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Association between Abacus Training and Improvement in Response Inhibition: A Case-control Study

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Objective: The abacus, first used in Asian countries more than 800 years ago, enables efficient arithmetic calculation via visuo-spatial configuration. We investigated whether abacus-trained children performed better on cognitive tasks and demonstrated higher levels of arithmetic abilities compared to those without such training.
Methods: We recruited 75 elementary school children (43 abacus-trained and 32 not so trained). Attention, memory, and arithmetic abilities were measured, and we compared the abacus with the control group.
Results: Children who had learned to use an abacus committed fewer commission errors and showed better arithmetic ability than did controls. We found no significant differences between children with and without abacus training in other areas of attention.
Conclusion: We speculate that abacus training improves response inhibition via neuroanatomical alterations of the areas that regulate such functions. Further studies are needed to confirm the association between abacus training and better response inhibition.

KEY WORDS: Cognitive science; Attention; Inhibition; Child; Mathematics.

INTRODUCTION

The abacus is a unique traditional arithmetic tool that has been used in Asian countries such as Korea, Japan, China, and India since 1200 AD.[1,2] Arithmetic calculations are performed by altering the configurations of beads that represent numbers (Fig. 1). Several studies have reported improvements in the arithmetic ability of subjects trained to use an abacus. For instance, Hatano and Osawa[3] reported that elementary school children trained to use an abacus performed significantly better on tests of calculation speed and accuracy compared with those who were not so trained. Most studies of arithmetic ability have measured the ability to perform simple calculations, such as addition and subtraction, among subjects not trained to use an abacus, whereas trained abacus users can perform complicated arithmetic calculations, including multiplication and division.[4]

In terms of other cognitive functions, previous studies have focused primarily on memory[2,5,6] and general intelligence[7]; other cognitive domains, such as attention, have not been evaluated in children and adolescents trained to use an abacus. Because attention may serve as the neurocognitive basis for better memory and intelligence, this may be another important cognitive domain influenced by abacus training. It has been established that attention is crucial in terms of academic achievement.[8] Attention deficit/hyperactivity disorder (ADHD), for example, is one of the most common neuropsychiatric disorders in childhood, with an estimated prevalence of 5.3-9.5%.[9,10] Previous studies have indicated that attentional problems in such children are associated with poor academic achievement in areas such as reading, writing, and calculation,[11,12] suggesting the existence of a common neurocognitive substrate for these cognitive domains. Despite the substantial impact of attention on academic achievement and children's school adjustment, pharmacological treatment has been reserved for those ADHD children with severe and uncontrolled symptoms.[13] Thus, children with moderate or mild atten-

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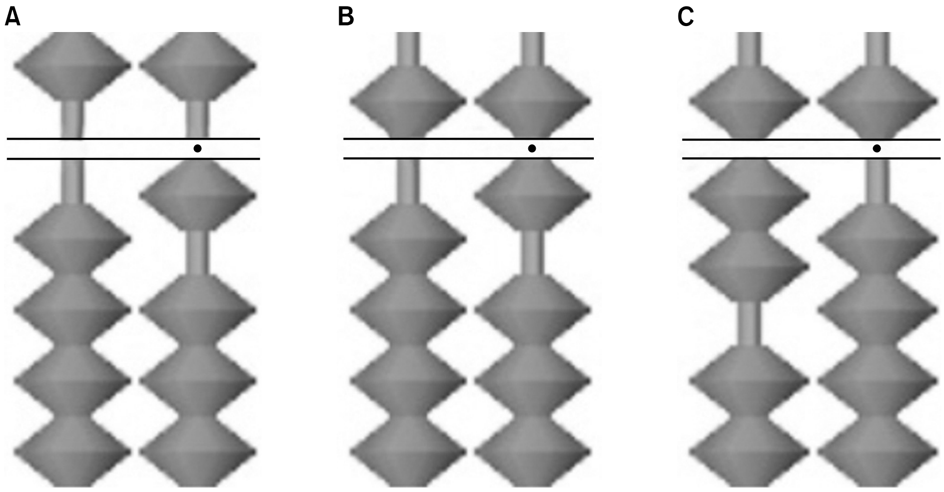

Fig. 1. Introduction to the abacus, and the calculation procedure. (A) The number one (1) as represented on an abacus. The abacus calculator employs the decimal system from right to left; each positional number is shown by the location of a bead. Each bead in the upper deck has a value of five, and each bead in the lower deck a value of one. When counted, beads are moved toward the horizontal bar that separates the two decks. (B, C) The procedure for calculating 56+19 on the abacus. Here, 56+19 is changed to 56+(20−1) to simplify the calculation. The calculation requires pushing two beads in the lower deck of the second row upward (+20) and one bead in the lower deck of the first row downward (−1).

tional or hyperactive-impulsive symptoms, and impaired academic performance, may not receive pharmacotherapy, and may be left entirely untreated. Hence, it is important to develop and encourage alternative modalities that may be helpful for improving attention in children and adolescents.

This study aimed to investigate attention as well as comprehensive arithmetic abilities and memory in children who were trained to use an abacus. To the best of our knowledge, this is the first study to examine the possible role of abacus training in comprehensive cognitive functions.

METHODS

Subjects

The sample, which was recruited via local advertising, consisted of elementary school students without psychiatric disorders, including mood, anxiety, psychotic, substance abuse, developmental, or behavioral disorders, as assessed using the Korean version of the Kiddie Schedule for Affective Disorders and the Schizophrenia-Present and Lifetime Version (K-SADS-PL),[14] and the Diagnostic and Statistical Manual of Mental Disorders, fourth edition (DSM-IV). All children had intelligence quotients (IQs) above 80. All diagnostic procedures were conducted by experienced psychologists and supervised by board-certified child and adolescent psychiatrists.

All abacus-trained children were above the seventh level of abacus use, as certified by the International Abacus and Arithmetic Association. Individuals who are certified above the seventh level can perform multiplication as well as addition and subtraction. Control subjects had no experience with an abacus.

The study protocol was fully explained to the children and their legal guardians (parents or caregivers). All participants and guardians provided informed consent. The Institutional Review Board of the Soonchunhyang University Bucheon Hospital approved this study (SCHBC-IRB-10-07), which was conducted in a manner adherent to the Declaration of Helsinki as revised in 1989.

Instruments

Arithmetic abilities: Korea Institute for Special Education–Basic Academic Achievement Tests: Math (KISE–BAAT: Math)

The KISE-BAAT: Math instrument is widely used to assess the mathematical ability of children in Korea.[15] The KISE-BAAT: Math addresses abilities related to numbers, figures, calculations, measurement, probability and statistics, and problem-solving. Scores on the six subtests are standardized to a mean (standard deviation, SD) of 50 (15). Higher scores represent better arithmetic abilities.

Attention: Comprehensive Attention Test (CAT)

The CAT measures visual selective attention, auditory selective attention, sustained attentional response, inference selective attention, and spatial working memory.

The scores are standardized based on normative data from 912 children and adolescents in Korea.[16] Four measures (omission errors, commission errors, mean reaction times, and response-time variability) are estimated for the six subtests. The results are presented as attention quotients (AQs) based on age- and sex-matched normative data. The mean (SD) of the AQ is 100 (15). AQ scores below 76 (representing 1.6 SD from the mean) are regarded as reflecting low attention, scores between 76 and 85 (representing 1.0-1.6 SD from the mean) borderline attention, and scores above 85 (within 1.0 SD) normal attention.

Visuospatial working memory: Finger Windows Test

The Finger Windows Test is a subtest of the Wide Range Assessment of Memory and Learning 2 (WRAML-2).[17,18] In the forward version, participants are required to reproduce the sequence, whereas they are required to reproduce the sequence in reverse order in the backward version. The number of sequences was increased by one every trial. One point was given for each correctly recalled sequence, and each trial was discontinued after three consecutive errors.

Verbal and auditory working memory: Digit Span task

The Digit Span task, perhaps the most widely used instrument for assessing verbal and auditory working memory, was adapted from the Korean Wechsler Intelligence Scale for Children, third edition (K-WISC-III).[19,20]

Statistical Analysis

Demographic data were compared using independent *t*-tests for continuous variables and chi-squared tests for dichotomous variables; we compared children with and without a history of abacus training. Cognitive functions, including arithmetic abilities, attention, and memory, were analyzed by analysis of covariance (ANCOVA), adjusted for grade. A two-tailed p-value <0.05 was considered statistically significant. All statistical analyses were performed with the aid of the Statistical Package for Social Sciences, version 16.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Subjects

Seventy-five elementary school students were recruited for participation in this study. Of these, 43 were trained to use an abacus, and 32 were not. Detailed data on participants' demographic characteristics are presented in Table 1. We found no significant differences with regard to age, gender, or grade between the two groups.

Neurocognitive Functions

In terms of arithmetic abilities, children trained to use an abacus performed significantly better in the number and calculation subtests (Table 1). We found no significant differences between the two groups with respect to figures, measurement, probability and statistics, or problem-solving. In terms of attentional testing, abacus-trained children committed fewer commission errors in tasks requiring sustained attention inhibition and selective inference attention. No significant differences between children with and without abacus training were found in other areas of attention. Additionally, children with and

Table 1. Comparison of cognitive functions between abacus-trained children and controls

Variable	Abacus (n=44)	Controls (n=32)
Age (yr)	9.28 (1.28)	9.09 (1.38)
Sex (female)	24	14
Grade	3.67 (1.17)	3.50 (1.37)
KISE-BAAT: Math		
Number*	13.98 (1.92)	12.93 (2.42)
Whole number	20.90 (2.12)	21.50 (3.09)
Fractional number and prime number	7.90 (3.48)	6.53 (4.02)
Proportion and percentage	1.90 (2.12)	1.93 (1.89)
Figure	12.98 (2.22)	12.50 (2.56)
Calculation*	13.54 (2.84)	12.10 (3.19)
Addition*	14.56 (2.50)	13.23 (3.27)
Subtraction*	13.73 (2.79)	12.30 (3.91)
Multiplication*	13.29 (3.57)	11.30 (5.34)
Division†	11.61 (4.02)	9.30 (5.13)
Mental arithmetic‡	12.15 (3.10)	8.87 (4.35)
Measurement	13.34 (2.07)	12.87 (2.19)
Measurement	16.24 (4.02)	14.70 (4.33)
Time and currency	14.29 (2.29)	13.87 (3.42)
Estimation	9.59 (3.56)	8.67 (3.98)
Probability and statistics	14.17 (2.39)	13.90 (2.17)
Problem solving	13.98 (2.52)	12.93 (2.86)
CAT		
Commission error		
Visual selective attention	102.28 (15.33)	98.78 (14.05)
Auditory selective attention	108.44 (7.82)	109.63 (5.68)
Sustained attention response*	103.09 (15.10)	95.30 (17.55)
Inference selective attention*	100.58 (13.90)	93.16 (17.26)
FWT		
Forward	16.52 (2.34)	15.63 (3.49)
Backward	12.88 (4.24)	13.41 (3.58)
Digit span task		
Forward	10.83 (2.76)	11.33 (3.04)
Backward	7.10 (2.42)	6.70 (2.87)

All data are presented as mean (standard deviation).
KISE-BAAT: Math, Korea Institute for Special Education-Basic Academic Achievement Tests: Math; CAT, Comprehensive Attention Test; FWT, Finger Windows Test.
$^*p<0.05$, $^\dagger p<0.01$, $^\ddagger p<0.001$.

without abacus training performed similarly in tasks assessing auditory and visuospatial memory.

DISCUSSION

This study was designed to determine whether children trained to use an abacus differed from controls in terms of cognitive functioning. As expected, given that the essential purpose of the abacus is to increase calculating ability, children trained to use an abacus performed better in arithmetic tasks than did controls. Additionally, abacus-trained children committed fewer commission errors, suggesting that they exhibited better response inhibition. Children who learn and use an abacus may subsequently use a "mental abacus" (i.e., they may imagine manipulating an abacus through visual representation, mainly in the parietal lobe).

Response inhibition is regulated primarily in the orbitofrontal and dorsolateral prefrontal cortices, which have various neural network connections with the temporal and parietal lobes.[21-23] The right inferior frontal gyrus, which has been consistently associated with abacus training, is the main brain structure involved in response inhibition.[22] Several studies have suggested that the brain areas involved in abacus training and use are closely associated with the inferior and posterior superior parietal cortices.[24,25] Additionally, abacus experts exhibit distinct neural correlates in the fronto-temporal and fronto-parietal lobes.[26] A recent neuroimaging study reported that the inferior parietal and right prefrontal cortices were activated during response inhibition.[27] Another study revealed that posterior and inferior parietal lobe activity was positively correlated with response inhibition in adolescents with a restrictive type of eating disorder.[28]

The possible neural mechanisms by which abacus training improves neurocognitive functions, including response inhibition, may feature neurogenesis and synaptic plasticity. Some evidence suggests that mental training, such as abacus training, can change brain structures and induce neuroplasticity.[29] Repeated practice and learning may trigger various neuroanatomical changes, such as neurogenesis, gliogenesis, and synaptic plasticity,[30-32] which, in turn, enhance neurocognitive functioning. Hence, we speculate that repetitive and sustained abacus training leads to neuronal changes in the frontal and parietal lobes, which, in turn, improve arithmetic ability and response inhibition.

Although our study did not replicate this finding, several previous studies reported that working memory was significantly better in abacus-trained children compared with controls.[2,3,33] For example, Irwing *et al.*[7] reported that children trained to use an abacus scored approximately 7 points higher on IQ tests than did controls, and abacus-trained children performed better in visual and auditory working memory tasks,[2] and had better visuo-spatial working memory, compared with controls.[6] Although we cannot fully explain these among-study differences, the age, duration of training, and skill level of abacus-trained children may have contributed to the observed discrepancies.

Our study has several limitations. First, because this study employed a case-control, cross-sectional design, we could not demonstrate possible changes in cognitive function during the abacus-training process. Second, we included only healthy controls. Given that response inhibition may be improved by abacus training, clinical trials including patients, such as individuals with ADHD, are needed. Third, the neural substrate responsible for the differences in cognitive functioning between abacus-trained children and controls was not investigated. Fourth, the sample size was insufficient to completely prevent type I errors caused by multiple comparisons. Additionally, we could not set an *a priori* effect size and statistical power. Upon *post hoc* power analysis of the sustained attention response and inference selective attention, which yielded the principal findings in this study, the effect sizes were 0.48 and 0.47, respectively. The statistical powers for identification of sustained attentional responses and inference selective attention were 0.525 and 0.521, respectively. Finally, it is possible that selection bias affected our sample. Students who are good at mathematics may also have an interest in the abacus, which requires mathematical ability.

In summary, we found that abacus training may improve attention and comprehensive arithmetic abilities in children. Our results may be applicable in clinical practice as well as in education. Although it is premature to directly apply our results to children with psychiatric diagnoses such as ADHD, non-pharmacological interventions, such as abacus training, may be an option for children with cognitive problems, as issues of safety versus efficacy are major concerns when pharmacological treatment for children is contemplated.[34] Future comparative studies using large samples and prospective designs should be conducted to more precisely evaluate the possible role of abacus training in the neurocognitive functioning of children.

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