NOTE

LEARNING OF A COMPLEX ARITHMETIC SKILL IN DEMENTIA: FURTHER EVIDENCE FOR A DISSOCIATION BETWEEN COMPILATION AND PRODUCTION

Regina McGlinchey-Berroth[1], William P. Milberg[1] and Neil Charness[2]

([1]GRECC, Veterans Administration Medical Center, West Roxbury, MA; [2]Psychology Department, University of Waterloo)

Preserved learning in amnesia has been demonstrated by a number of researchers in the acquisition of perceptual motor skills (Milner, 1962; Milner, Corkin and Teuber, 1968), cognitive skills (Kinsbourne and Wood, 1975; Cohen, 1984; Glisky, Schacter and Tulving, 1986) and in certain implicit learning measures such as the repetition priming paradigm (see Shimamura, 1986, for a review). A great deal of evidence has accumulated recently indicating that the pattern of performance typical of most amnesics on these measures cannot be generalized to patients with Alzheimer's Disease (AD). For example, Shimamura, Salman, Squire and Butters (1987) reported that alcoholic Korsakoff's patients exhibited normal "priming" in a word completion task whereas AD patients did not. In their study patients were given a list of words that were later presented in the form of three-letter stems. When asked to complete the word stems, the AD patients responded less often than control subjects with words that had been presented previously. This study has now been replicated and extended to include impaired priming in AD patients who were asked to free associate to the first word of a previously presented word pair (Salmon, Shimamura, Butters and Smith, 1988). Again, alcoholic Korsakoff's patients performed normally. Additional evidence exists indicating intact priming in Korsakoff's patients (Graf, Squire and Mandler, 1984; Shimamura and Squire, 1984). In addition, AD patients have been shown to be impaired in learning the mirror-reading task (Grober, 1985), whereas other amnesics including patients with Korsakoff's Disease, patients receiving bilateral ECT and patient NA acquired this skill at a normal rate (Cohen and Squire, 1980).

Recently, preserved learning in amnesia has been examined within the context of current models of skill acquisition. Charness, Milberg and Alexander (1988) and Milberg, Alexander, Charness, McGlinchey-Berroth and Barrett (1988) reported findings from three amnesic cases, one Korsakoff's patient and two Anterior Communicating Artery aneurysm (ACoA) patients, based on Anderson's (1982, 1983) model of skill acquisition. Their reports describe a paradigm, Charness and Champbell (1988), designed specifically to differentiate improvement in the performance of a complex mental/arithmetic skill based on learning the individual steps or components of the skill (the strengthening of individual "productions", in Anderson's terminology) from improvement based on the organization of those steps into a complex, but specific algorithm for mentally squaring two-digit numbers (the process of "compilation", in Anderson's terminology). Over several sessions, the time required to perform the mental squaring task decreased significantly for each patient. However, the patients differed in the extent to which their improvement could be attributed to the execution of the individual steps or operations versus improvement in the organization of those steps into an effective algorithm. A dissociation was revealed between the strengthening and compilation processes. For patient J.D., virtually all of the improvement in squaring time was accounted for by improvement in performing the individual steps of the algorithm and not by his ability to combine the steps of the algorithm into a single task specific act. In contrast, patient R.M.

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TABLE I

Neuropsychological Assessment Results for Patient B.G.

Wechsler Memory Scale		72
Logical Memory		5/23
Paired associate learning		6/21
Visual Reproductions		0/14
WAIS		
	Sum of scaled scores	*Age corrected IQ*
Verbal	42	91
Performance	11	70
Full scale	53	81
Folstein mini-mental state	23/30	
Orientation	6/10	
Registration	3/3	
Attention and calculation	5/5	
Recall	3/3	
Language	6/9	

(reported in Milberg et al., 1988) and patient G.P. (reported in Charness et. al., 1988) did appear to compile the individual steps of the algorithm, evidenced by far greater improvement in the squaring task itself than on the individual steps that comprised the algorithm. This suggests that as these subjects became more proficient with the squaring task, some (or all) of the steps that comprised the squaring algorithm were combined to form fewer but more complex productions. As a result, less processing resources (i.e. working memory) and hence less time was required to execute the algorithm as a whole than when executing the individual steps separately. Of course, it could be argued that with practice the steps were simply reorganized and could be executed in a more efficient manner.

Utilizing the procedures of Charness et al. (1988) and Milberg et al. (1988), the present study investigated skill acquisition in an amnesic Alzheimer's Disease (AD) patient. An analysis of cognitive skill acquisition in Alzheimer's Disease is particularly difficult because these patients usually have severe deficits in problem solving and abstraction that complicate their performance on any memory task. The patient reported in this study, B.G., is unusual in that he is an AD patient with a severe amnesia who nevertheless was able to perform basic arithmetic operations with great proficiency. B.G's premorbid history included a job with a strong dependence on mathematical abilities. Before retirement B.G owned a retail/food store for 35 years and served four years in the military service where he managed a large commissary. According to the patient, both jobs required constant practice of mental calculations. Thus, B.G. is a rare AD patient whose premorbid calculation abilities were practiced to an unusual extent and remained sufficiently intact to perform the tasks described in Charness et al. (1988) and Milberg et al. (1988).

The aim of the present investigation was to determine whether this patient could learn the complex skill of mentally squaring two-digit numbers, and if so, to determine what aspect(s) of skill acquisition are preserved that permit such a task to be acquired. The primary measure of preserved learning is defined as a decrease in the time necessary to square two-digit numbers. A differentiation between the strengthening and compilation processes (Anderson, 1982, 1983) of skill acquisition is made by comparing B.G.'s performance on the squaring task with his performance in executing the individual steps that comprise the algorithm to square two-digit numbers. This comparison will indicate whether any observed learning resulted from an intact procedural memory system (evidenced by improvement in both the algorithm and the individual steps), or if a dissociation is present between the production strengthening and compilation processes (evidenced by greater improvement in the individual steps of the task than in the entire algorithm to square two-digit numbers).

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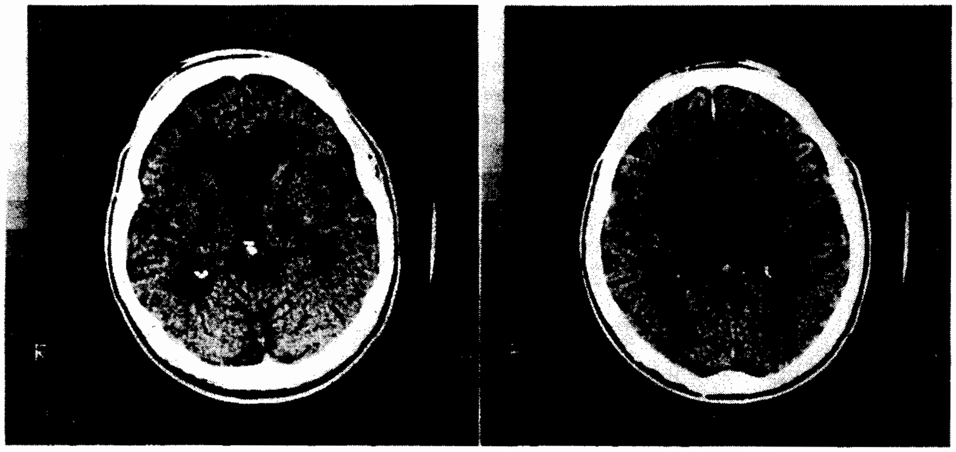

Fig. 1 – *CT scan of patient B.G. taken near the time of testing shows moderate cortical atrophy, ventricular enlargement and no evidence of focal abnormalities.*

MATERIALS AND METHODS

Subject

B.G. is an 82 year old white, right-handed male with a history of diabetes mellitus, type II. He was referred to the geriatric evaluation unit at the VA Medical Center, W. Roxbury, MA, at the request of his family to assess a gradual onset of memory deficits. B.G's medical history was otherwise unremarkable. In the six months prior to admission his family and friends noted that he forgot dinner engagements and religious services with increasing frequency, that he had forgotten to pay his rent, and that they had noticed a general reduction in his table manners and personal hygiene. His diabetes was under control at the time of testing.

A neuropsychological interview with B.G. quickly revealed an extreme inaccessibility of information regarding current events, although with prodding he did offer some vague information. A formal assessment was administered prior to the first testing session. The results of this assessment are presented in Table I. A CT scan showed evidence of cerebral atrophy and ventricular enlargement (see Figure 1). On the basis of these findings B.G. was diagnosed with probable Alzheimer's disease.

Apparatus

The stimulus materials for all experimental tasks were administered via a Commodore 64 microcomputer. A Lafayette Instruments voice operated relay (VOR) was interfaced with the computer to record voice response times. The registration of the patients' responses was inputted via the keyboard by the examiner(s). Response times are accurate to +/−34 msecs.

Procedure

In general, the procedure for testing B.G. was identical to that reported in Charness et al. (1988) and Milberg et al. (1988). Briefly, the patient was shown a fixation point that flashed on the computer screen for approximately two seconds to signal the onset of a trial. The fixation point was then removed from the screen and was replaced by the number(s) that comprised the trial. The number(s) remained presented on the computer screen until a verbal response was made. The experimenter entered the patients' response via the keyboard and initiated the next trial. Response time was recorded from the onset of the number(s) comprising the trial to the patients' verbal response. B.G. was prompted and encouraged continually throughout the sessions to perform as quickly and accurately as possible. He was also reminded of the task procedure whenever necessary.

The testing sessions were conducted in B.G.'s quiet hospital room in a series of 4 sessions lasting approxinately 2 hours each. A 15 minute scheduled break was given mid-way through each session and additional shorter breaks were given as needed. Each session began (after session 1) and ended with an interview during which the patient was asked to recall the examiner(s) name, purpose of the testing sessions, specific task procedures (i.e the squaring algorithm) and the number of previous sessions. All sessions were recorded on audio tape and were later transcribed.

Tasks

Prior testing with patient B.G. revealed visual deficits that would impair his ability to correctly read the materials presented on the computer screeen. Consequently, all of the tasks described below were read to him by the experimenter(s).

Hebb Digit-Span (Drachman and Arbit, 1966)

This task was divided into two parts. In the first part, forward digit span was assessed with a staircase procedure starting with three digits and incrementing by one digit if a trial was correct, and decrementing by one digit if a trial was incorrect. The procedure was halted when six reversals of direction were obtained. Digit span was defined as the mean of the string lengths at the last five reversals, rounded up to the nearest whole digit. This mean served as the baseline span for part two of the task. In part two, 30 trials were presented for recall; the number of digits in each string was determined by adding one digit to the baseline span determined in part 1. The string presented on the third trial was repeated every subsequent third trial unless it was recalled correctly in which case a new string was presented and similarly repeated. Strings were randomly generated from the digits 0 through 9, with repetition of digits permitted. B.G. sat facing the experimenter and listened while the strings were read to him at a rate of one digit per second. The experimenter initiated the trials by saying "ready". The dependent measure in part 2 is the proportion of digits correctly recalled in correct serial position. No feedback was given.

Squaring Components

The components of the squaring algorithm (see Charness and Campbell, 1988) were assessed individually in this task (COMP).

Step 1: Find the nearest multiple of ten (NMT) for a target number (e.g., given 27 generate 30).

Step 2: Find the other number (OTN) for a target that is as far from the target as is the nearest multiple of ten (e.g., given 27 generate 24).

Step 3: Find a constant (C) that represents the absolute value of the difference between the target number and the values generated in steps 1 and 2 (e.g., $30-27$ or $27-24$, $C=3$). The value of C was not measured independently in the COMP task because it is an automatic consequence of Step 2.

Step 4: Find the product of the nearest multiple of ten and the decade digit of the other number (MLT1; e.g. 30×20).

Step 5: Find the product of the nearest multiple of ten and the units digit of the other number (MLT2; e.g., 30×4).

Step 6: Find the sum of the latter two products (SUM; e.g., $600+120$).

Step 7: Add the square of the constant, C^2, to the sum of the two products in Step 5 ($S+C^2$; e.g., $720+3^2$).

For the NMT and OTN components, four problems involved a difference of 1, 2, 4 or 5 and two involved a difference of 3. There were 16 MLT1 and 16 MLT2 problems and 32 that were external to the squaring procedure (EMLT1 and EMLT2). There were also 16

SUM problems and 16 sum problems that were external to the procedure (ESUM). Finally, there were 16 $S + C^2$ problems that were all taken from the squaring environment. The total set of 148 probems was randomly ordered. Any trial in which a misreading of the digits occurred or where the trial was terminated incorrectly were repeated at the end. A verbal description of the operation to be performed on any given trial was presented on the computer screen prior to the trial and was read to the patient. If necessary the experimenter(s) elaborated the instructions prior to the trial and prompted the patient during the trial.

Squaring

The squaring task (SQR) involved 66 problems between 1 and 99. The problems were divided into 4 classes. Class 1 consisted of numbers between 1 and 12. Class 2 consisted of decade numbers (e.g., 10, 20, 30, etc.). Class three consisted of two digit numbers ending in 5 ranging between 15 and 95 (e.g, 15, 25, 35, etc.). The remaining numbers were Class four items and required the use of the entire squaring algorithm in order to be squared efficiently: 17, 18, 21, 42, 26, 32, 33, 37, 38, 41, 44, 46, 49, 52, 53, 57, 58, 61, 64, 66, 69, 72, 73, 77, 78, 81, 84, 86, 89, 92, 93. Class 4 numbers were further divided into two sets that were balanced as closely as possible with regard to the size of the constant, the decade digit for NMT and OTN, and the size of carries in the SUM Step. The first set designated the practice set and was presented during the testing sessions. Both sets were presented on the final session, with the second subset of the Class 4 problems designated as the transfer set.

On each trial the number to be squared was presented on the computer screen following an instruction to square the number and speak out loud while working through the problem. When a final answer was given the experimenter pressed a button which stopped the timer and entered the response via the keyboard. The order of trials was randomized and incorrectly terminated trials were repeated at the end. If necessary, the experimenter(s) elaborated the instructions prior to the trial and prompted the patient during the trial.

Prior to the administration of the SQR task during session 1, the algebraic equation, $a^2 = (a+c)(a-c)+c^2$, was visually presented and explained. The equation, however, was found to be more of a source of confusion than an aid to B.G. It was thus removed and all further instructions regarding the algorithm were given to him via verbal description and example.

Simple multiplication (MULT) and digit naming (NAME) were also assessed. The NAME data was found to be highly variable presumably due to B.G.'s visual deficits and was thus dropped. In MULT there was significant improvement in response time (RT) from session 1 to session 2 (mean correct RT 0.86 and 0.78, respectively, $t = 3.14$, d.f. $= 67$, $p < .001$) and from session 2 to session 3 (mean correct RT for session 3 was 0.70, $t = 2.68$, d.f. $= 69$, $p < .01$). The mean correct RT for session 4 (0.69) did not differ from session 3. It was felt that these data were repetitive with steps 3 and 4 of the COMP task and will therefore not be discussed further. The order of the tasks presented across testing sessions were: Day 1: NAME, MULT, COMP, HEBB-SPAN; Day 2-3: MULT, SQR, HEBB-SPAN; Day 4: NAME, MULT, COMP, HEBB-SPAN, SQR.

RESULTS

Correlated t-tests were used to examine performance differences across the testing sessions. A conservative alpha level of 0.01 was used to assess significance, although marginally significant differences are also noted. All correct response time (RT) data were trimmed to within 2 standard deviations of their mean. This excluded a total of 10 and 14 trials from the COMP and SQR tasks (class 4 problems only), respectively.

Hebb Digit Span

B.G.'s baseline digit span improved from the first to second testing session but then

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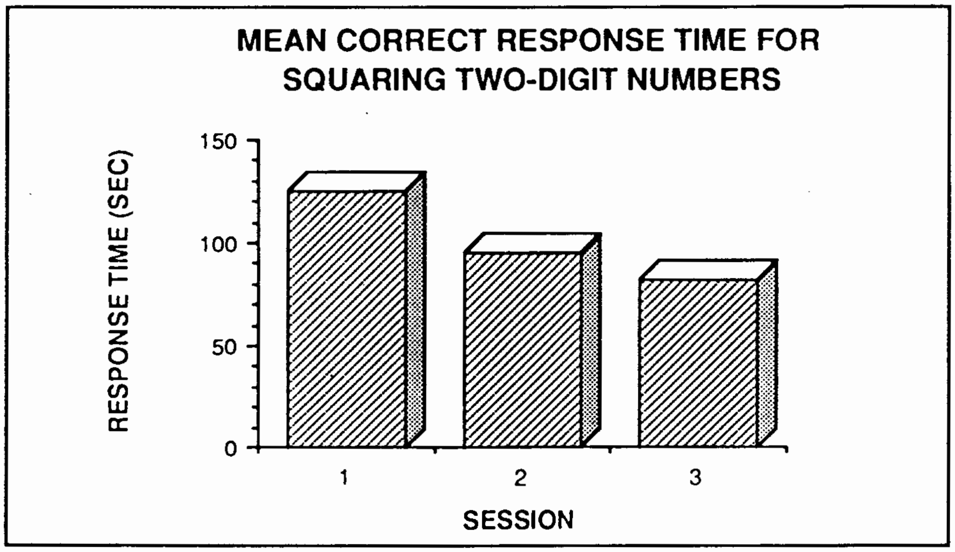
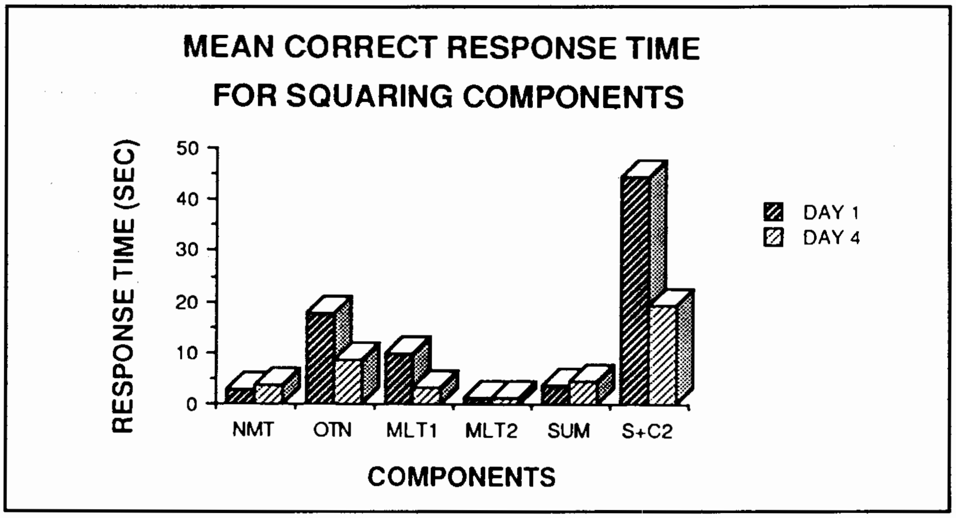


Fig. 2 – *Mean correct response time for squaring two-digit numbers.*

Fig. 3 – *Mean correct response time for squaring components.*



remained relatively stable through session 4. His digit span was 5.0 for the first session, 6.4 for the second, and 6.2 for the third and fourth sessions.

Comparison of the proportion of digits correctly recalled for repeated and non-repeated digits in the span plus one condition revealed little if any benefit for repeated digits. This difference was mildly significant for the first session, t =2.70, d.f. =9, p<.05, but did not differ in sessions 2 through 4. Also, no differences were observed for either the repeated or non-repeated digits across testing sessions.

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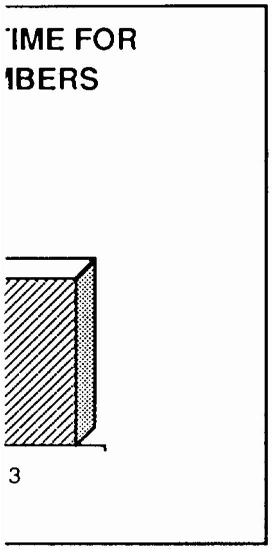

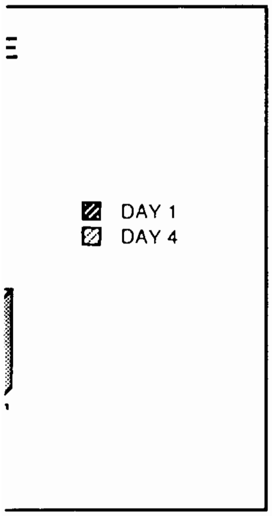

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Figure 2 displays the mean RT's for the first (administered during session 1) and second (administered during session 4) testing of the squaring components task. It is clear from this figure that B.G. improved from the first to second testing most significantly on the $S+C^2$ and OTN components ($t=3.37$, d.f. $=12$, $p=.005$; $t=2.68$, d.f. $=15$, $p=.01$, respectively). B.G. also improved slightly on the MLT1 component ($t=1.85$, d.f. $=12$, $p=.08$). A significant increase in RT was found for the NMT component ($t=2.57$, d.f. $=16$, $p=.02$). The remaining components were found to be similar in the two testing sessions.

Squaring

The mean RT for squaring class 4 numbers are displayed in Figure 3. B.G.'s improvement in RT approached significance from session 1 to session 2 ($t=1.85$, d.f. $=25$, $p=.07$) and from session 2 to session 3 ($t=1.85$, d.f. $=35$, $p=.07$). Comparing his performance from session 1 to session 3 indicated a very significant improvement in RT ($t=3.24$, d.f. $=25$, $p=.003$). The mean RT of 81.27 (sec) for practice problems did not differ significantly from the mean RT of 85.38 (sec) for transfer problems in session 3.

B.G. required constant encouragement and cueing throughout the squaring task. The encouragement and cues were divided into two general categories: implicit and explicit. Explicit cues were defined as cues that provided a specific description of the next step in the algorithm and implicit cues were defined as the use of general encouragement to proceed to the next step or a general reference as to the nature of the next step without a specific description of how to complete the step. The experimenters used explicit cues primarily upon B.G.'s request or when it became clear that an implicit cue would not facilitate his performance. Analysis of these cues indicated a reduction from the first (8.44 cues) to the second testing (6.42 cues) and from the first to the third testing (6.17) in the mean number of implicit cues needed per trial ($t=2.12$, d.f. $=24$, $p=.01$; $t=2.52$, d.f. $=24$, p. $=.02$, respectively). The mean number of explicit cues necessary to square class 4 problems did not differ significantly across testing sessions (session 1: 6.96; session 2: 6.63; session 3: 6.17). There was a trend toward more implicit than explicit cues given per trial in the first session ($t=1.48$, d.f. $=24$, $p=.06$). The number of implicit and explicit cues per trial were similar in sessions 2 and 3.

Comparison of COMP TO SQR

The sum of the response time to complete the steps in the COMP task for the first session totaled 80.21 seconds and 40.74 seconds for the second testing session. This yields an improvement in RT of 39.47 seconds. The length of time complete Class 4 squaring problems was 125.09 seconds in the first session and 81.86 seconds in the last session, a difference of 43.23. Thus 91% of the improvement in RT for SQR is accounted for by improvement in performing the individual steps or components of the squaring algorithm.

DISCUSSION

As the clinical case description suggests, B.G.'s poor performance on the Wechsler Memory Scale, WAIS-R and Hebb Digit Span indicate that he suffers from moderate-to-severe amnesic symptoms. It is therefore not surprising that B.G. was never able to recite the entire algorithm without considerable prompting (when asked explicitly or when asked to do so in the context of an example) and could recall the examiner's names only after four sessions during which he was consistently reminded of them.

The results of the squaring task indicated that B.G. improved considerably in his ability to use an algorithm to square two digit numbers. However, it appears that the improvement was based on his ability to perform the individual component steps of the algorithm more quickly with practice than on his ability to execute the entire algorithm as one coherent act. This finding is supported by the fact that the mean number of explicit cues necessary for B.G. to complete the algorithm remained relatively constant across the testing sessions (recall that these cues provided a specific description of the next step in the algorithm).

Of primary interest is the fact that, in constrast to normal control subjects and other amnesics, the AD patient reported in this study did not consolidate the steps of the algorithm into a single goal directed problem solving skill. This result is similar to patient J.D. reported in Milberg et al. (1988) and lends support to the claim that the processes of "compilation" and "production" strengthening are dissociable aspects of skill learning in amnesic patients (Milberg et. al., 1988).

The mechanism by which performance may have improved in patients B.G. and J.D. is suggested in Anderson (1982, 1983). When learning a new skill, Anderson argues that specific productions (or task steps) are matched in working memory with declarative knowledge. The amount of time necessary for this matching process is in part a function of the strength of the production. He suggests that as the relative frequency of the use of a production increases, its strength also increases. This "strengthening" then functions to decrease the time necessary to match declarative knowledge and thus execute the production. In patients B.G. and J.D., then, practice with the individual steps over the course of the testing sessions may have strengthened the productions associated with the component steps which lead to improved performance as measured by response time.

The question remains as to how such a dissociation occurs in amnesia. Interestingly, the two patients who are known to have displayed this dissociation are etiologically distinct (B.G. and J.D.), and two patients whose amnesia resulted from similar neurologic events displayed different patterns of skill learning (R.M. and J.D. both suffered ACoA's). Alzheimer's disease is thought to impair cognitive function due to the development of neurofibrillary tangles and neuritic plaques in cortical areas thought to subserve various cognitive functions (most notably the temporal and parietal lobes). In contrast, the distribution of cerebral dysfunction in the case of an ACoA is thought to stem from damage to the medial septal nucleus (Alexander and Freedman, 1984). Given that the distribution of cerebral dysfuction is so different in these cases, it is now quite unlikely that etiology alone or location of dysfunction can account for differences in the learning performance of different amnesic patients. Another factor that may play a role in the observed dissociation is the time of onset of amnesic symptoms. B.G. was tested within six months of the reported onset of cognitive decline (as reported by friends and family members) and within only a couple of months of any real notable memory difficulties. Similarly, J.D. was originally tested within weeks of onset and was followed-up at six months. In contrast, patients R.M. and G.P., were tested at 9 months and several years post-onset, respectively. It is possible that the compilation of components is a more volatile process than the strengthening of productions associated with the individual components of a task, and that this process is simply the first to be disrupted by some type of cerebral dysfunction or trauma and the last to be restored following such events. Clearly more work is needed to resolve this issue.

ABSTRACT

An amnesic Alzheimer's Disease patient was tested on his ability to learn an algorithm to square two-digit numbers. The results indicated a dissociation in the patient's ability to execute the individual steps of the algorithm and his ability to combine the steps of the algorithm, the former accounting for almost all of the improvement in response time. The results are discussed in conjunction with findings from Charness et al. (1988) and Milberg et al. (1988) and suggest that skill learning in Alzheimer's Disease may be compromised due to an inability to combine individual steps of a procedure.

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Regina McGlinchey-Berroth, GRECC (182), VA Medical Center, 1400 VFW Parkway, West Roxbury, MA 02132, U.S.A.