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Dementia and Working Memory

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This study explored the hypothesis that patients suffering from dementia of the Alzheimer type (DAT) are particularly impaired in the functioning of the Central Executive component of working memory, and that this will be reflected in the capacity of patients to perform simultaneously two concurrent tasks. DAT patients, age-matched controls and young controls were required to combine performance on a tracking task with each of three concurrent tasks, articulatory suppression, simple reaction time to a tone and auditory digit span. The difficulty of the tracking task and length of digit sequence were both adjusted so as to equate performance across the three groups when the tasks were performed alone. When digit span or concurrent RT were combined with tracking, the deterioration in performance shown by the DAT patients was particularly marked.

Introduction

Dementia was defined by the Committee of Geriatrics of the Royal Society of Physicians as follows:

> Dementia is a global impairment of higher cortical functions, including memory, the capacity to solve the problems of everyday living, the performance of learned perceptual motor skills and the correct use of social skills and control of emotional reactions, in the absence of gross clouding of consciousness (Anon., 1981).

The condition is characteristically irreversible and progressive. Although dementia may result from a range of causes, the most common is Alzheimer's disease. One of the clearest and most sensitive indicators

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of Alzheimer's disease is provided by memory performance, where patients show both lapses in everyday memory and grossly impaired performance on a range of laboratory tasks (Miller, 1977). The present study attempts to provide a more detailed analysis of the breakdown in memory. It is hoped that such an analysis may be of interest at three distinct levels: (1) it may provide a better understanding of the disease, (2) it may provide new and more sensitive tests for the early detection of dementia, and (3) it may cast light on the functioning of normal memory, as has proved the case in other studies of memory deficits.

The memory deficit shown by patients suffering from Alzheimer's disease resembles that of both the classic amnesic and the head-injury patient in showing poor long-term learning but differs from these groups in the extent of the working memory deficit. Performance of demented patients is impaired on digit span (Miller, 1977), suggesting a superficial resemblance to STM deficit patients. However, demented patients differ from STM patients in showing a decrement in performance on the Corsi non-verbal memory span task (Spinnler, Della Sala, Bandera and Baddeley, submitted). This latter study also indicated that DAT patients show comparatively unimpaired performance on the recency component of free recall, an observation also made by Wilson, Baker, Fox and Kaszniak (1983), in contrast to STM patients who typically show impaired recency (Shallice and Warrington, 1970).

One framework for attempting to explain this pattern of results is offered by the working memory model of Baddeley and Hitch (1974). This suggests that working memory comprises a controlling Central Executive system aided by a number of slave systems, with access to passive storage as reflected in the recency effect. It has been suggested (Baddeley, 1986) that such demented patients may be particularly impaired in the functioning of the Central Executive. Such a deficit would be likely to impair learning ability and also lead to poorer performance on span tasks that are assumed within the model to depend at least in part upon the adequate functioning of the Central Executive. It would also lead to an impairment in the capacity for scheduling two or more concurrent tasks. On the other hand, the recency effect would be much less likely to be impaired by a Central Executive deficit as it is based on passive storage and is comparatively uninfluenced by concurrent load (Baddeley and Hitch, 1977).

A recent study by Morris (1984) suggests that DAT patients show every sign of using the Articulatory Loop component of working memory, as indicated by the presence of clear effects of phonological similarity, word-length and articulatory suppression on span performance, coupled with an overall impairment in immediate memory span. Subsequent experiments by Morris (1986) indicate impaired performance on the Peterson and Peterson (1959) task in which subjects are required to maintain verbal material over a brief delay filled by a secondary distracting task. The capacity to store information while simultaneously processing a heavy cognitive load is assumed to be one of the functions of working memory, a function that would be expected to depend on the Central Executive component.

While a case can certainly be made for the view that patients suffering from Alzheimer's disease show a particular decrement in Central Executive function, testing this hypothesis is far from easy, largely because the detailed functioning of the Central Executive has not been adequately explored in normal subjects. Baddeley (1986) has suggested that the attentional control model posed by Norman and Shallice (1980) and applied to the study of frontal lobe deficits by Shallice (1982) might prove a suitable candidate for a model of the Central Executive in working memory. The Norman and Shallice model assumes that behaviour is controlled at two levels, the first of these involving a series of ongoing programmes or schemata that typically run in parallel, with contention scheduling procedures available to resolve conflicts. Such programmes can, however, be initiated, terminated or modified by a higher-level Supervisory Activating System, which is necessary for initiating new behaviour, for making changes in ongoing activity and for resolving major conflicts that may occur in the concurrent performance of two or more activities. Such a system can, of course, be defective at a number of different points, and it is suggested that normal ageing, damage to the frontal lobes and dementia all affect the Central Executive in somewhat different ways (Baddeley, 1986).

It is, however, clearly the case that the sort of detailed analysis that is possible within the Articulatory Loop component of working memory is simply not yet available for investigating hypothetical deficits of the Central Executive. One response to this state of affairs is to delay the application of the executive component of the working memory model to the analysis of neuropsychological problems until it is more adequately established using normal subjects. This approach has the drawback that it would lead to the postponement of neuropsychological investigation of any but the simplest cognitive functions until sometime in the distant future when available models are regarded as sufficiently well developed. An alternative is to use the existing working memory model, despite its limitations, as a framework to explore the nature of the neuropsychological deficit. Provided that tests of the model are not too narrowly limited, they are likely to provide data that will shape the current model and at the same time yield information that is likely to be useful regardless of the ultimate fate of the working memory model.

The study of dementia encounters two further problems, that of specificity of diagnosis of dementia, and that of its degree of severity. Any sample of patients referred for diagnosis is likely to contain patients with a range of different aetiologies in addition to those suffering from Alzheimer's disease. These include rarer dementias such as Huntingdon's disease and normotensive hydrocephalus, as well as patients suffering from multi-infarct dementia, which results from multiple minimal brain lesions caused by a series of minor strokes. In addition to having different causes, such dementias may well produce different dysfunction, with the result that any clear analysis is likely to depend crucially on adequate diagnosis. This is far from easy, demanding information from a range of sources together with the skills of an experienced clinical neurologist. Even under such circumstances, a diagnosis is typically only finally confirmed after the patient has died, and his brain has been found to yield the characteristic pattern of neurofibrilary tangles and plaques; hence patients are typically diagnosed in terms of the somewhat tentative classification of "dementia of the Alzheimer's type" (DAT).

A second important variable in studying dementia is that of severity. The disease is typically progressive, developing from a pattern of initial deficits that may possibly be quite specific to one of massive and general deterioration. Severe cases are likely to show decrement on virtually any test used and, indeed, are likely to have great difficulty in even understanding instructions. Such cases are unlikely to provide insight into the detailed nature of the underlying psychological deficit, and for that reason studies are likely to be more informative if they focus on mild to moderate cases. The present study therefore compares the performance of mild to moderate dements with a sample of non-demented patients of a similar age and background. A third young control group was also tested so as to allow a comparison between the effects of dementia and those of normal ageing.

The focus of the study was on the capacity for successfully coordinating performance on two parallel tasks. We chose pursuit tracking as our primary task. This allowed us to adjust the difficulty of the task so as to match performance across our groups and also allowed a continuous monitoring of performance. We combined tracking with each of three secondary tasks. The first of these was articulatory suppression, selected as being a task that would make minimal demands on the Central Executive. As suppression relies primarily on the Articulatory Loop, it would be unlikely to produce substantial direct interference with tracking, a task that is assumed to depend primarily on the Visuo-spatial Sketchpad component of working memory (Baddeley, 1986). However, although the information load of suppression is minimal, combining it with tracking does require the concurrent performance of two activities, and hence it is conceivable that performance would be impaired in DAT patients.

We chose as a more demanding secondary task simple reaction time to a tone. While simple reaction time is a relatively undemanding task, there is evidence that it will reflect the attentional capacity available to a subject (Posner, 1978), hence allowing the concurrent measurement of performance on both tasks, something that is hard to achieve in the case of articulatory suppression. While simple reaction time allows performance on the secondary task to be measured, it does not allow us to control task difficulty across groups, leaving open the possible objection that the reaction time is simply more difficult for the DAT patients than for the controls. We therefore opted for a third condition, in which task difficulty could be matched across groups. The task we used was concurrent digit span, a task that earlier work suggests does make significant demands on both the Central Executive of working memory and the Articulatory Loop system (Baddeley and Hitch, 1974).

Method

Experimental Subjects

DAT patients

A total of 28 DAT patients were tested. They form part of the larger sample described by Della Sala, Nichelli and Spinnler (1986), referred to the Neurological Service in Milan over a three-year period. Of the 224 people referred, 129 were provisionally diagnosed as DAT patients on the basis of clinical history and neurological examination, combined with CT scan and laboratory data, which were used to exclude other possible dementing illnesses. Of the 129, 63 were excluded as being too severe. Severity was assessed on the basis of conventional cut-off points on the following pre-tests: Temporal orientation score on the Benton, Van Allen and Fogel (1964) test should be at least 50%. Orientation in terms of personal identity using the test devised by Della Sala and Spinnler (in press) should be at least 50%. Ability to provide appropriate information on family members should be at least 70% on the test devised by Della Sala, Nespoli, Ronchetti and Spinnler (1984). Finally, score on a scale of everyday coping ability should be at least 70%.

A second feature of dementia is that it should be progressive; hence patients were included only if they showed unequivocal evidence of deterioration as measured by neurological and psychological assessment over a period of at least six months. Other criteria for inclusion included availability and willingness to be tested and the capacity to read and write as measured informally. Patients with a history of other neurological or psychiatric diseases were excluded, as were patients with evidence of chronic progressive liver, kidney, lung or heart failure, history of alcohol abuse or evidence of having within the last 48 hours taken drugs affecting CNS functions. Finally, patients were excluded if they were not currently living in a family setting without need of special care, or if they did not live within Milan or its hinterland. When these criteria were applied, the initial sample of 224 referred for diagnosis reduced to a total of 28 DAT patients comprising 12 men and 16 women with a mean age of 64.9 years (SD = 7.0, range 51–80) and a mean of 9.5 years of education (SD = 4.3, range 5–17). The mean length of illness was 2.0 years (SD = 1.7, range 1–4).

The overall level of intellectual performance of the patients was further assessed using Raven's Matrices (Raven, 1954) to measure overall intelligence, the Token Test (De Renzi and Faglioni, 1977) as a measure of language performance, and the Street Gestalt Completion Test as a measure of perceptual performance (Street, 1931). Normative data are available for all of these, based on an ongoing study involving a sample of 321 normal subjects. Performance of the DAT patients on Raven's Matrices gave a mean of 18.0 (SD = 11.1), whereas the median score for normals was 28.5, and the fifth percentile cut-off point is 15.0. In the case of the Token Test, the patients scored a mean of 24.8 (SD = 7.8) as compared to a normal median of 33.0 and a fifth percentile cut-off of 26.5. Mean performance on the Street Test was 4.8 (SD = 3.2) for the patients, as against a median for normal subjects of 7.0 and a fifth percentile cut-off of 2.25. The profile of impairment across intelligence language and perception was relatively homogeneous in 15 cases, while 13 showed a more selective pattern of dysfunction. While all patients showed evidence of memory impairment, 12 showed additional evidence of a language deficit and 1 a particular impairment of spatial cognition.

Of the 28 DAT patients, 5 had a CT scan that was within the expected range for their age, 9 showed gross evidence of atrophy, and 14 showed minimal-to-moderate atrophy. Two patients showed atrophy that was more marked in the left hemisphere. On the standard neurological examination, 15 patients presented so-called release signs (chiefly tonic mouth reflex) or paratonia. Some degree of motor impersistence (Joynt, Benton and Fogel, 1962) occurred in 17 of the patients, while 2 patients presented with some degree of extrapyramidal rigidity.

Control Groups

Two control groups were used, one matched on age and educational background with the DAT patients, the other comprising young subjects. All controls were free of evidence of present or past nervous, organic or physical disease that might be expected to impair cognitive performance and were free of alcohol or any other substance that might influence CNS performance. The 28 age-matched controls comprised 13 men and 15 women with mean age 64 years (SD = 4.5, range 57–72) and a mean of 9.2 years of education (SD = 3.7, range 5–17). The young controls comprised 9 men and 11 women with a mean age of 24.3 years (SD = 2.8, range 20–31). Their mean educational level was 15.8 years (SD = 1.9, range 12–17). This is, of course, substantially in excess of the two elderly groups, a difference that is due at least in part to the increase in number of statutory years of education required since the early years of this century. The absence of matching on this variable should be borne in mind in considering the performance of the young control group.

Procedure

Adaptive Tracking

The basic tracking task involved presenting subjects with a 2 × 2 cm white square on a colour monitor. The square moved in random directions around the screen, and the subject's task was to follow the movement of the square by means of a light-sensitive pen. Whenever the pen moved off the square, the colour of the square changed to orange. When the pen was replaced on the square, the colour returned to white. In the adaptive version of the task, the square initially moved relatively slowly, and the speed gradually increased until the subject was unable to maintain the pen on target for more than 60% of the time. The speed of movement was always constant for a period of 20 sec before it was increased. The total time required on the task for this pretesting phase was variable as it depended upon the performance of each individual subject, but averaged about 4 min. The movement of the square and the monitoring of the light pen were controlled by an Apple II computer.

Primary Tracking Task

The basic tracking task was as for adaptive tracking, except that the speed at which the target moved around the screen was stable. Before continuing with the experiment, subjects were given three 20–sec periods of tracking with the level of difficulty set as described above. If subjects improved their performance above 60% time on target, the difficulty level was increased (by increasing the speed of movement of the target), and three further 20-sec trials were given at this new level. This procedure continued until the subject's performance appeared to stabilize between 40% and 60% time on target. This level of difficulty was then used for the primary tracking task throughout the remaining conditions and acted as a baseline level of performance on the tracking task performed alone. The tracking task was performed for 2 min on each trial, and the subject's performance was measured in terms of percentage time on target. In pilot tests it was found that tracking on a vertical screen for periods of more than a few seconds was physically tiring, particularly with the elderly. Thus the monitor was set into a table at an angle of 30° from the horizontal.

Adaptive tracking and tracking alone at a stable rate were completed prior to all other conditions. The subject was then introduced to each of the secondary tasks. However, the order of the tasks was counterbalanced within each subject group.

Secondary Tasks

Articulatory Suppression. In this task, the subject was required to count from one to five repeatedly at a regular rate. Subjects were encouraged to maintain a rate of two per second throughout the testing period. The experimenter demonstrated this rate, and then subjects were given practice. This task was then combined with the primary tracking task for a 2-min session. The rate of suppression was not formally recorded, but where the suppression rate slowed noticeably, the experimenter encouraged the subject to speed up.

Reaction Time to Tones. In this task, the subject was presented with a series of tones from a loudspeaker. The task involved pressing a footswitch as rapidly as possible after commencement of the tone. The inter-tone interval was randomly varied between a maximum of 4 and a minimum of 6 sec, in order to ensure that the subject was unable to use the rhythmic cues associated with a regular rate. The number of missed tones and the correct response times were recorded by an Apple II computer. Subjects were given a few tones for practice, and then the task was performed for two 2-min trials, one alone and the other combined with the tracking task. Because of the random inter-tone interval, the number of tones in each 2-min period ranged between 23 and 25 tones, with a mean over all subjects of 24 tones.

Memory Span. Here subjects were first tested using a standard digit span procedure. The subject was presented with a list of digits at one digit per second and was asked for immediate ordered spoken recall. Initially only one digit was presented, and the number in each list was gradually increased by one item, with three lists at each length. Presentation ceased when the subject was unable to recall two of the three sequences at a given length, and span was taken to be the previous list length. Subjects were then presented with digit lists at their own span for a period of 2 min alone and for 2 min combined with the primary tracking task. Performance was measured by the percentage of sequences that were recalled completely correctly. The number of lists presented in 2 min was dependent on the individual span of each subject and ranged from 11 to 15 sequences.

Results

The primary interest of the study lies in the comparison between DAT patients and age-matched controls, hence this will be considered first. The comparison of the performance of the normal elderly and young groups provides useful background information but is of secondary importance and will be considered later. In comparing the various groups, we shall begin by considering overall performance on the primary tracking task, asking two preliminary questions: (1) does tracking performance vary as a function of secondary task, and (2) if so, do such differences interact with subject group? As explained in the introduction, a working-memory hypothesis would predict both of these, namely a disruption of tracking by secondary task and an enhancement of this disruption in the case of the DAT patients. Should these predictions by upheld in the overall analysis, then a more detailed examination of performance on both primary and secondary tasks will be made in turn for the effects of suppression, concurrent reaction time and concurrent digit span.

One further point should be considered before discussing the analysis of results. Performance of our three groups of subjects on the tracking task was equated by varying the speed at which the target moved. This avoids the problem of comparing performance at markedly different time-on-target scores but introduces the further problem as to whether a 5% decrement at the fast rate is equivalent to a 5% drop in time-on-target at the slow rate achieved by the DAT patients. We make the assumption that it is, since we see no way of comparing our groups meaningfully without such an assumption. In theory, our assumption could be tested by plotting performance operating characteristic curves for our three groups. In practice this is not feasible, for two reasons. First, the amount of data necessary to established reliable functions would place unrealistic demands on the attentional capacity of our DAT patients. Secondly, the plotting of such functions assumes that the same strategy will be used across the function, an assumption that we feel is highly questionable in the case of our demented patients (for a further discussion of this point see Baddeley, Eldridge, Lewis and Thomson, 1984). We shall therefore argue as follows: If our DAT patients under control conditions show a time-on-target performance equivalent to, or better than, the control groups and, when a secondary task is added, decline to a level below that of the controls, then a prima facie case has been established for their greater vulnerability to secondary task interference. While the task concerned is different, it involves a more slowly moving target, which, other things being equal, ought to be less susceptible to interference that the rapidly moving target experienced by the control groups.

Figure 1 shows the mean overall percentage of time on target for the three subject groups as a function of condition. An analysis of variance was carried out involving the elderly and DAT groups and the four conditions. There proved to be no overall effect of subject group ($F < 1$) but significant effects of conditions [$F(3, 162) = 22.46$, $p < 0.001$] and a significant interaction between subject group and conditions [$F(3, 162) = 4.36$, $p < 0.01$]. When the two groups were examined individually using one-way analysis of variance, the normal elderly subjects showed an overall effect of conditions [$F(3, 81) = 4.55$, $p < 0.01$], and a further analysis using the Newman–Keuls test indicated that the only significant difference was between performance on the tracking task alone and performance when tracking was combined with span ($p < 0.01$). When an equivalent analysis was performed on the DAT patients, there again proved to be a significant effect of conditions [$F(3, 81) = 19.28$, $p < 0.001$] but in this case tracking alone led to significantly higher performance than tracking with suppression ($p < 0.05$) or than tracking with concurrent RT ($p < 0.01$) or tracking with concurrent span ($p < 0.01$). Having obtained the predicted interaction between dementia and secondary task effects, we felt justified in performing a more detailed analysis of the individual tasks.

Tracking and Suppression

Mean tracking performance with and without suppression is shown in Figure 1. An analysis of variance of percentage of time on target for the DAT and age-control patients indicated no overall difference between the groups ($F < 1$), but a significant effect of suppression [$F(1, 54) = 4.71$, $p < 0.05$] and no interaction ($F < 1$).

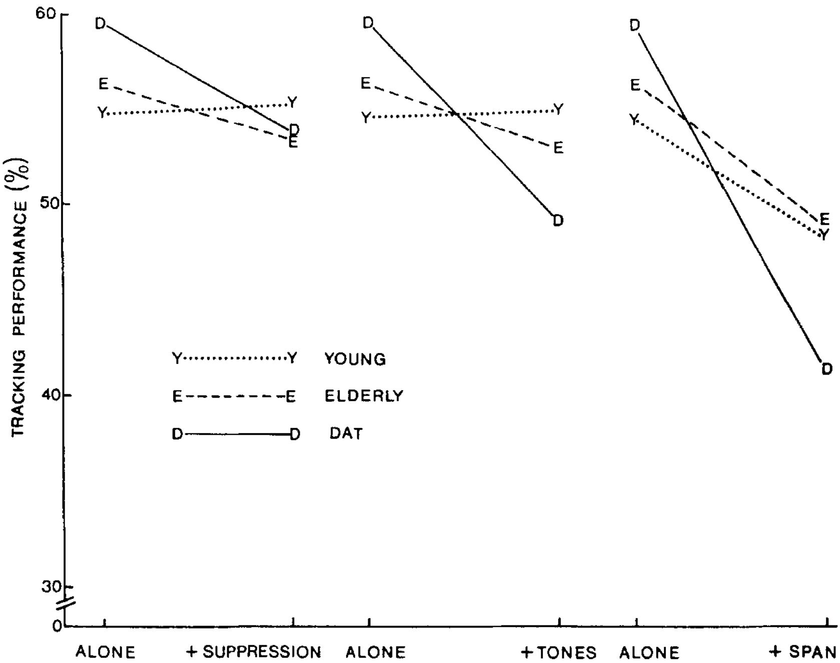

Figure 1. Adaptive tracking performance of senile dementia patients (DAT) and elderly and young controls when tracking is performed alone and when it is combined with concurrent articulatory suppression, RT to a tone or auditory digit span.

Tones and Tracking

Figure 1 shows overall performance on tracking and the effect of adding the RT task. Analysis of variance of time on target on the primary task again indicated no difference between the groups ($F < 1$), but a significant effect of the RT task on tracking [$F(1, 54) = 23.53$, $p < 0.001$] and a significant interaction [$F(1, 54) = 6.13$, $p < 0.05$]. Reaction time and error data are shown in Table I. Three of the DAT group missed all of the tones while tracking, and their data were excluded from the reaction time analysis. Analysis of variance of the reaction time data suggested an overall difference in reaction time between the two groups [$F(1, 51) = 55.13$, $p < 0.001$], together with a significant effect of combining tracking and RT [$F(1, 51) = 44.56$, $p < 0.001$] and a significant interaction between these two [$F(1, 51) = 20.54$, $p < 0.001$]. The elderly control subjects made virtually no errors on this task (mean = 0.18) in contrast to the DAT group, who omitted a mean of 2.79 responses under control conditions, and 9.82 when RT was combined with tracking.

Table I

Effects of Concurrent Tracking on Mean RT to Tones[a]

	Young	Elderly controls	DAT patients
RT alone	381.4 (0)	418.0 (0.11)	721.3 (2.79)
RT while tracking	434.6 (0)	479.4 (0.25)	1041.9 (9.82)

[a] In msec.
Note: Mean number of omission errors shown in brackets.

Tracking and Digit Span

Figure 1 shows performance on combined tracking and digit span. Analysis of variance on tracking scores indicated no significant overall effect of subject group ($F < 1$) but a highly significant effect of condition [$F(1, 54) = 61.47, p < 0.001$] and a significant interaction between subject group and condition [$F(1, 54) = 11.09$, $p < 0.01$]. Performance on the memory task is shown in Table II. Analysis of variance suggests that the DAT group made significantly more errors in the span task than did the elderly group [$F(1, 54) = 18.71$, $p < 0.001$], and both groups made more errors when span was combined with tracking [$F(1, 54) = 219.74$, $p < 0.001$]. There was also an interaction between groups and the dual task effect [$F(1, 54) = 34.11, p < 0.001$].

Table II

Memory Span and Tracking

	Young	Elderly controls	DAT patients
Span task alone	0	2.42	1.79
Span task with tracking	13.76	20.39	43.11

Note: Mean percentage of erroneous sequences as a function of subject group.

Effects of Normal Ageing on Performance

Overall analysis of tracking performance for the young and the elderly indicated a significant effect of condition [$F(3, 138) = 6.36$, $p < 0.01$], but no overall difference between young and old ($F < 1$) and no interaction between age and conditions ($F < 1$). This general lack of an age effect on performance was also reflected in the more detailed analysis. There was no significant effect of articulatory suppression on performance ($F < 1$), no effect of age ($F < 1$) and no interaction ($F < 1$). Analysis of the effects of the concurrent RT task indicated no overall effect on tracking of age ($F < 1$), no significant overall effect of tones [$F(1, 46) = 1.42$, $p > 0.05$] and no interaction between age and concurrent task effects [$F(1, 46) = 2.18$, $p > 0.05$]. As Table I suggests, mean RT did not differ significantly between the young and the old [$F(1, 46) = 2.6$, $p > 0.1$]. RT was, however, increased by concurrent tracking [$F(1, 46) = 33.81$, $p < 0.001$], but this did not interact with age [$F(1, 46) < 1$]. Number of tonal signals missed did, however, show a difference between the young and the elderly, with the young never missing a signal, while the elderly had a mean miss rate that was low (0.18 out of 24), but nevertheless significantly greater than the young [$F(1, 46) = 4.74$, $p < 0.05$]. Bearing in mind that the incidence is extremely low and that the distribution of responses clearly does not conform to the assumptions appropriate to analysis of variance, this difference should be treated with considerable caution. There was no significant interaction between age and condition [$F(1, 46) = 1.16$, $p > 0.1$].

Analysis of the tracking and concurrent span data indicated a significant overall effect of span on tracking [$F(1, 46 = 20.07$, $p < 0.001$] but no effect of age and no interaction between age and concurrent task ($F < 1$ in each case). Span performance is shown in Table II. Analysis of variance indicated a highly significant effect of concurrent tracking on span [$F(1, 46) = 67.85$, $p < 0.001$], together with a small effect of age [$F(1, 46) = 4.28$, $p < 0.05$], but no interaction between age and concurrent tracking [$F(1, 46) = 1.19$, $p > 0.1$]. In general, then, there is clear evidence that combining tasks impairs performance for both groups, together with some minimal evidence for general age effects on performance, but no suggestion of an interaction between age and secondary task.

Discussion

We shall begin by discussing the principal comparison between DAT patients and age-matched controls. It is clear from the initial analysis that dements are more disrupted than controls by the addition of a secondary task, even when pains are taken to ensure that the primary tracking task is set at a comparable level of difficulty for DAT and control patients. However, interpretation of this predicted interaction is by no means unequivocal in some of the cases. In the case of articulatory suppression, the dual task effect is very small, even in the case of the DAT patients. Furthermore, since monitoring performance on the suppression task was not undertaken, we cannot rule out some form of differential trade-off between tasks, though this does not seem a likely explanation of the difference between DAT patients and controls.

The data from combining tracking and RT are somewhat more compelling. Performance on tracking shows a crossover interaction indicating that DAT patients are more dramatically impaired by concurrent RT than are controls. It is clear from performance on the RT task that this interaction does not reflect a differential trade-off between the two groups, since RT and errors both show an interaction between dementia and conditions, indicating that the DAT patients are more vulnerable to the demands of combining two tasks. Interpretation of this result, however, is constrained by the fact that DAT patients perform more poorly than the controls when RT is studied alone. This raises the possible objection that the secondary task was simply more difficult for the dements than the controls. If this is so, then our results may simply indicate that adding a difficult task to tracking impairs performance more than adding an easier task.

Fortunately such an objection cannot be applied to the third condition, since here the digit span task was adjusted so as to ensure that performance on the secondary task was equivalent for the dements and controls. Under these conditions we again observe a crossover interaction between performance on concurrent tracking and subject group, coupled with an equivalent interaction between condition and subject group for the secondary span task. In short, adding two tasks that are equated between the groups for difficulty produces a disproportionately large decrement in performance for the DAT patients. This is, of course, exactly what was predicted by the Central Executive interpretation, which suggests that DAT patients will have particular difficulty in integrating and coordinating two concurrent tasks.

In contrast to the very marked interactions between dementia and secondary task effects, we observed little or no differential disruption of performance in the elderly when compared to the young controls. This is particularly striking since the young controls are of higher educational level and hence might be expected to have some advantage over the elderly, beyond that afforded by differences in age. Two interpretations of this are possible. The first is that our study was, for one reason or another, relatively insensitive. While this is possible, our results certainly indicate that the study was sensitive enough to pick up differences among conditions, and of course clear effects of dementia.

A second interpretation is to conclude that the lack of difference between the young and old control subjects simply indicates that we have been successful in equating the difficulty of the various tasks for our subjects. If so, one might expect to observe differences between the elderly and the young in the level of difficulty on the tracking task that yielded the mean pretest matching score of 40–60% time on target. Examination of the data indicate that the elderly achieved the criterion tracking performance at a reliable lower difficulty level than did the young [$F(1, 46) = 4.54$, $p < 0.05$]. The DAT group, in turn, achieved 40–60% tracking performance at an even lower difficulty level than the elderly [$F(1, 54) = 31.08$, $p < 0.001$]. As Table I shows, the elderly also showed longer mean RTs than the young. It appears to be the case, then, that the elderly and the young do differ in cognitive capacity, but that when performance on the two concurrent tasks is equated between young and old, then combining them does not lead to any greater decrement in the elderly than in the young.

Our results are therefore consistent with the initial hypothesis that DAT patients are particularly impaired in the operation of the Central Executive, and that this system is important for integrating the performance of two or more concurrent tasks. As mentioned earlier, such a prediction is not, of course, peculiar to a working memory interpretation of dementia. A sceptic might, for example, suggest that anything that makes a task more difficult will differentially penalize DAT patients. Such an interpretation does, of course, leave open the question of how difficulty should be specified, and as such runs the risk of circularity.

It seems unlikely that such a "difficulty" hypothesis can confidently be rejected on the basis of any single experiment. Consider, for example, the following hypothetical experiment in which a primary task such as tracking is combined with two other tasks, A and B. It might well be the case that when performed alone, A led to shorter RTs than B, but when combined with tracking, it produced more impairment than B. An advocate of the difficulty hypothesis could then argue that the "difficulty" came from the problem of combining tasks rather than from the difficulty of the tasks per se. Such a result would not therefore refute the "difficulty" interpretation but would force it in the direction of beginning to specify the nature of the underlying processes.

Having an existing model such as that of working memory will, we believe, help us to look for patterns of results that will increasingly constrain the interpretation of the effects of dementia on performance, just as using the complex web of results on the role of phonological coding in immediate memory has allowed us to develop and refine the articulatory loop hypothesis. It is, however, only fair to point out that the same argument could be used to defend, for example, Craik's (1984) interpretation of the decline of memory with age in terms of reduced "processing resources". We find a working memory framework useful for conceptualizing our results but cannot yet claim that it gives a substantially better account of dementia than other available models. Few, if any, current models are sufficiently precise to be unequivocally supported, or refuted, by our data.

What, finally, are the possible practical implications of our results? One of the problems facing any attempt to treat dementia is the need to detect it an an early stage. Whatever the underlying cause of dementia, it seems likely that any treatment that is devised will be most effective if provided during the early stages, before the occurrence of profound neural and intellectual deterioration. This calls for the development of tests that are sensitive to dementia and capable of screening out the patients suffering from dementia from those exhibiting the normal signs of ageing. Our secondary task approach seems promising in this respect, since it combines considerable sensitivity to the effects of DAT while being relatively impervious to the effects of normal ageing. However, dual task techniques tend to be inherently more complex logistically than single tasks. It remains to be seen whether sufficient increase in sensitivity occurs to offset these potential logistic costs.

REFERENCES

Anon. (1981). Organic mental impairment of the elderly. *Journal of the Royal College of Physicians of London*, **15**, 142–167.

Baddeley, A. D. (1986). *Working memory*. London: Oxford University Press.

Baddeley, A. D., Eldridge, M., Lewis, V. and Thomson, N. (1984). Attention and retrieval from long-term memory. *Journal of Experimental Psychology: General*, **113**, 518–540.

Baddeley, A. D. and Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), *Recent advances in learning and motivation, Vol. VIII*. New York: Academic Press, pp. 47–90.

Baddeley, A. D. and Hitch, G. J. (1977). Recency re-examined. In S. Dornic (Ed.), *Attention and performance VI*. Hillsdale, N.J.: Lawrence Erlbaum Associates, pp. 647–667.

Benton, A. L., Van Allen, W. M. and Fogel, M. L. (1964). Temporal orientations in cerebral disease. *Journal of Nervous and Mental Diseases*, **139**, 110–119.

Craik, F. I. M. (1984). Age differences in remembering. In L. R. Squire and N. Butters (Eds.), *Neuropsychology of memory*. New York: Guildford Press, pp. 3–12.

Della Sala, S., Nespoli, A., Ronchetti, E. and Spinnler, H. (1984). Does chronic liver failure lead to chronic mental impairment? In *Advances in hepatic encephalopathy and urea cycle diseases*. Basle: Targer, pp. 448–456.

Della Sala, S., Nichelli, P. and Spinnler, H. (1986). An Italian series of patients with organic dementia. *Italian Journal of Neurological Science*, 7, 27–41.

Della Sala, S. and Spinnler, H. (1986). Indifference Amnesique in a case of global amnesia following acute brain hypoxia. *European Neurology*, **25**, 98–109.

De Renzi, E. and Faglioni, P. (1977). Normative data and screening power of a shortened version of the Token Test. *Cortex*, **13**, 424–433.

Joynt, R. J., Benton, A. L. and Fogel, M. L. (1962). Behavioral and pathological correlates of motor impersistence. *Neurology*, **12**, 876–881.

Miller, E. (1977). *Abnormal ageing*. New York: Wiley.

Morris, R. (1984). Dementia and the functioning of the articulatory loop system. *Cognitive Neuropsychology*, **1**, 143–157.

Morris, R. (1986). Short-term forgetting in senile dementia of the Alzheimer's type. *Cognitive Neuropsychology*, **3**, 77–97.

Norman, D. A. and Shallice, T. (1980). Attention to action: Willed and automatic control of behavior. *University of California San Diego CHIP Report 99*.

Peterson, L. R. and Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology*, **58**, 193–198.

Posner, M. I. (1978). *Chronometric explorations of mind*. Hillsdale, N.J.: Lawrence Erlbaum Associates.

Raven, J. C. (1954). *Progressive matrices*. Firenze: Edizione Italiana Organizzazione Speciale.

Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society London B*, **298**, 199–209.

Shallice, T. and Warrington, E. K. (1970). Independent functioning of verbal memory stores: A neuropsychological study. *Quarterly Journal of Experimental Psychology*, **22**, 261–273.

Spinnler, H., Della Sala, S., Bandera, R. and Baddeley, A. (submitted). Dementia, ageing and the structure of human memory.

Street, R. F. (1931). *A gestalt completion test*. New York: Teachers' College Press.

Wilson, R. S., Baker, L. D., Fox, J. H. and Kaszniak, A. (1983). Primary memory and secondary memory in dementia of the Alzheimer type. *Journal of Clinical Neuropsychology*, **5**, 337–344.

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