerberg, 2002). Still, transfer of WM training to inhibition has previously been reported in children (Klingberg et al., 2005), but this study investigated children with ADHD who usually show marked deficits in inhibitory control and thus have significant room for improvement (i.e., compensatory effects) in this domain. More importantly, the training regime in that study included a number of different training tasks tapping visuospatial and verbal short-term memory and WM, while the tasks in the present study mostly tapped verbal WM.

Considering this emphasis of the training regime on verbal WM, it may indeed be surprising that we found no transfer of WM training to task-set maintenance and selection in task-switching situations, even though training on maintenance and selection (by means of a switching task that heavily relied on verbal WM) has benefitted WM performance in children and adolescents in previous studies (Karbach & Kray, 2009; Kray, Karbach, Haenig, & Freitag, 2012). Moreover, WM-updating training including verbal components improved task-set maintenance and selection in younger adults (Salminen, Strobach, & Schubert, 2012). In contrast, complex training of action video games and multitasking training requiring several control processes, such as the maintenance of multiple activities, did not improve task maintenance and selection in young adults (Schubert & Strobach, 2012; Strobach, Frensch, & Schubert, 2012; Strobach, Frensch, Soutschek, & Schubert, 2012). Thus, transfer to the ability to maintain and select task sets in switching situations may be relatively task specific and more likely to occur after task-switching training (Karbach & Kray, 2009; Karbach, Mang, & Kray, 2010; Kray et al., 2012; Minear & Shah, 2008; Zinke, Einert, Pfennig, & Kliegel, 2012).

In the domain of academic abilities, our data showed short-term transfer to reading ability but not to math ability. The benefits for reading were substantial (*d'* = 1.08) and extend the findings on healthy children from Loosli et al. (2012) by showing that transfer of adaptive WM training is also significant when the adaptive WM training is compared to an active control condition. Adding further evidence indicating that WM training benefits reading is especially important because previous studies, mostly focusing on children with cognitive deficits, have yielded very mixed results (Titz & Karbach, 2014). Still, the finding is less consistent with recent perspectives arguing against the possibility of transfer effects to nontrained tasks (e.g., Redick et al., 2013; Shipstead et al., 2012). However, the combination of an adaptive practice protocol applied in a sample of healthy children that were assessed by means of ecologically valid transfer tests (i.e., standardized tests that are highly correlated with performance in the classroom and validly test WM-related reading ability) may explain these transfer findings. But why does adaptive working memory training benefit reading ability? The fact that the training and the transfer task shared important features may help us to understand the underlying processes. WM models like that of Daneman and Carpenter (1980) do not make a sharp distinction between executive and storage mechanisms in WM and between their respective capacities (but see Baddeley, 2010). Therefore, both the executive domain of WM and storage components, including phonological processing and other storage mechanisms, are related to reading comprehension skills in adults (Daneman & Carpenter, 1980; Daneman & Merikle, 1996). In children, executive processing and storage equally contributed to reading comprehension (de Jonge & De Jong, 1996). Thus, complex span tasks, such as the one applied in this study, are related to reading comprehension (cf. Just & Carpenter, 1992) but also to memory retrieval processes (Unsworth & Engle, 2006). Given that the present reading task strongly relied on both comprehension and memory retrieval processes, it seems likely that benefits in these domains have contributed either in combination or separately to the observed general improvements of the reading test score. On a different note, it may be argued that the transfer of WM training to reading results from the involvement of attentional control in both tasks (e.g., Hasher, Lustig, & Zacks, 2008), suggesting that the training procedure facilitated the ability to control attention (cf. Loosli et al., 2012). Consequently, this interpretation would lead us to expect transfer of WM to mathematical ability, which also heavily relies on attentional processes (Marshall, Hynd, Handwerk, & Hall, 1997).

However, despite the strong association between mathematical ability and WM, we found no evidence for such a transfer to performance on the math test (cf. St. Clair-Thompson et al., 2010). One may attribute this lack of transfer to the specific nature of the training task applied in the present study: When performing math tasks, children seem to shift from more procedural-based (e.g., counting) to more memory-based (e.g., fact retrieval) strategies as they grow older (Titz & Karbach, 2014). While spatial WM is particularly important for procedural-based strategies that are essential for the learning and application of new mathematical skills and concepts, verbal WM is more relevant when learned skills have to be applied, and mathematical processing relies on memory-based retrieval of solutions or facts (Laski et al., 2013). Recent studies support this notion by showing that younger children rely more on the visuospatial sketchpad to solve calculations while older children make more use of the phonological loop (e.g., DeSmedt et al., 2009; McKenzie, Bull, & Gray, 2003). Given that the children in the present study were relatively young (mean age = 8.4 years), the selection of a training regime that relied not only on verbal WM but also included visuospatial WM demands or even multiple aspects of executive control may have resulted in a transfer to other academic abilities, including math.

Finally, the analysis of individual differences pointed to a pattern of compensation effects with the largest transfer benefits occurring in subjects with low WM and reading scores at pretest. In addition, participants showing the largest WM-training gains also showed the largest transfer effects. The fact that the participants who needed it the most also benefitted the most is supported by findings from other process-based training studies (e.g., Dahlin, 2013; Karbach & Spengler, 2012). Moreover, this pattern of compensation effects certainly has important implications for the application and effectiveness of cognitive training interventions in educational and clinical settings.

For instance, WM impairments are typically found in children suffering from developmental disorders and learning difficulties, such as ADHD, dyslexia, and dyscalculia (e.g., Barkley, 1997; Schuchardt et al., 2008). Moreover, the extent of WM deficits was directly associated with the extent of deficits in reading and math in children with reading disabilities (Gathercole et al., 2006). Considering that both abilities form the basis of many aspects of subsequent academic development, interventions tailored to improve WM in these children may induce cascading benefits, particularly considering the compensatory effects found in the present study. On the one hand, these benefits may occur by directly facilitating task performance, for instance by improving the maintenance of intermediate steps while solving calculations or the temporary storage of letters in order to combine them into a word. On the other hand, academic benefits of WM training may occur in a more indirect manner by improving the child's ability to remember and follow task instructions in the classroom and to maintain and integrate different sources of information in complex assignments.

Although the present findings point to the potential of adaptive WM training, our study has some limitations that have to be considered: The sample size is only moderate and the findings will have to be replicated in larger samples. Still, the transfer to WM and reading was considerable, even after correcting the effect sizes for small-sample bias. Moreover, we are aware that the achievement tests we applied may not capture the full range of abilities in the domains of reading and mathematics, but, since they are strongly related to teacher ratings (r = .61–.66), they can be considered very good proxies for academic success in these domains. Aside from the adaptive training group, we did not include a passive control group to test for potential retest effects. However, instead we included an active control group to test for such retest effects but also to control for general effects as a result of training (e.g., motivational effects). Finally, the study included a relatively broad age range (7–9 years) at which the WM span substantially increases because of cognitive maturation and because children intensively practice WM when they learn to read and to perform mental calculations. Given that the training group and the control group were carefully matched for age in the present study, it is unlikely that training and transfer effects were affected by age differences between groups. Still, future studies may want to test whether the training-induced gains reported in this study vary as a function of age and grade across the elementary-school years.

Thus, despite these considerations, this research provides strong new evidence for the effectiveness of WM training. The present findings are consistent with the idea that a training regime requiring participants to constantly perform at their individual limit of

WM capacity may be particularly effective to induce long-term plasticity by improving the efficiency of neuronal responses and the cognitive processes serving WM (e.g., Holmes et al., 2009). Even though the intervention was relatively brief, it yielded considerable transfer to other WM tasks that was maintained over 3 months. Our study is one of the first ones showing that the WM training not only benefits children's performance on experimental tasks in the laboratory but also extends to achievement measures that are highly relevant for education and subsequent academic success.

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REFERENCES

Adleman, N. E., Menon, V., Blasey, C. M., White, C. D., Warsofsky, I. S., Glover, G. H., & Reiss, A. L. (2002). A developmental fMRI study of the Stroop color-word task. *NeuroImage, 16*, 61–75. doi:10.1006/nimg.2001.1046

Alloway, T. (2009). Working memory, but not IQ, predicts subsequent learning in children with learning difficulties. *European Journal of Psychological Assessment, 25*(2), 92–98. doi:10.1027/1015-5759.25.2.92

Alloway, T. (2012). Can interactive working memory training improving learning? *Journal of Interactive Learning Research, 23*(3), 197–207.

Alloway, T., & Alloway, R. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology, 106*(1), 20–29. doi:10.1016/j.jecp.2009.11.003

Alloway, T., Bibile, V., & Lau, G. (2013). Computerized working memory training: Can it lead to gains in cognitive skills in students? *Computers in Human Behavior, 29*(3), 632–638. doi:10.1016/j.chb.2012.10.023

Alloway, T. P., Gathercole, S. E., Adams, A.-M., Willis, C., Eaglen, R., & Lamont, E. (2005). Working memory and phonological awareness as predictors of progress towards early learning goals at school entry. *British Journal of Developmental Psychology, 23*(3), 417–426. doi:10.1348/026151005X26804

Andersson, U. (2008). Working memory as a predictor of written arithmetical skills in children: The importance of central executive functions. *British Journal of Educational Psychology, 78*(2), 181–203. doi:10.1348/000709907X209854

Baddeley, A. D. (2010). Working memory. *Current Biology, 20*, R136–R140. doi:10.1016/j.cub.2009.12.014

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin, 121*(1), 65–94. doi:10.1037/0033-2909.121.1.65

Brehmer, Y., Westerberg, H., & Bäckman, L. (2012). Working-memory training in younger and older adults: Training gains, transfer, and maintenance. *Frontiers in Human Neuroscience, 6*, 63. doi:10.3389/fnhum.2012.00063

Buschkuehl, M., Jaeggi, S., Kobel, A., & Perrig, W. J. (2008). *Braintwister—Aufgabensammlung für kognitives Training*. Bern: Universität Bern, Institut für Psychologie.

Buschkuehl, M., Jaeggi, S. M., & Jonides, J. (2012). Neuronal effects following working memory training. *Developmental Cognitive Neuroscience, 2*, S167–S179. doi:10.1016/j.dcn.2011.10.001

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences* (Rev. ed.). New York, NY: Academic Press.

Dahlin, K. I. E. (2011). Effects of working memory training on reading in children with special needs. *Reading and Writing, 24*, 479–491. doi:10.1007/s11145-010-9238-y

Dahlin, K. I. E. (2013). Working memory training and the effect on mathematical achievement in children with attention deficits and special needs. *Journal of Education and Learning, 2*(1), 118–133. doi:10.5539/jel.v2n1p118

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450–466. doi:10.1016/S0022-5371(80)90312-6

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review, 3*(4), 422–433. doi:10.3758/BF03214546

de Jonge, P., & De Jong, P. F. (1996). Working memory, intelligence, and reading ability in children. *Personality and Individual Differences, 21*, 1007–1020. doi:10.1016/S0191-8869(96)00161-4

DeSmedt, B., Janssen, R., Bouwens, K., Verschaffel, L., Boets, B., & Ghesquière, P. (2009). Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to second grade. *Journal of Experimental Child Psychology, 103*(2), 186–201. doi:10.1016/j.jecp.2009.01.004

DeStefano, D., & LeFevre, J. (2004). The role of working memory in mental arithmetic. *European Journal of Cognitive Psychology, 16*(3), 353–386. doi:10.1080/09541440244000328

Diamond, A. (2012). Activities and programs that improve children's executive functions. *Current Directions in Psychological Science, 21*(5), 335–341. doi:10.1177/0963721412453722

Dunning, D. L., Holmes, J., & Gathercole, S. E. (2013). Does working memory training lead to generalized improvements in children with low working memory? A randomized controlled trial. *Developmental Science,* doi:10.1111/desc.12068

Engel de Abreu, P. M. J., Gathercole, S. E., & Martin, R. (2011). Disentangling the relationship between working memory and language: The roles of short-term storage and cognitive control. *Learning and Individual Differences, 21*(5), 569–574. doi:10.1016/j.lindif.2011.06.002

Gathercole, S., Alloway, T., Willis, C., & Adams, A. (2006). Working memory in children with reading disabilities. *Journal of Experimental Child Psychology, 93*(3), 265–281. doi:10.1016/j.jecp.2005.08.003

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology, 18*(1), 1–16. doi:10.1002/acp.934

Geary, D., Hoard, M., Byrd-Craven, J., Nugent, L., & Numtee, C. (2007). Cognitive mechanisms underlying achievement deficits in children with mathematical learning disability. *Child Development, 78*(4), 1343–1359. doi:10.1111/j.1467-8624.2007.01069.x

Gottfredson, L. S. (2002). Where and why g matters: Not a mystery. *Human Performance, 15*, 25–46.

Green, C., Strobach, T., & Schubert, T. (2013). On methodological standards in training and transfer experiments. *Psychological Research,* doi:10.1007/s00426-013-0535-3

Gustafsson, J.-E., & Undheim, J. O. (1996). Individual differences in cognitive functions. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 186–242). New York, NY: Prentice Hall International.

Hasher, L., Lustig, C., & Zacks, R. (2008). Inhibitory mechanisms and the control of attention. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (pp. 227–249). Oxford, NY: Oxford University Press.

Hedges, L. V., & Olkin, I. (1985). *Statistical methods for meta-analysis*. Orlando, FL: Academic Press.

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science, 12*, F9–F15. doi:10.1111/j.1467-7687.2009.00848.x

Jolles, D. D., & Crone, E. A. (2012). Training the developing brain: A neurocognitive perspective. *Frontiers in Human Neuroscience, 6*, 76. doi:10.3389/fnhum.2012.00076

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual difference sin working memory. *Psychological Review, 99*, 122–149. doi:10.1037/0033-295X.99.1.122

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review, 9*, 637–671. doi:10.3758/BF03196323

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*, 978–990. doi:10.1111/j.1467-7687.2009.00846.x

Karbach, J., Mang, S., & Kray, J. (2010). Transfer of task-switching training in older age: The role of verbal processes. *Psychology & Aging, 25*, 677–683. doi:10.1037/a0019845

Karbach, J., & Spengler, M. (2012). Who benefits the most? Individual differences in the transfer of executive control training in younger and older adults. In A. Bröder, E. Erdfelder, B. E. Hilbig, T. Meiser, R. F. Pohl, & D. Stahlberg (Eds.), *Abstracts of the 54th TEAP* (p. 64). Lengerich: Pabst.

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., … Westerberg, H. (2005). Computerized training of working memory in children with ADHD—A randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*, 177–186. doi:10.1097/00004583-200502000-00010

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Increased brain activity in frontal and parietal cortex underlies the development of visuo-spatial working memory capacity during childhood. *Journal of Cognitive Neuroscience, 14*, 1–10. doi:10.1162/089892902317205276

Krajewski, K., Liehm, S., & Schneider, W. (2004). *Deutscher Mathematiktest für zweite Klassen (DEMAT2 +)*. Göttingen: Hogrefe.

Kray, J., Karbach, J., Haenig, S., & Freitag, C. (2012). Can task- switching training enhance executive control functioning in children with attention deficit/-hyperactivity disorder?. *Frontiers in Human Neuroscience, 5*, 180. doi:10.3389/fnhum.2011.00180

Landerl, K., & Wimmer, H. (2008). Development of word reading fluency and spelling in a consistent orthography: An 8-year follow-up. *Journal of Educational Psychology, 100*(1), 150–161. doi:10.1037/0022-0663.100.1.150

Laski, E. V., Casey, B. M., Yu, Q., Dulaney, A., Heyman, M., & Dearing, E. (2013). Spatial skills as a predictor of first grade girls' use of higher-level arithmetic strategies. *Learning and Individual Differences, 23*(0), 123–130. doi:10.1016/j.lindif.2012.08.001

Loosli, S. V., Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012). Working memory training improves reading processes in typically developing children. *Child Neuropsychology, 18*, 62–78. doi:10.1080/09297049.2011.575772

Lu, L., Weber, H. S., Spinath, F. M., & Shi, J. (2011). Predicting school achievement from cognitive and non-cognitive variables in a Chinese sample of elementary school children. *Intelligence, 39* (2–3), 130–140.

Marshall, R. M., Hynd, G. W., Handwerk, M. J., & Hall, J. (1997). Academic underachievement in ADHD subtypes. *Journal of Learning Disabilities, 30*(6), 635–642. doi:10.1177/002221949703000607

Marx, H. (1998). *Knuspels Leseaufgaben: Handanweisung*. Göttingen: Hogrefe.

McKenzie, B., Bull, R., & Gray, C. (2003). The effects of phonological and visual-spatial interference on children's arithmetical performance. *Educational and Child Psychology, 20* (3), 93–108.

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology, 49*, 270–291. doi:10.1037/a0028228

Minear, M., & Shah, P. (2008). Training and transfer effects in task switching. *Memory & Cognition, 36*(8), 1470–1483. doi:10.3758/MC.336.8.1470

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. doi:10.1006/cogp.1999.0734

Pickering, S. (Ed.). (2006). *Working memory and education*. Chicago, IL: Academic Press.

Montgomery, J., Magimairaj, B., & O'Malley, M. (2008). Role of working memory in typically developing children's complex sentence comprehension. *Journal of Psycholinguistic Research, 37*(5), 331–354. doi:10.1007/s10936-008-9077-z

Redick, T. S., Shipstead, Z., Harrison, T. L., Hicks, K. L., Fried, D. E., Hambrick, D. Z., … Engle, R.W. (2013). No evidence of intelligence improvement after working memory training: A randomized, placebo-controlled study. *Journal of Experimental Psychology: General, 142*(2), 359–379. doi:10.1037/a0029082

Roick, T., Gölitz, D., & Hasselhorn, M. (2004). *Deutscher Mathematiktest für dritte Klassen (DEMAT 3 +)*. Göttingen: Hogrefe.

Salminen, T., Strobach, T., & Schubert, T. (2012). On the impacts of working memory training on executive functioning. *Frontiers in Human Neuroscience, 6*, 166. doi:10.3389/fnhum.2012.00166

Schmiedek, F., Hildebrandt, A., Lövdén, M., Wilhelm, O., & Lindenberger, U. (2009). Complex span versus updating tasks of working memory: The gap is not that deep. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*, 1089–1096.

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. doi:10.1016/j.actpsy.2012.06.010

Schuchardt, K., Maehler, C., & Hasselhorn, M. (2008). Working memory deficits in children with specific learning disorders. *Journal of Learning Disabilities, 41*(6), 514–523. doi:10.1177/0022219408317856

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

St. Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *The Quarterly Journal of Experimental Psychology, 59*, 745–759. doi:10.1080/17470210500162854

St. Clair-Thompson, H. L., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children's working memory and classroom performance. *Educational Psychology, 30*, 203–219. doi:10.1080/01443410903509259

Strobach, T., Frensch, P. A., & Schubert, T. (2012). Video game practice optimizes executive control skills in dual-task and task switching situations. *Acta Psychologica, 140*(1), 13–24. doi:10.1016/j.actpsy.2012.02.001

Strobach, T., Frensch, P. A., Soutschek, A., & Schubert, T. (2012). Investigation on the improvement and transfer of dual-task coordination skills. *Psychological Research, 76*(6), 794–811. doi:10.1007/s00426-011-0381-0

Swanson, H. (2004). Working memory and phonological processing as predictors of children's mathematical problem solving at different ages. *Memory & Cognition, 32*(4), 648–661. doi:10.3758/BF03195856

Swanson, H. L., & Berninger, V. (1995). The role of working memory in skilled and less skilled readers' comprehension. *Intelligence, 21*(1), 83–108. doi:10.1016/0160-2896(95)90040-3

Swanson, H. L., & Berninger, V. W. (1996). Individual differences in children's working memory and writing skill. *Journal of Experimental Child Psychology, 63*(2), 358–385. doi:10.1006/jecp.1996.0054

Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12*, 106–113. doi:10.1111/j.1467-7687.2008.00745.x

Titz, C., & Karbach, J. (2014). Working memory and executive functions: Effects of training on academic achievement. *Psychological Research*. Advance online publication. doi:10.1007/s00426-013-0537-1

Unsworth, N., & Engle, R. W. (2006). A temporal-contextual retrieval account of complex-span: An analysis of errors. *Journal of Memory and Language, 54*, 346–362. doi:10.1016/j.jml.2005.11.004

Wechsler, D. (1981). *Manual for the Wechsler adult intelligence scale-revised*. New York, NY: Psychological Corporation.

Zheng, X., Swanson, H. L., & Marcoulides, G. A. (2011). Working memory components as predictors of children’s mathematical word problem solving. *Journal of Experimental Child Psychology, 110*(4), 481–498. doi:10.1016/j.jecp.2011.06.001

Zinke, K., Einert, M., Pfennig, L., & Kliegel, M. (2012). Plasticity of executive control through task switching training in adolescents. *Frontiers in Human Neuroscience, 6*, 1–15. doi:10.3389/fnhum.2012.00041