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The Effects of Training on Children's Addition Performance

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The present study was designed to examine whether extensive training would alter the processes underlying young children's addition performance from reconstructive processes to automatic retrieval of facts. Children in the second grade were trained until their mean response times and errors on an addition verification task were equal to those of children in the sixth grade. Before and after training, automatic retrieval was assessed with number naming and number matching tasks. The effect of training on retrieval processes was evaluated by comparing changes in retrieval processes for children who were trained and who were not. The effect of training was very systematic on overall response times. On the verification task, mean response times decreased significantly over training sessions. Similarly,on the number matching and number naming tasks, mean response times decreased significantly after training. However, training on the addition verification task did not significantly affect the retrieval of addition knowledge. On the number matching task, addition knowledge was retrieved automatically in the experimental group as indicated by a significant probe effect. However, the effect of probe did not vary either with test or stimuli. In contrast, the control group did not show a significant effect of probe. These results imply that automatic retrieval observed in the experimental group is not due to training per se, but due to other factors associated with the experimental group. A similar result was obtained from the number naming task. A fairly constant magnitude of facilitation was observed at most SOAs. However, this effect of probe was not modified by group, test and stimuli as in the matching task, implying that addition training did not affect the effect of probe.

Developmental changes in the process underlying simple arithmetic performance have been the focus of intensive investigation for several years. The result of this work is evidence of qualitative differences in children's and adults' arithmetic performance. That is, adults' performance is primarily based on retrieval, whereas children's performance relies primarily on reconstructive processes. The developmental transition from reconstructive processes to retrieval is thought to occur around grade 3 (Ashcraft, 1982 ; Kaye, 1986 ; Kaye, Post, Hall, & Dineen, 1986).

Although extant models of mental addition focus on a single transition-from reconstruction to retrieval-another transition is plausible. After retrieval becomes a dominant strategy, further development might cause retrieval to become automatic, resulting in two developmental phases : one of nonautomatic retrieval and a second of automatic retrieval.

Automatic retrieval of arithmetic facts, especially addition facts, has been intensively investigated with both children and adults. Automatic retrieval has often been assessed with a version of Stroop task or a version of priming task. For example, in a cross-operation confusion paradigm, multiplication problems are presented with three kinds of lures: a correct answer, an incorrect answer, and an associative answer that is the sum of the multipliers (e.g., $4 \times 3 = 7$). Subjects decide whether the equation is true or false. If the sum of the presented problem is activated in the multiplication problem, then it would be more difficult to reject the associative answer. Consequently, subjects would be slower to rejec the associative answer than to reject the incorrect answer. Thus, in this paradigm, automatic retrieval of addition facts is measured by its interference with multiplication.

Winkelman and Schmidt (1974) were the first to study the associative confusion effect. Associative answers were rejected about 50ms slowly than nonassociative answers. This result was replicated by Zbrodoff and Logan(1986) and Park, Babu,and Kail(1988). Zbrodoff and Logan examined problems involving all possible pairs of the digits from 1 to 9 as multiplicands. Here associative lures were rejected 48ms more slowly than nonassociative lures. However, the confusion effect was much larger(85ms) than those from the previous two studies when the number pairs consisted of only small numbers (i.e., the pairs whose sums are less than 11)(Park et al., 1988). These results imply that in adults, addition knowledge is automatically retrieved even in an irrelevant condition (e.g., multiplication).

Stronger evidence of automatic retrieval can be provided by showing the time course of interference effect. If the interference is due to the automatic activation of addition knowledge, then interference would decrease or disappear with time because automatic activation decays very rapidly(Neely,1977). LeFevre, Bisanz,& Mrkonjic (1987) conducted a study in which delay between the onset of addition problems and the onset of probes (stimulus onset asynchrony or SOA) varied. In this study, an addition problem was presented, followed 60 to 480ms later by one of three kinds of probe:a sum, one addend of the addition problem, or a neutral probe that was unrelated to the addition problem (i.e., neither a sum nor an addend). Subjects decided whether or not the probe was in the preceding problem. Sum probes were rejected more slowly than neutral probes. Moreover, the difference in the response latency was significant only at a short delay (i.e., 120ms), indicating that the interference from the activated sum is most pronounced at a short delay and disappears at long delays.

In a related study (Pilon, LeFevre, & Bisanz, 1987), automatic retrieval was assessed in terms of facilitation. The general precedure was quite similar to that of the number matching task from LeFevre at al's study except that subjects were asked to name the probe.The probe was the sum on the half of the trials and the number unrelated to a given problem on the other half of the trials.The addition problem was followed after one of several SOAs (60, 120, 180, 240, and 480ms) by the probe. The sum probe was named significantly faster than the neutral probe at all SOAs. However, the largest facilitation effect was observed at the shortest SOA.

In summary, across disparate research paradigms, it has been consistently found that retrieval of addition facts is quite automatic in adults as indicated by slower rejection and faster naming of related false answers relative to unrelated ones. Further, it has also been shown that facilitation and interference effects are larger at the short delay, suggesting that these effects are the result of automatic retrieval.

These same paradigms have been used to investigate automatic retrieval of arithmetic facts in children (Findley, 1978; Hamann & Ashcraft, 1985 ; Park, Babu, & Kail, 1988 ; LeFevre & Bisanz, 1987). LeFevre and Bisanz (1987) studied children in grades 2 and 6 with the number matching task. SOAs varied from 120 ms to 960ms. For children in grade 2, response times on sum and neutral probes did not differ significantly, regardless of delay. LeFevre and Bisanz interpreted this to mean that sums of addition problems are not activated automatically in this age group. At grade 6, sum probes were rejected more slowly than neutral probes. As was found in adults, the difference in the latency was significant at the SOAs of 120 ms and 180 ms even though the interaction between probe and SOA was not significant. This result suggests that addition facts are retrieved automatically around grade 6. In contrast, Park et al. (1988) found automatic retrieval of addition facts for children in grades 3 and 4. The cross-operation confusion paradigm was used. Associative lures (i.e., sums) were rejected 223 ms more slowly than neutral lures. This result suggests that addition facts are retrieved automatically from the middle elementary school years.

Thus, there is evidence indicating a transition to automatic retrievel of addition facts in grades 3 and 6, but not grade 2. If we assume that children in grade 2 use nonautomatic retrieval to solve many addition problems (rather than counting), this would suggest a three phase model of development, from reconstruction, to retrieval, to automatic retrieval. Note, however, that a common mechanism is thought to be responsible for these changes : the development of strong representations of addition facts (Ashcraft, 1987 ; Kaye, 1986 ; Siegler & Shrager, 1984). That is, more frequent exposure to a problem and a corresponding answer produces stronger association. For very young children (and for older children and adults for problems involving large addends, e.g., 15 + 38 = ??), associations are so weak that a retrieved answer never exceeds the confidence criterion, which means that other strategies are always used. Subsequently, associations are strengthened so that the answer, though not necessarily selected on the first retrieval attempt, will be chosen before retrieval is abandoned (i.e., before the search length parameter is exceeded). As associations are strengthened further, the correct answer will routinely be retrieved first, which would define the phase of automatic retrieval of addition facts.

A more direct way to assess the role of associative strength on children's performance on addition problems would be to provide massive amount of practice with different problems. That is, extensive presentation of problems with the correct answer should increase the associative strength of that answer so that, in Siegler's terms, the correct answer would have the greatest associative strength and the associative strength would be above the confidence criterion. As a result, trained addition problems are more likely to be solved viaautomatic retrieval rather than a conscious algorithm or nonautomatic retrieval after training.

Thus, the present experiment was designed to determine whether massive amount of addition training can lead to automatic retrieval of addition knowledge, where automatic retrieval is indicated by the interference and facilitation effect described earlier.

METHOD

Subjects

Thirty two children in grade 2 (16 boys and 16 girls) and thirty six children in grade 6 (18 boys and 18 girls) participated. These two age groups were selected because it has found that retrieval of addition facts is automatic in the sixth graders, but not in the second graders (LeFevre & Bisanz, 1987).

These children were recruited through advertisement. Most children were from the middle class families in Lafayette and West Lafayette areas. Parental consent was obtained for all children before the experiment started.

Design

This study used the pretest and posttest experimental and control group design. Thus, there were 4 different groups of children: one criterion group, one experimental group, and two control groups, one from each grade level. 20 children in grade 6 were assigned to the criterion group. This group was included only to provide criteria of training for children in the experimental group and were not included in the main experiment. These children were tested only once with an addition verification task before the main experiment started.

Half of the children in grade 2 were randomly assigned to the experimental group. The remaining second graders and sixth graders were assigned to the control groups. The second grade control group was included to examine the impact of addition taining on retrieval of addition facts. The sixth grade control group was included to evaluate developmental changes in retrieval processes. There was an equal number of boys and girls in each group.

All children in three groups were tested with the number matching and the number naming tasks as a pretest. Following the pretest, childen in the experimental group were trained to verify simple addition problems until they reached the performance of the sixth graders in the criterion group. Then, they were tested again with both tasks as a posttest. Children in the control groups were tested only with pre- and posttests.

Stimuli

The stimuli for number matching and number naming tasks are presented in Table 1. with corresponding probes. For the matching task, ten problems from the leftmost column were paired with three kinds of probes: a sum, a neutral probe, and one addend of the problem (i.e,. the probe from the pair-control condition in Table 1). The other 10 problems were paired only once with one addend of the problem (i.e., the probe from the probe-control condition in Table 1). Trials with sum probes were included to measure the extent to which the sums are automatically activated. Trials with neutral probes were included to provide a baseline to evaluate automatic activation of addition knowledge.

The probe-control and pair-control conditions were included to have the same number of "yes" and "no" responses. 40 problem pairs in Table 1

Table 1. Problem Sets for Pretest, Posttest and Training

Problems	Sum	Neutral	Pair Control	Probe Control	Problems
1+2	3	6	1	6	1+6
1+3	4	7	3	7	7+3
2+1	3	6	2	6	2+6
2+4	6	9	4	9	9+4
2+5	7	4	5	4	4+8
3+1	4	7	3	7	3+7
4+2	6	3	2	3	3+2
5+1	6	3	5	3	5+3
5+2	7	4	2	4	4+1
5+4	9	6	5	6	5+6

were presented five times across four different blocks of 50 trials, once at each of 5 SOAs (120, 180, 240, 480, and 960 ms).

Stimuli for the number naming task were the 10 addition problems used in the number matching task (i.e., problems from the leftmost column in Table 1) and 20 single digit numbers as probe numbers. Addition problems were paired once with two kinds of probes: a sum and a neutral probe. The probe control and the pair control conditions were not included in this task. 20 problem pairs were presented five times, once at each SOA.

The 10 problems presented in the leftmost column of Table 1 were used to prepare the stimuli for the addition verification tasks for the criterion and the experimental groups. For the criterion group, all 10 problems were paired with a correct answer and an incorrect answer.

For the experimental group, 10 problems were divided into two sets of 5 problems. Set 1 consisted of the problems 1 + 2, 2 + 1, 2 + 4, 5 + 1, and 5 + 2. Set 2 consisted of the problems 1 + 3, 2 + 5, 3 + 1, 4 + 2, and 5 + 4, With each set of 5 problems, 10 different lists of training stimuli, each consisting of 100 problems, were constructed. Within each list, each problem was paired with a correct answer on the half of the trials and with incorrect answers on other half of the trials.

Procedures

Pretest and Posttest. The pretest was administered for two days and so was the posttest. Within each day, children were tested with both number matching and number naming tasks. The order of two tasks was counterbalanced across subjects.

Each child was tested individually in a quite room. The experiment was controlled by an IBM personal computer. All instructions and stimuli were presented on the computer color monitor which was located about 70 cm from a child.

In the number matching task, each trial started with a warning signal. Four asterisks were presented in the center of the computer monitor for a second. Then, the warning signal was replaced by an addition problem, which was presented horizontally. This problem was again replaced by a probe number after one of following SOAs: 120 ms, 180ms, 240ms, 480ms, and 960ms. A probe was presented one line below the addition problem and remained on the screen until a child responded.

Instead of adding two numbers in the addition problem, children decided whether a probe digit was presented in an addition problem. They indicated their decision by pushing the joystick attached to the computer. Children were asked to respond as fast and accurately as they could. Auditory feedback was provided when the children's response was correct. A fifteen second break was provided after every 50 trials. The computer recorded errors and response times from the onset of the probe to the onset of subject's response.

The procedure for the number naming task was very similar to that of the number matching task. The only difference was that children read probe numbers into a voice key that was interfaced with the computer. Children were also asked to respond as fast and accurately as they could. As soon as a child read the probe number, the screen was cleared and the next trial started, a second later.

A 15 second break was given after 50 problems. Naming latency was measured from the onset of the probe number to the naming response. The experimenter recorded errors and trials on which the computer responded to extraneous sounds such as coughs.

Traing. 20 children in the sixth grade finished 100 addition problems to provide the criterion response times and error rates for the children in the experimental group. On each trial, an addition problem was presented in the center of the computer monitor with either a correct sum or an incorrect sum. Children decided whether each answer was correct or not for a given problem. They indicated their decision by pushing the joystick. They were asked to respond as fast and as accurately as they could. When the response was correct, the word "CORRECT" was presented on the monitor. The mean response times were 1493 ms and 1131 ms on the problem set 1 with movement of the joystick to the left side and to the right side as a correct answer, respectively. On the problem set 2, the mean response times were 1506 ms and 1128 ms. Overall error rate was very low(3%). Mean response times for two sets of problems were not different, $F(1, 16) < 1$.

Half of the children in the experimental group were trained with the problems in set 1 and other half with the problems in set 2 until s/he met the criteria in the following ways:(1) Mean response time averaged over five trained problems was the same or smaller than that of children in grade 6 ; and (2) Error rates equal to or less than those of the children in grade 6. Before each training session started, a child was informed of these criteria. Training for each day consisted of 200 trials, divided into 2 blocks of 100 trials. Within each block, a 15 second break was provided after 50 trials. At the end of each block, children were informed of their mean response times and error rates on a given block.

RESULTS

For the analyses reported here, the alpha level was set at 0.05. However, because effects involving probe were the focus of the study, Fs are reported for these effects when they approach significance ($p < .10$).

Number Matching Task

In the analyses of the number matching task, only data from the trials presented with the sum and neutral probes were analyzed because data from other trials (probe control and pair control conditions) are not relevant to the hypotheses under consideration .

Table 2. Mean Response Times(in ms) and Mean Error Rates(%) on the Number Matching Task for the Sixth Grade Control Group by Test, SOA, and Probe

	Pretest			Posttest		
SOA	Sum	Neutral	INT	Sum	Neutral	INT
120	752(9)	740(8)	12(1)	689(7)	649(7)	40(0)
180	937(8)	941(8)	-4(0)	884(5)	889(6)	-5(-1)
240	732(5)	700(6)	32(-1)	639(5)	624(5)	15(0)
480	722(8)	698(4)	24(4)	631(7)	629(4)	2(3)
960	677(7)	667(4)	10(3)	627(2)	628(3)	-1(1)

Note 1. INT indicates the interference effect. 2. Errors are presented in parentheses.

In the matching task, errors occured rarely(5%) and the error data typically followed the general pattern of the latency data. Thus, the analyses of errors will not be reported.

Analyses of Sixth Grade Control Group. In order to provide the baseline pattern of automatic retrieval, data from the sixth grade control group were analyzed. In this and all other analyses, extreme response times were excluded from the analyses if they were more than 2 times the mean response time for that condition. For each subject, ten mean response times were calculated for each test(pre-and posttests), one for each combination of SOA (120, 180, 240, 480 and 960 ms) and probe (sum and neutral probes). Mean response times and error rates are presented in Table 2. The interference effect was computed by subtracting mean response times on the neutral probe condition from mean response times on the sum probe condition.

These data were analyzed by 2(test) × 5 (SOA) × 2 (probe) analysis of variance with repeated measures on all variables. In the analysis of response times the main effects of test., $F(1, 15) = 6.45$, $MSe = 56669$, $p < .05$ and SOA, $F(4, 60) = 341.41$, $MSe = 2194$, $p < .01$, were significant. The average response was about 68 ms faster on the posttest than on the pretest. Response times increased from SOA 120 ms to 180ms and then decreased for all larger SOAs. The interaction between test and SOA was significant, $F(4,60) = 3.03$, $MSe = 1667$, $p < .05$. Response times decreased from the pre- to the posttest, significantly so at SOAs of 120, 240, and 480ms, $F(1,15) = 6.13$, $MSe = 15321$, $F(1, 15) = 9.19$, $MSe = 12388$, $F(1.15) = 7.95$, $MSe = 12793$, $p < .05$, respectively.

More importantly, the main effect of probe approached significance, $F(1, 15) = 3.94$, $MSe = 3199$, $p < .10$: The sum probe was rejected 13 ms more slowly than the neutral probe. The interaction between probe and SOA was not significant, $F(4.60) = 1.33$, $MSe = 1971$, $p > .10$. However, the effect of probe at each SOA was tested in order to compare the results with those from LeFevre and Bisanz's study(1987). As in that study, the effects of probe were significant at SOA 120 ms, $F(1,15) = 3.72$, $MSe = 2906$, $p < .10$ and 240ms, $F(1,15) = 5.25$ $MSe = 1661$, $p < .05$.

In summary, sum probes tended to be rejected more slowly than neutral probes at relatively short SOAs(i.e., 120 ms and 240 ms). These results imply that addition knowledge is automatically activated and interfered with the performance on the matching task in sixth graders.

Analyses of Second Grade Control and Experimental Groups. For each subject, twenty mean response times were calculated for each test, one for each combinations of stimulus set, SOA, and probe. Mean response times and mean error rates are presented in Table 3 and 4 for the ex-

Table 3. Mean Response Times (in ms) and Mean Error Rates(%) on the Number Matching Task for the Experimental Group by Test, Stimuli, SOA, and Probe

	Pretest					
	Trained Stimuli			Untrained Stimuli		
SOA	Sum	Neutral	INT	Sum	Neutral	INT
120	1465(9)	1414(9)	51(0)	1427(11)	1335(2)	92(9)
180	1520(4)	1488(6)	32(-2)	1651(7)	1530(7)	121(0)
240	1339(4)	1299(4)	40(0)	1315(4)	1423(4)	-108(0)
480	1311(6)	1327(5)	-16(1)	1262(6)	1335(4)	-73(2)
960	1220(3)	1196(4)	24(-1)	1218(2)	1224(4)	-6(-2)

	Posttest					
	Trained Stimuli			Untrained Stimuli		
SOA	Sum	Neutral	INT	Sum	Neutral	INT
120	831(2)	850(4)	-19(-1)	864(7)	833(5)	31(3)
180	1044(3)	1004(2)	40(1)	1139(7)	1049(2)	90(4)
240	808 (4)	765 (1)	43(3)	852(4)	854(2)	-2(2)
480	829 (3)	783 (4)	46(-1)	822(4)	806(2)	16(1)
960	827 (1)	748 (2)	79(-1)	795(4)	787(1)	8(3)

Table 4. Mean Response Times (in ms) and Mean Error Rates(%) on the Number Matching Task for the Control Group by Test, Stimuli, SOA, and probe

	Pretest					
	Trained Stimuli			Untrained Stimuli		
SOA	Sum	Neutral	INT	Sum	Neutral	INT
120	1436(3)	1495(4)	-59(-1)	1410(4)	1459(9)	-49(-5)
180	1521(7)	1566(8)	-45(-1)	1682(4)	1621(3)	61(1)
240	1330(5)	1339(4)	-9(1)	1349(6)	1390(4)	-41(2)
480	1365(3)	1341(3)	24(0)	1354(5)	1345(2)	9(3)
960	1297(2)	1286(4)	11(-2)	1219(2)	1237(2)	-18(0)

	Posttest					
	Trained Stimuli			Untrained Stimuli		
SOA	Sum	Neutral	INT	Sum	Neutral	INT
120	1404(11)	1359(7)	45(4)	1440(11)	1334(6)	106(5)
180	1534(12)	1551(7)	-17(4)	1609(7)	1562(9)	47(-1)
240	1347(9)	1282(6)	65(3)	1374(12)	1481(12)	-107(0)
480	1304(5)	1303(4)	1(1)	1302(10)	1332(9)	-30(1)
960	1318(4)	1298(6)	20(-2)	1268(6)	1482(7)	-214(-2)

perimental and control groups.

Prior to the main analysis of variance, data from the pretest were analyzed by 2(group) × 5(SOA) × 2(probe) analysis of variance with repeated measures on the last two factors to determine whether the two groups were comparable before training. No main effect was significant except the effect of SOA, $F(4,120) = 46.5$, $MSe = 43610$, $p < .01$. In particular, the group effect was not significant, $F(1, 30) < 1$, suggesting that mean response times were quite comparable in both groups before training started. Equally important, neither the effect of probe nor the interactions involving group and probe (i. e., group × probe and group × SOA × probe) were significant, Fs < 1.42. These results are quite consistent with LeFevre and Bisanz's (1987), which showed neither a significant effect of probe nor an interaction between probe and SOA in second grades.

To assess the effect of addition training, mean response times were subjected to 2(group) × 2(test) × 2(stimuli) × 5(SOA) × 2(probe) analysis of variance with repeated measures on last four factors. For mean response times, the main effects of stimuli, $F(1, 30) = 4.77$, $MSe = 44219$, $p < .05$, SOA, $F(4,120) = 71.72$, $MSe = 45276$, $p < .01$, group, $F(1, 30) = 6.24$, $MSe = 4117577$, $p < .05$, and test, $F(1, 30) = 23.8$ $MSe = 865456$, $p < .01$, were significant. Responses to the trained problems were 26 ms faster than to the untrained problems. Response times increased from SOA 120 ms to 180 ms and then decreased for all larger SOAs. The main effect of group and test was qualified by the significant interaction between these two factors, $F(1, 30) = 22.42$. $MSe = 865456$, $p < .01$. For subjects in the experimental group, responses during posttest were 501 ms faster than during pretest; for subjects in the control group, responses were 8 ms faster during posttest than during pretest.

The main effect of probe was not significent, $F(1, 30) < 1$. However, there was a significant interaction between probe and group, $F(1, 30) = 4.62$, $MSe = 20580$, $p < .05$. The sum probe was rejected 24 ms more slowly than the neutral probe only in the experimental group. Notably, within the experimental group, none of the interaction that would indicate an interference effect specific to training (viz. test × probe, test × SOA × probe, and test × stimuli × SOA × probe) were significant, Fs > 1.1

Concerning the effect of addition training, the effect of probe was significant only in the experimental group. However, the probe effect was not significantly altered by any variables (i.e., test and stimuli) associated with training. These results suggest that training per se did not contribute to automatic retrieval of addition knowledge, which was indicated by a significant probe effect.

Number Naming Task

In the analyses of the number naming task, data from all trials were analyzed because all trials were presented either with the sum or the neutral probes. Data were missing from 3% of the trials because extraneous sound(e.g., coughs) stopped the voice key prematurely and, very rarely, because subjects named digits incorrectly.

Analyses of Sixth Grade Control Group. Mean naming latenices for the sixth grade control group are presented in Table 5. A facilitation effect was computed by subtracting the mean response times on the sum probe condition from the mean response times on the neutral probe condition. Here, positive numbers indicate facilitation.

These data were analyzed by 2 (test) × 5(SOA) × 2(probe) analysis of variance with repeated measures on all factors. The main effect of test, $F(1, 15) = 40.79$, $MSe = 4993$, $p < .01$ and SOA, $F(4,60) = 564.41$, $MSe = 1557$, $p < .01$, were significant. As was found in the number matching task, the mean naming response was 50 ms faster on the posttest than on the pretest. Naming latencies increased from SOA 120 ms to 180 ms and decreased thereafter. The effect of probe approached significance, $F(1, 15) = 3.17$, $MSe = 2064$, $p < .1$: Sum probes were named about 10 ms faster than neutral probes. The interaction between probe and SOA also approached significance, $F(4, 60) = 2.09$, $MSe = 650$, $p < .1$. Faci-

Table 5. Mean Response Times(in ms) on the Number Naming Task for the Sixth Grade Control Group by Test, SOA, and Probe

	Pretest			Posttest		
SOA	Sum	Neutral	FAC	Sum	Neutral	FAC
120	653	644	-9	581	576	-5
180	871	873	2	813	840	27
240	615	624	9	561	577	16
480	608	616	8	547	568	21
960	577	589	12	546	556	10

Note. FAC indicates the facilitation effect.

litation was -7 ms, 14ms, 12ms, 14ms, and 11 ms at SOAs of 120, 180, 240, 480, and 960ms, respectively. Facilitation was fairly constant for all SOAs except 120ms. Even though the interaction between probe and SOA approached significance, it was not due to the gradual decay of automatic activation.

In summary, the sum probe tended to be named faster than the neutral probe, implying that the sum is automatically activated as a response to the addition problem. However, this conclusion was weakened by the fact that facilitation did not decrease with SOA.

Analyses of Second Grade Control and Experimental Groups. With this baseline pattern of facilitation in mind, data from the second graders were analyzed. Mean response times are shown in Tables 6 and 7 for the two groups. First, pretest data were analyzed by 2(group) × 5(SOA) × 2(probe) analysis of variance with repeated measures on the last two factors. Only the main effect of SOA was significant, $F(4,120) = 166.07$, MSe

Table 6. Mean Response Times(in ms) on the Number Naming Task for the Experimental Group by Test, Stimuli, SOA, and Probe

	Pretest					
	Trained Stimuli			Untrained Stimuli		
SOA	Sum	Neutral	FAC	Sum	Neutral	FAC
120	861	860	-1	862	868	6
180	1082	1112	30	1111	1134	23
240	849	854	5	799	797	-2
480	803	797	-6	800	805	5
960	730	790	60	742	754	12

	Post test					
	Trained Stimuli			Untrained Stimuli		
SOA	Sum	Neutral	FAC	Sum	Neutral	FAC
120	726	709	-17	722	741	19
180	939	955	16	954	966	12
240	707	730	23	690	734	44
480	697	700	3	667	665	-2
960	680	676	-4	665	679	14

Table 7. Mean Response Times(in ms) on the Number Naming Task for the Control Group by Test, Stilmuli, and Probe

	Pretest					
	Trained Stimuli			Untrained Stimuli		
SOA	Sum	Neutral	FAC	Sum	Neutral	FAC
120	817	825	8	847	811	-36
180	1045	1077	32	1053	1084	31
240	809	798	-11	781	772	-9
480	757	743	-14	757	781	24
960	693	710	17	686	675	-11

	Posttest					
	Trained Stimuli			Untrained Stimuli		
SOA	Sum	Neutral	FAC	Sum	Neutral	FAC
120	738	790	52	727	767	40
180	1016	1004	-12	1010	1025	15
240	745	786	41	714	715	1
480	718	743	25	720	724	4
960	672	700	28	697	714	17

$= 7633$, $p < .01$. Neither the effect of probe nor any high order interactions involving group, probe and SOA were significant. As in the number matching task, second grade control and experimental groups did not differ significantly from each other before training in the performance on the naming task.

In order to examine the effect of training, data from two groups were analyzed with a 2(group) × 2(test) × 2(stimuli) × 5(SOA) × 2(probe) analysis of variance with repeated measures on the last four factors. The main effects of test, $F(1, 30) = 12.99$, $MSe = 158329$, $p < .01$ and SOA, $F(4, 120) = 341.90$, $MSe = 12873$, $p < .01$, were significant. The mean naming latency was 80 ms less during posttest than during pretest. The mean naming latency increased from 120 to 180 ms and decreased steadily thereafter. The interaction between group and test approached significance, $F(1, 30) = 3.28$, $MSe = 158329$, $p < .10$: The experimental group showed a 120 ms decrease in mean response time from pretest to posttest whereas the control group showed only a 40 ms decrease.

The main effect of probe was significant, $F(1, 30) = 5.69$, $MSe = 8073$, $p < .05$: The sum was named 12 ms faster than the neutral probe. However, as was found in the sixth graders, the effect of probe did not vary with SOA. More importantly, there were no significant high order interactions between group, test, stimuli, and probe(e.g., group × probe, group × test × probe, and group × test × stimuli × probe). The results from the naming task are similar to those from the matching task in that there was no evidence for the training effect even though the effect of probe was significant.

Data from Training Sessions

Children were trained with the addition verification task until they reached the criterion response times and error rates. The number of training sessions ranged from 4 to 13, with a mean of 8.

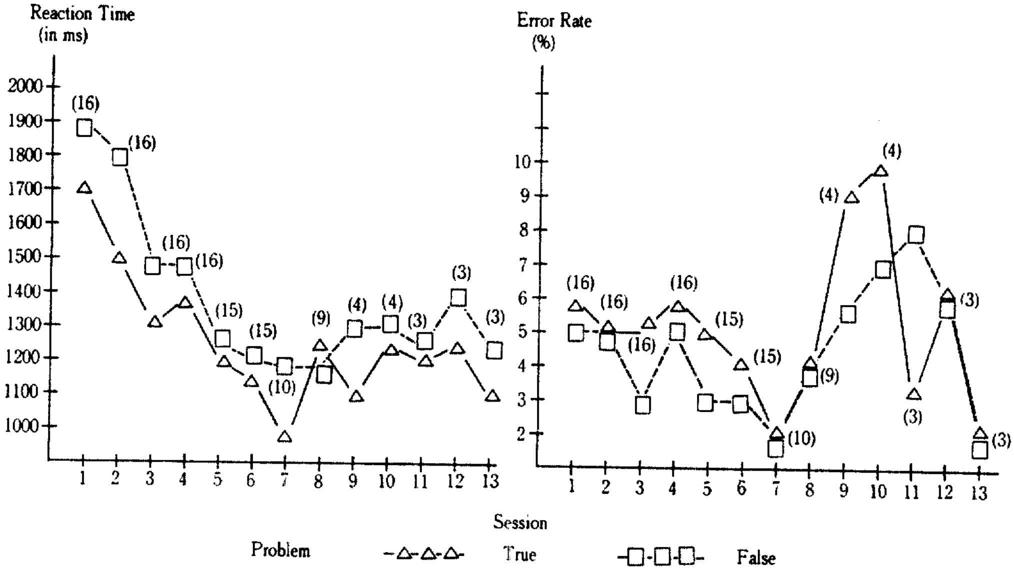

Figure 1. Mean Response Times for True and False Problems for Each Training Session

Note. The numbers in the parentheses indicate the number of children for each taining session

Figure 2. Mean Error Rates for True and False Problems for Each Training Session

Note. The numbers in the parentheses indicate the number of children for each training session

Mean response times and mean error rates for each session are presented in Figure 1 and 2, respectively.

All response times presented in Figure 1 were not subjected to a formal analysis because the number of subjects was different for each session. Therefore, the data from the first four sessions were analyzed by a 2 (problem set) × 2(sex) × 2(side of the correct answer : right vs left) × 2(problem: true vs false) × 4(session) analysis of variance with repeated measures on last two factors. The main effect of problem was significant, $F(1,8) = 27.04$, $MSe = 45936$, $p < .01$: True problems were answered about 200 ms faster than false problems as was found in other studies (Ashcraft & Fierman, 1982 ; Hamann & Ashcraft, 1985). The main effect of session was also significant, $F(3,24) = 14.02$, $MSe = 93420$, $p < .01$: Mean response times decreased steadily from 1806 ms to 1413 ms over 4 sessions.

DISCUSSION

The purpose of the present experiment was to examine how practice on addition problems would affect retrieval processes of addition knowledge. Before the effect of training is described, developmental changes in the nature of retrieval process will be discussed A developmental change from nonautomatic to automatic retrieval was found in the pretest data from two number tasks. In the matching task, addition knowledge was retrieved automatically in sixth graders as indicated by a marginally significant probe effect at short SOAs(120ms and 240ms). In contrast, for second graders, neither the effect of probe nor the interaction between probe and SOA was significant on the pretest, implying that addition knowledge is not yet automatically retrieved in this age group.

A similar developmental change was also observed in the naming task. The effect of probe approached significance in sixth graders: The sum probe was named faster than the neutral probe regardless of SOA. However, the effect of probe was not significant in the second graders. These results are quite consistent with the results from LeFevre et al's study(1987) in that addition knowledge was retrieved automatically only in sixth graders.

However, this developmental change in retrieval processes should be interpreted with caution because the interaction between age, SOA, and probe was not significant when data from the two age groups were analyzed together.

Training affected performance on two number tasks designed to assess automaticity. Overall response times on the two number tasks for the experimental group were significantly less after training than before and the change was greater than that found for control subjects. These results showed that practice on the addition verification task facilitates responses on the matching and the naming tasks. This training effect may be due to the fact that all three tasks are speeded tasks. Through experience with the verification task, children may learn a general strategy(e.g., optimal speed-accuracy tradeoff) to respond on the speeded task and this general learning may facilitate responses on other two tasks even though the nature of decisions and mode of response were different on those tasks.

However, training did not affect the nature of retrieval process. This is shown by the fact that the effect of probe did not vary with the three variables that are associated with the effect of training (i.e., group, test, and stimuli). On the naming task, the effect of probe was significant. However, none of three variables significantly alters the probe effect. On the matching task, the effect of probe was significant only in the experimental group. However, the group difference in the effect of probe cannot be attributed to training perse because the probe effect did not vary significantly with either test or stimuli.

One interpretation of these results from the matching task is that even though children were randomly assigned to two experimental groups, at the outset children in the experimental group may have been more advanced in their general arithmetic ability than the children assigned to the control group. The significant interaction between group and probe found in the matching task may be attributed to the joint effect of training and presumably better arithmetic ability of the children in the experimental group.

The general findings from the present experiment suggest two different issues that need to be investigated further. First, the proposed hypothesis needs to be tested more rigorously because this experiment failed to reveal changes in retrieval processes due to practice. Even though children in the second grade were chosen as a target group on the basis of prior research, addition knowledge might be retrieved automatically in some second graders (i.e., children in the experimental group). These unexpected individual differences may be confounded with the effect of training and made it hard to interpret the results from the present study. Therefore, the proposed hypothesis should be tested again with children who exclusively use nonautomatic retrievel or counting strategies. One possibility is to use children who are younger than the second grade or second graders whose arithmetic performance is below average. Moreover, the number of subjects should be increased in order to improve the power of the experiment.

Second, individual differences in the efficiency of arithmetic processing could be examined further. In the past, individual differences in arithmetic ability were primarily understood in terms of accuracy of children's performance. Recently, individual differecnes in strategies for addition, multiplication, and subtraction have been documented

(Siegler, 1987a; 1987b; 1987c) even in first grade children. However, the efficiency(e.g., speed) of arithmetic processing (e.g., computation or direct retrieval) was not properly considered to explain the differences across children (but see Ashcraft, 1982; Kaye, 1986).

This study was not formally designed to assess individual differences in automaticity. However, as was shown by a significant interaction between group and probe from the matching task, some second graders(i.e., children in the experimental group) showed significant interference effect whereas other children(i.e., children in the control group) didn't. This informal finding implies that automaticity is a dimension which can distinguish children's arithmetic performance even in the second grade.

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아동의 더하기 문제 해결에 미치는 훈련의 효과

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이 실험에서는 단기간에 걸쳐 실시된 더하기 훈련이 문제 해결의 과정을 비자동적 인출이나 재구성적 과정으로 부터 자동적 인출로 변화시킬 수 있느냐를 밝히고자 하였다. 16명의 2학년 아동들이 더하기 문제를 푸는데 걸리는 평균 반응시간과 평균 오답률이 6학년 아동의 수준에 이를 때까지 컴퓨터로 더하기 문제를 공부했고 다른 16명의 아동은 이와같은 훈련을 받지 않았다. 훈련의 효과는 훈련이전과 이후에 실시된 숫자 명명과제와 숫자 맞추기 과제에서의 아동들의 수행을 통해 평가되었다. 훈련은 실험집단 아동들이 더하기문제를 푸는데 걸리는 시간, 오답률, 그리고 숫자 명명과제와 숫자 맞추기 과제에서의 평균반응시간을 유의하게 감소시켰다. 그러나 더하기 훈련은 문제의 답 즉 합이 인출되는 과정 자체에는 유의한 영향을 미치지 않았다. 즉 숫자 맞추기 과제에서는 실험집단 아동들의 반응은 제시된 probe 가 더하기 문제의 합인 경우에 그렇지 않은 경우보다 유의하게 느렸고 이 결과는 훈련을 받지 않은 아동들과는 달리 이집단의 아동들이 자동적 인출에 의해 문제를 해결함을 시사한다. 그러나 이런 경향은 검사나 자극과 같이 훈련의 효과를 직접적으로 평가할 수 있는 변인들에 의해 변하지 않았으므로 실험집단에서 관찰된 자동적 인출의 사용이 "훈련"에 의한 것만은 아님을 시사한다. 숫자 명명과제에서도 probe 로 제시된 더하기 문제의 합이 probe 로 제시된 다른 숫자보다 더 빠르게 명명되었으나 이러한 경향도 숫자 맞추기 과제에서처럼 훈련과 관련과 어떤 변인에 의해서도 변하지 않았다.