Hong Kong Journal of Mental Health
2009, *35*, 18-30

Copyright © 2009 by
The Mental Health Association of Hong Kong

Computerized Working Memory Training for Children with ADHD: A Pilot Study in Hong Kong

Y Q He
Department of Psychology
The Chinese University of Hong Kong

Raymond W S Chan
Child and Adolescent Team
Kwai Chung Hospital

Abstract

Working memory is the ability to hold and manipulate information for a short period of time. It plays an important role in a wide range of higher-level cognitive skills. Working memory impairment is frequently found among children with Attention-Deficit/Hyperactivity Disorder (ADHD), but the interactive relationship between working memory and ADHD is unclear. Recent studies have shown that working memory can be improved by intensive and systematic computerized training. In the present study, a computerized working memory training programme for school-age children was developed and its effects on the working memory and behaviours of three ADHD children were studied. The subjects were evaluated 5 weeks before the start of the training, upon completion of the training as well as at a 5-week follow-up. The results demonstrated a significant and lasting effect of the training on the subjects' working memory but not on their ADHD behaviours. Implications of the findings on working memory training and treatment of ADHD were discussed.

Keywords: working memory, training, attention-deficit/hyperactivity disorder

Introduction

Working Memory and Its Importance

The term working memory has been defined in a number of different ways. In his seminal model of working memory, Baddeley defined working memory as holding information in mind while simultaneously manipulating that information (Baddeley 1992; Baddeley & Hitch, 1974; Baddeley, 2007). His model (Fig. 1) posits separate phonological and visuospatial storage and rehearsal components that are controlled by a central executive. The phonological loop processes verbal or acoustic information and temporally stores this information through subvocal rehearsal; whereas the visuospatial sketchpad processes and conserves imagery and spatial material through visualization. The central executive has an overseeing role: it is the control centre of the working memory system and it actively manipulates the information in storage in order to perform complex cognitive tasks.

Working memory serves a critical role in guiding everyday behaviors and underlies the capacity to perform many real-world activities, such as learning, comprehension, reasoning, and planning (Baddeley, 2003; 2007). For example, mathematical problems often involve remembering the totals of certain calculations while performing other mathematical operations and then combining the outcomes. Similarly, when reading one often has to hold in mind relevant information such as a subclause or the referent of a pronoun, decode other text, and integrate these meanings. Consistently, children's reading and mathematical abilities have been found to be reliably correlated to their level of working memory capacity (Hitch et al., 2001; Gathercole et al., 2004; Gathercole & Alloway, 2008). Individuals with poor working memory experience great problems with maintaining focus, remembering instructions and completing tasks (Gathercole & Alloway, 2008). In addition, other researches have suggested that working memory is fundamental to general intelligence (Gray et al., 2003; Hockey & Geffen, 2004; Süβ et al., 2002). Despite the different working memory tasks used, measures of working memory have be en found to account for about 50-70% of the variance of general intelligence. Süβ et al. (2002) have stated that "at present, working memory capacity is the best predictor for intelligence that has yet been derived from theories and research on human cognition" (p. 284).

Correspondence concerning this article should be addressed to Dr. Raymond W S Chan, Yaumatei Child Psychiatric Centre, 8/F, 143 Battery Street,Yaumatei, Kowloon, Hong Kong SAR.
E-mail: cprc@hkusua.hku.hk

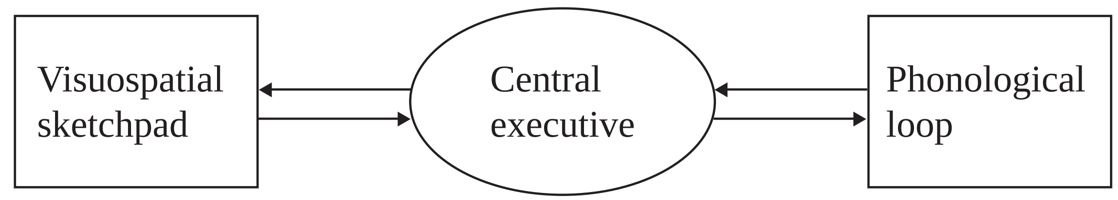

Fig. 1. The three-component model of working memory. Derived from Baddeley & Hitch (1974).

Working Memory Capacity and Its Training

In his well-known article "The Magic Number Seven", Miller (1956) summarized that seven is the working memory capacity limit often found for storing single digits, letters or spatial positions. Yet, later research has confirmed that working memory capacity is not fixed to seven items, but can be modified and improved with practice. It differs from individual to individual. Animal and human studies have demonstrated that the neural substrates underlying working memory are plastic (McNab, et al., 2009; Olesen et al., 2004; Rainer & Miller, 2000; Westerberg & Klingberg, 2007). In human, training of working memory is associated with an increased working memory capacity and an accompanied increased activity in the prefrontal and parietal cortex. Studies have also shown working memory capacity can be improved by systematic computerized working memory training (Klingberg, Forssberg & Westerberg, 2002). These are encouraging findings given the importance of working memory in the higher-level cognitive activities.

Working Memory Training Among Children with Attention-Deficit & Hyperactivity Disorder (ADHD)

The working memory construct has often been assumed in the nascent models of ADHD (Barkley, 1997; Castellanos & Tannock, 2002; Martinussen et al., 2005; Willcutt et al., 2005). Two recent meta-analytic reviews provide confirmatory evidence of working memory deficits in children with ADHD relative to typically developing controls, even after controlling for comorbid learning and language disorders (Martinussen et al. 2005) and deficits in overall intelligence and reading achievement (Willcutt et al. 2005). Recently, systematic computerized working memory training has been shown to improve ADHD children's working memory span as well as to reduce parent's rating of ADHD symptoms (Klingberg et al., 2005). However, the exact source contributing to the latter improvement is unclear. There are different models positing the relationship between working memory deficit and ADHD. Some have proposed that working memory is a central feature of ADHD (Castellanos & Tannock, 2002; Rapport et al., 2001); whereas others have argued that it is only one of the executive functions that make up the ADHD neurocognitive profile (Willcutt et al. 2005). Thus further research on the question whether improving working memory would bring forth a significant cascading effect on ADHD behaviours is warranted.

Construction of Current Computerized Working Memory Training Programme

The present study is set out to be a pilot investigation to examine the training effects of a locally developed computerized working memory training programme on ADHD children. It is the first attempt in the local community. The design of the current programme is based on Baddeley and Hitch's (1974) working memory model. There are two main categories of training tasks, namely auditory and visuospatial tasks, tapping the operation of the phonological loop and the visuospatial pad respectively. In order to be accounted as a working memory task, the task must involve active maintenance and manipulation of the to-be-remembered stimuli, in which attention must be shifted back and forth between the representation of the stimuli and the processing demand of the task. These reflect the operation of the central executive component of the working memory model. Thus repeating digits backward which involves manipulation of the memorized stimuli is a working memory training task whereas recalling digits in the exact same order as presented is not. In addition, as reviewed above, working memory is a cognitive skill that can be improved with practice. But not just any practice will do. It has to be a certain kind of practice that challenges and refines the working memory system, even as it gets better. Klingberg, Forssberg and Westerberg, (2002) mentioned two key features of a training regime that have been proved to be effective in inducing cortical plasticity in sensory and motor corteces: "(1) training is performed close to the capacity of the individual by using an adaptive staircase method that adjusted difficulty on a trial-by-trial basis; and (2) training is performed at least 20 minutes per day, 4-6 days a week, for at least 5 weeks" (p.782). Previous studies have shown that mere repeated training without adjusting the difficulty level leads to increased reaction time but no increase in working memory capacity (e.g. Phillips & Nettelbeck, 1984).

Taken all these considerations into account, all tasks designed for the current working memory training programme have the following features: (i) short delays during the presentations of stimuli, (ii) maintenance and manipulation of multiple stimuli at the same time, (iii) random presentation of stimuli in each trail, (iv) difficulty level adjusting in accordance with the ongoing performance, (v) regular daily training around 30 minutes per day, 5 days a week, lasting for 5 weeks. A detailed description of the training tasks is presented in the Method Section.

Hypotheses of the Present Study

The effectiveness of the computerized working memory training programme on improving the working memory of children with ADHD would be examined. Using the subjects as their own control, it was hypothesized that i) there would be no significant changes in working memory performance during the waiting period; ii) there would be significant improvements in working memory performance after completion of the training and iii) the improvements would be maintained at a 5-week follow up. In relating to ADHD, it was hypothesized that there would be significant improvements in the reported symptoms and problems after completion of the training.

Method

Participants

For the present study, the inclusion criteria were (1) a diagnosis of ADHD of either combined or predominantly inattentive subtype; and (2) 6 to 12 years old. Exclusion criteria were: (1) on treatment with stimulants, atomoxetine, neuroleptic, or any other psychoactive drugs; (2) fulfilling criteria for diagnosis of clinically significant oppositional defiant disorder, autistic spectrum disorder or depression; (3) history of seizures during past two years; (4) IQ < 80 (based on an IQ test or clinical impression and school history); and (5) motor or perceptual handicap that would prevent using the computer programme.

Three children were recruited for the current pilot study, two of them (YH and YC) were boys, aged 8 and 7 respectively. Both of them had a diagnosis of ADHD of combined subtype. The third participant (SY) was an 8-year-old girl, with a diagnosis of ADHD of predominantly inattentive subtype.

Pre- and Post-Training Measures

Working memory assessment. The following established tests for working memory assessment were administered. (1) The span-board task from the WAIS-RNI testing battery (Wechsler, 1981). The raw score from trials with backward repeating of the memoranda was used to measure visuospatial working memory. (2) The digit-span test from the HK-WISC (Education Department, Hong Kong Government & Hong Kong Psychological Society, 1981). The raw score of the backward trials was used to measure verbal working memory. (3) The Stroop task (interference score) was used to measure response inhibition (Lezak, et al., 2004).

Measures of ADHD symptoms/problems. (1) The 18 DSM-IV-TR items were used as a rating scale for ADHD symptoms (Barkley & Murphy, 1998). Each item of the rating scale corresponds to one of the symptoms in the fourth edition of the DSM (DSM-IV), with 9 items corresponding to inattention symptoms and 9 items corresponding to hyperactivity-impulsivity symptoms. It is designed for parents or teachers to rate the frequency of a child's symptoms on a scale of 0 to 3: 0= never or rarely, 1= sometimes, 2= often, 3= very often. Two scores are obtained, one for inattention and the other for hyperactivity-impulsivity. Score is obtained by counting the number of items whose rating is equal or over 2. (2) The Home Situation Questionnaire (HSQ) and School Situation Questionnaire (SSQ) were also used for parents and teachers respectively (Barkley & Murphy, 1998). The HSQ and SSQ are designed to assess the pervasiveness and severity of child's disruptive behaviors in multiple home and school situations respectively. The HSQ comprises of 16 items and the SSQ 12 items. For each item, informants first indicate whether a child presents problems in that situation or not. If yes, the severity of the problems in that situation is rated on a 9-point scale raging from mild to severe. The number of problem settings is scored as well as the mean severity of problems. (3) The ADAPT Academic

Performance Inventory (Parker, 1992) was also used for teachers. This inventory is designed for teachers to evaluate a student's academic performance across multiple academic situations. It comprises of 19 items and each item is rated on a 5-point scale ranging from not good at all to very good performance.

The Training Programme

The training consists of performing working memory tasks implemented in a computer programme developed for this study. The programme is a video-game like software and is used by the child on a personal computer. The programme includes visuospatial working memory tasks (remembering the location and orders of objects and shapes) as well as auditory working memory tasks (remembering sequences of letters, digits or words). Responses are made by clicking with the mouse on the targets.

There are eight training tasks (see Table1 for a detailed description of each task). Each task has nine levels, with difficulty increasing with higher levels. There are 4 trials within each level. The level of difficulty is adjusted, on a level-by-level basis, to match the working memory span of the child on each task. Task difficulty is usually manipulated through increasing the number of stimuli that has to be remembered. The software directly includes reinforcement, which is implemented via verbal feedback on performance for each trial, e.g., 'well done' 'keep the good work' 'keep going' 'what a near miss'. Visual feedback in the forms of '√' and 'x' is also given for each trial. Feedback for each level is given in the form of an energy bar – the energy bar is filled up or emptied as a function of advancing or declining in performance level. The child goes through all eight kinds of training tasks and performs about 90 trials on each day of training. The total training time for each session is about 35 minutes. All the training sessions are supervised by a trainer who also works with the child and parent to develop a reward system for the programme.

Procedures

Three children meeting the inclusion and exclusion criteria were recruited. Verbal information regarding the training details was given. The subjects were first scheduled for two baseline evaluations with a 5-week interval. This served as the waiting control. Training started immediately after the second evaluation. The training took place after school every Monday to Friday, and lasted for 5 consecutive weeks. The post-training evaluation took place 2 days after the training ended, and the follow-up assessment was done 5 weeks thereafter. On all occasions, the first author (a clinical psychologist trainee) administered the working memory tests and distributed the ADHD rating scales for completion by the parents and the teachers.

Results

Working Memory Assessment

Paired-samples T-tests were conducted to examine the differences between different time periods for all participants and all tests (Fig. 2). Results revealed that three participants' performance on the working memory tasks remained stable across the waiting control period, i.e. $t(2) = 1.000$, $p=0.423$ for backward span board score; $t(2) = -1.109$, $p=0.383$ for backward digit span score; $t(2) = -0.848$, $p=0.486$ for interference score of Stroop task. Therefore, mean scores of the two assessments done during the waiting control period were used as baselines for subsequent comparisons.

Table 1

Working memory training tasks in the computerized programme

Task	Description
Auditory Tasks	
Backward digit span	Digits (0-9) arranged in a four-by-three grid are displayed. Digits generated by the computer randomly are read out. Participants listen and then reproduce the digits in a reversed sequence.
Backward letter span	The alphabets are shown .in sequence. Letters generated by the computer randomly are read out. Participants listen and then reproduce the letters in a reversed sequence.
Letter-Number sequence	The digits (0-9) and the alphabets (A-Z) are displayed. A combination of digits and letters generated by the computer randomly are read out. A digit is always followed by a letter, or vice versa. Participants listen and then produce all the digits first in an ascending order, and then produce all the letters according to their ascending order as well. For example, if "3-h-1-t-5-g" is read out, the correct response will be 1-3-5-g-h-t.
Visuospatial Tasks	
Identifying word positions in a circle of star	Ten stars arranged in a circle are displayed. A sequence of words is read out, while a star flashes for each word that is spoken. When all the words are vocalized, one of the words just read out will be displayed on the screen, and the participant has to indicate which star corresponding to this word is lit as the word is read out.
Reproducing a stone sequence	16 stones of various sizes are randomly displayed. Participants watch several stones lit up and then produce the stones in their reversed sequence.
Reproducing a star sequence	16 stars of various sizes are randomly displayed. Participants watch several stars lit up and then produce the star in their reversed sequence.
Circle-Square span	8 circles and 8 squares are randomly displayed. A sequence of them is lit up one by one. A square is always followed by a circle, or vice versa. Participants watch and then produce all the circles first according to their presentation order, and then produce all the squares according to their presentation order as well.
Reproducing the route of a frog jumping over a pond full of stones and lotus leaves	A pond covered by various stones and lotus leaves is displayed. A frog jumps in a random route, either on a stone or on a lotus leaf. Participants reproduce the route the frog has just taken.

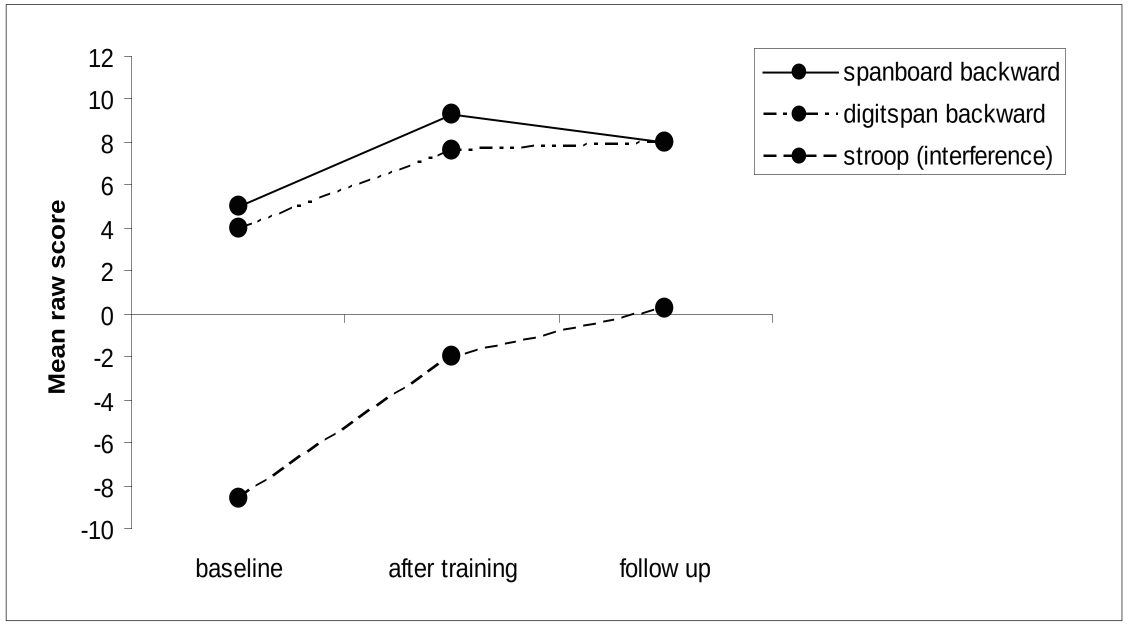

Fig. 2. Mean raw scores of working memory tasks

Upon completion of the training, the backward span board task showed a significant improvement [$t(2) = -13$, $p=0.006$]. Participants' score at post-training (mean=9.3) was almost double as compared to the score at baseline (i.e., mean =5). The improvement was maintained at follow-up, $t(2) = 2$, $p=0.184$. For the backward digit span task, participants' performance at post-training (mean= 7.6) was also twice as good as that at baseline (mean = 3), and the improvement was marginally significant, $t(2) = -3.951$, $p=0.058$. The improvement was also maintained in 5-week's time, $t(2) = -1$, $p=0.423$. For the Stroop task, the inference score was also examined with the paired-samples t-test. Participants' score improved by more than a half from baseline (mean= -8) to post-training (mean = -2), but the improvement did not approach significance, $t(2) = -1.121$, $p=0.379$. Yet, when examined individually (Fig.3), two out of three participants displayed a trend of improvement after training.

Participants' Acceptance Towards the Training Programme

Across the 5-week training period, the attendance rate was extremely well among the three participants. Participant YC attended all training sessions, whereas participants YH and SY were absent for one session each because of sickness. In addition, participants had to travel everyday from their schools to the psychiatric centre. The participants and their parents did not show any complaint about the arrangement. Moreover, they usually came earlier than the scheduled time and waited patiently for the training to start. All participants found the cartoon and colourful designs of the software appealing. At the first few sessions of the training, as the difficulty level was relatively low, participants generally maintained high level of motivation. They reported enjoying the tasks presented, and the intrinsic rewards of successfully completing the tasks and advancing to higher levels. However, as they

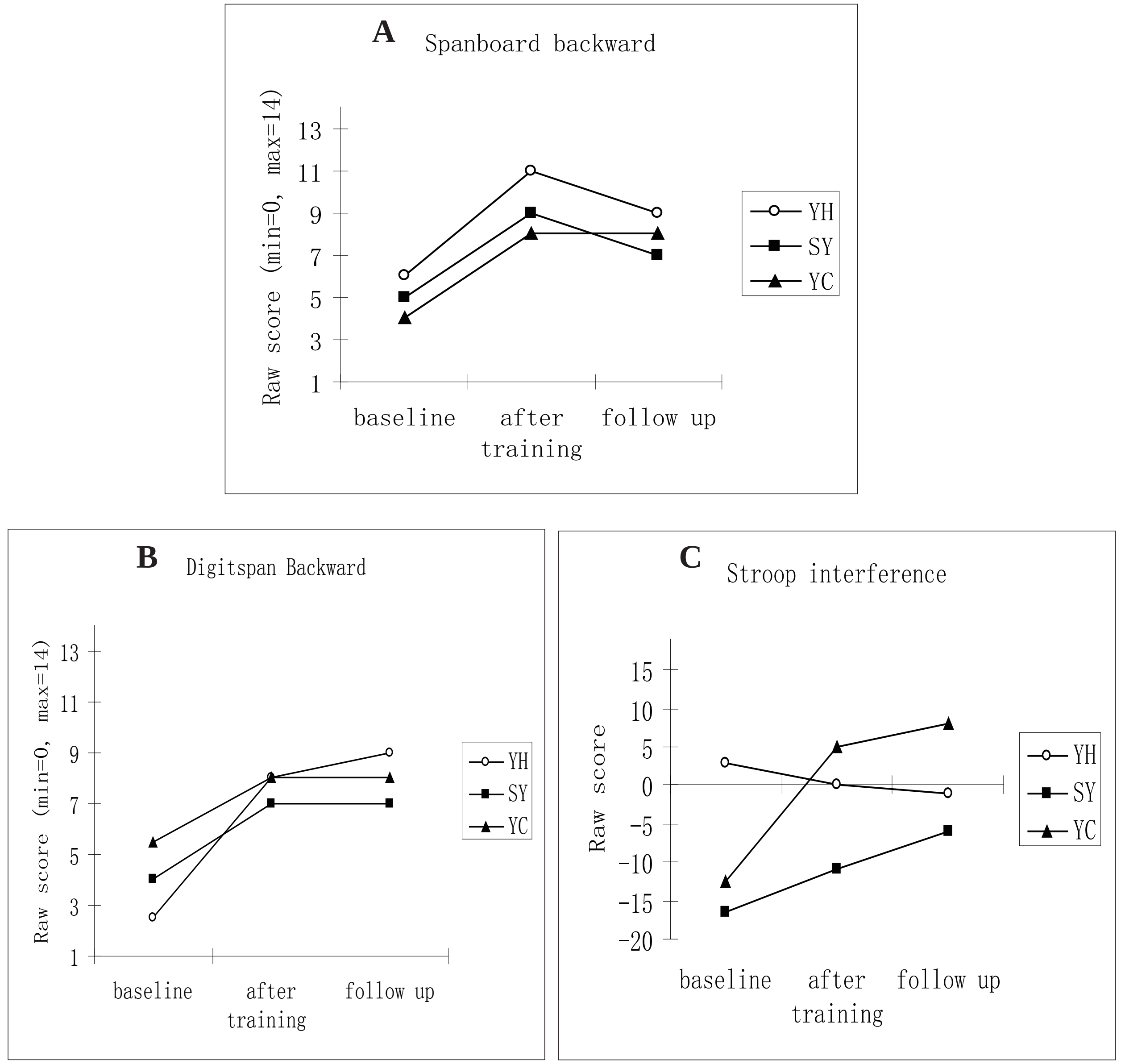

Fig. 3 Performance of individual participants on the working memory tests

advanced to levels of greater difficulty, one of the participants found the training to be very challenging and grew frustrated. A great deal of encouragement and reinforcement were needed to support him. For the other two participants, they maintained a high level of motivation throughout their training. By the end of the training period, participants were asked how much they liked the training programme on a 1-10 rating scale. YH rated 10/10; SY rated 8/10 and YC rated 7/10. Participants were also asked about their favorite training task. All participants chose the task of " Frog Jumping over Stones and Lotus Leaves" . They reported enjoying the lively presentation of the task. Two of the participants also stated they would like to take the training again.

Table 2

Means and SDs of the scores on the ADHD symptoms/problems

Questionnaires administered / Time phase	Baseline		After training		Follow up	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
DSM-IV-TR						
Inattention#	6.67	0.76	5.67	0.57	5	1.73
Hyperactivity/Impulsivity#	4	4.58	3.33	4.04	6.33	1.15
Home Situation Questionnaire						
No. of problems identified*	10.5	3.12	11.33	3.5	8.5	0.85
Mean severity&	4.69	1.99	4.07	1.92	4.85	1.62
School Situation Questionnaire						
No. of problems identified+	5.83	4.37	6	3.6	4	4.2
Mean severity&	2.47	1.82	2.37	1.2	2.2	1.3
Academic Performance Inventory^	2.5	0.96	2.89	0.64	2.37	0.32

range =0-9; * range =0-16; & range =1-9; + range =0-12; ^ range =1-5, 1= not good at all, 5 = very good

Behavioral measures

Rating of ADHD symptoms. In the parent rating of ADHD symptoms (according to DSM-IV-TR), there was no significant change for either inattention [$t(2)=2$, $p=0.184$] or hyperactivity/impulsivity score [$t(2) = 1.89$, $p=0.199$] before and after training (Table 2).

Rating of problem behaviors at home and in school. At home, parents' rating did not change considerably before and after training [$t(2) = -0.640$, $p=0.588$]. This also applied to school situation [$t(2) = -0.122$, $p=0.914$] and academic performance [$t(2) = -1.945$, $p=0.191$] as well except for participant YH, whom the teacher's rating for his school behavior and academic performance showed positive changes after training.

Discussion

This pilot study evaluated ADHD children's acceptance toward and the effect of an intensive computerized working memory training programme developed for local use. The training procedure was well-accepted by the participants. They reported enjoying the presented tasks and the intrinsic rewards of advancing to higher challenges and successfully completing the tasks.

The results of the present study demonstrated significant improvements in verbal and visuospatil working memory after training. The computerized working memory training gradually increased the amount of information that the participants could keep in working memory. Moreover, increased performance was seen for both trained (i.e., the digit span backward task) and non-trained (i.e., the span board backward task) working memory tasks, showing that the training effect was generalized to other non-trained stimuli. The current results also demonstrated that the improvements in working memory were maintained at a 5-week follow-up. Thus, the present findings converge with previous demonstrations that systematic working memory training is able to enhance working memory capacity (e.g. Klingberg et al., 2002; 2005). This supports the effectiveness of the working memory training programme developed by the authors for local usage.

By contrast, the improvement with the outcome measure on inhibition (i.e. Stroop task, interference score), a more basic cognitive function, was not significant. The aforesaid score measures the ability to inhibit a prepotent response, which is often found to be impaired among ADHD children (Barkley, 1997; 2006). Meanwhile, there is a suggestion that deficit in nonverbal working memory among ADHD children underlies their deficit in inhibition ability (Barkley, 1997). In addition, there are studies showing that visuospatial working memory and response inhibition share the same cortical areas, i.e. the superior part of the prefrontal cortex and the parietal cortex (Duncan & Owen, 2000; Klingberg, Forssberg, & Westerberg, 2002; McNab et al, 2009; Prabhakaran, et al., 1997). However, the present results failed to show the improvement in the nonverbal working memory had a significant impact on the inhibition performance. This is in line with Rueda et al.'s (2005) results, who also failed to find a significant effect of attention training on a flanker-like task, which measures a similar construct as the Stroop task. Thus further study to elucidate the relationship between cognitive inhibition and working memory is needed.

Meanwhile, the findings revealed that, despite the improvements in working memory capacity of the participants, the working memory training had no effect on parent or teacher's ratings of the children's ADHD symptoms or problems. Therefore, there was a lack of positive cascading effect from working memory improvements to ADHD behaviours. In fact, among the existing studies, there is only one study that reported improved parent-rated ADHD symptoms after computerized working memory training (Klingberg et al., 2005). Apart from not supporting the proposition that working memory improvements would ameliorate ADHD symptoms, the present results also question the central role of working memory in ADHD symptoms. Thus further studies to elucidate the interactive relationship between working memory and ADHD behaviours are needed.

Limitations

The present study results demonstrated the working memory of children with ADHD could be significantly improved with a locally developed computerized working memory training programme. However, the improvements in working memory were not associated with any significant change in ADHD symptoms and problems. Given the small number of subjects (N=3) and the lack of a control group, the results of the present study should be taken with caution. Further randomized control studies are needed to confirm the findings of the present study.

Acknowledgement

We are very grateful to Mr. Zhao Qiguang for his generous technical help in constructing the computerized training programme for the study. Thanks are also due to the participants, their parents and teachers who took part in this pioneer work.

摘要

工作記憶電腦訓練與過度活躍症

工作記憶是一種在短時間內對信息進行儲存與加工的能力。它對許多高層的認知能力有著很重要的影響。工作記憶能力在患有過度活躍症的孩子中有不同程度的缺失，但兩者之間的關係在目前還不是很清晰。近期的研究發現工作記憶的容量可以透過高強度及有系統的訓練去擴充。本實驗專爲本地學齡兒童設計了一套工作記憶訓練軟件， 並針對其對工作記憶與過度活躍行爲的改變進行研究。三名患有過度活躍症的學童參與是項研究。他們於訓練前，完成訓練時及跟進時（五星期後）均接受評估。研究發現，參與訓練後，學童的工作記憶容量有顯著提高，這個進步在訓練結束後的五個星期後依然保持。但是，學童的過度活躍行爲沒有明顯改變。最後本文討論了研究結果對工作記憶訓練及過度活躍症治療的啓示。

References

Baddeley, A. D. (1992). Working memory. *Science, 255, 556-559.*

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience, 4,* 829–839.

Baddeley, A. D. (2007). *Working memory, thought, and action.* New York: Oxford University Press.

Baddeley, A. D. & Hitch, G. J. (1974). Working memory. In G. A. Bower (Ed.), *Recent Advances in Learning and Motivation* (pp. 47–89). New York: Academic Press.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive function:Constructing a unified theory of ADHD. *Psychological Bulletin, 121,* 65−94.

Barkley, R. A. (2006). *Attention-deficit hyperactivity disorder: A handbook for diagnosis and treatment,* 3rd Edition. New York: Guilford Press.

Barkley, R. A. & Murphy, K. R. (1998). *Attention-Deficit Hyperactivity Disorder: A Clinical Workbook.* (2nd Edition). New York: The Guilford Press.

Castellanos, F. X. & Tannock, R. (2002). Neuroscience of attention-deficit/hyperactivity disorder: the search for endophenotypes. *Nature Reviews Neuroscience, 3,* 617-628.

Duncan, J. & Owen, A.M. (2000). Common regions of the human frontal lobe recruited by diverse cognitive demands. *Trends in Neuroscience, 23,* 475-483.

Gathercole, S. E. & Alloway, T. P. (2008). *Working Memory and Learning: A Practical Guide for Teachers.* London: Sage.

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, 1−16.*

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

Hitch, G. J., Towse, J. N. & Hutton, U. (2001). What limits children's working memory span? Theoretical accounts and applications for scholastic development. *Journal of Experimental Psychology: General, 130,* 184–198.

Hockey, A. & Geffen, G. (2004). The concurrent validity and test-retest reliability of a visuospatial working memory test. *Intelligence, 32,* 591–605.

Hong Kong Government, Education Department & Hong Kong Psychological Society (1981). *HK-WISC.* Hong Kong Government Printer.

Kerns, K. A., Eso, K. & Thomson, J. (1999). Investigation of a direct intervention for improving attention in young children with ADHD. *Developmental Neuropsychology, 16,* 273-295.

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., Gillberg, C. G., Forssberg, H. & 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.

Klingberg, T., Forssberg, H. & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology, 24,* 781−791.

Lezak, M. D., Howieson, D. B., Loring, D. W., Hannay, H. J. & Fischer, J. S. (2004). *Neuropsychological Assessment.* New York: Oxford University Press.

Martinussen, R., Hayden, J., Hogg-Johnson, S. & Tannock, R. (2005). A metaanalysis of working memory impairments in children with attention-deficit/ hyperactivity disorder. *Journal of American Academy of Child and Adolescent Psychiatry, 44,* 377−384.

McNab, F., Varrone, A., Farde, L., Jucaite, A., Bystritsky, P., Forssberg, H. & Klingberg, T. (2009). Changes in cortical dopamine D1 receptor binding associated with cognitive training. *Science, 323,* 800-802.

Miller, G. A. (1956). The magical number seven, plus-or-minus two or some limits on our capacity for processing information. *Psychological Review, 63,* 81-97.

Olesen, P. J., Westerberg, H. & Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience, 7,* 75-79.

Parker, H. C. (1992). *ADAPT: Attention deficit accommodation plan for teaching teacher accommodation planbook.* Impact Publications.

Phillips, C.J. & Nettelbeck, T. (1984). Effects of practice on recognition memory of mildly mentally retarded adults. *American Journal of Mental Deficiency, 88,* 678-687.

Prabhakaran, V., Smith, J.A., Desmond, J.E., Glover, G.H. & Gabrieli, J.D. (1997). Neural substrates of fluid reasoning: An fMRI study of neocortical activation during performance of the Raven's Progressive Matrices Test. *Cognitive Psychology, 33,* 43-63.

Rainer, G. & Miller, E.K. (2000). Effects of visual experience on the representation of objects in the prefrontal cortex. *Neuron, 27,* 179–189.

Rapport, M. D., Chung, K. M., Shore, G. & Isaacs, P. (2001). A conceptual model of child psychopathology: Implications for understanding attention-deficit/hyperactivity disorder (ADHD) and treatment efficacy. *Journal of Clinical Child Psychology – Special Edition, 30,* 48–58.

Rueda, M. R., Rothbart, M. K., McCandliss, B. D. & Posner, P. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences, 102,* 14931-14936.

Süβ. H-M., Oberauer, K., Wittmann, W. W., Wilhelm, O. & Schulze, R. (2002). Working-memory capacity explains reasoning ability—and a little bit more. *Intelligence 30,* 261–288.

Wechsler, D. (1981). *WAIS-R Manual.* New York: The Psychological Corporation

Westerberg, H. & Klingberg, T. (2007). Changes in cortical activity after training of working memory – a single-subject analysis. *Physiology & Behavior, 92,* 186-192.

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V. & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry, 57,* 1336–1346.