THE ABILITY OF AMNESIC SUBJECTS TO ESTIMATE TIME INTERVALS

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Abstract—Amnesic subjects suffering from Korsakoff's syndrome and post-viral encephalitis were assessed on their ability to estimate short temporal durations using two quite different tasks. In the first experiment subjects were required to reproduce and estimate intervals of between 3 and 96 sec. In the second experiment subjects carried out an automated Fixed Interval task using intervals of 15 and 30 sec. On both tasks the Korsakoff group were impaired at all intervals compared to an alcoholic control group, whereas the post-encephalitic subjects were unimpaired compared to a normal control group. The results suggest that temporal estimation can be independent of memory function. There was, however, evidence of a relationship between the ability to estimate time intervals and performance on a particular test of frontal lobe function, cognitive estimation. The results are discussed in relation to these findings and to theories of temporal perception.

INTRODUCTION

Anecdotal evidence has long suggested that anterograde amnesia produces a severe distortion of the sense of time. Over a hundred years ago KORSAKOFF [21] noted that memory for temporal location is often more severely affected than memory for events. More recently, SACKS [35] vividly described how a person suffering from Korsakoff's syndrome was apparently unaware of the passing of decades, while WILLIAMS and ZANGWILL [45] commented on how Korsakoff subjects often wrongly estimated the passage of time.

The first formal evidence that amnesic subjects cannot accurately judge the duration of time came from a study of the amnesic patient H.M. [34] who had received a bilateral medial temporal lobectomy for intractable epilepsy. It was found that H.M.'s ability to reproduce temporal durations was severely impaired. Whilst H.M.'s temporal judgements appeared normal for intervals up to 20 sec, he consistently underestimated longer intervals [31]. By extrapolation it was possible to estimate H.M.'s equivalence for 1 hr as 3 min, 1 day as 15 min, and 1 year as 3 hr. More recent studies have again shown that amnesic subjects are impaired at estimating periods of elapsed time of more than 15–30 sec [19,30], although they can accurately reproduce much shorter intervals such as 1 sec [19,30]. In the large majority of cases the failure to measure the passage of longer intervals is seen as an underestimation of elapsed time [19,30,46].

Other evidence concerning the way in which anterograde amnesia affects estimations of...
temporal duration derives from the finding that both temporal lobe and diencephalic amnesia disrupt the ability to make judgements about temporal context. For example, when amnesic subjects are required to learn two lists of words they may show a deficit in discriminating the list in which an item occurred that is disproportionately greater than that associated with recognition of the same item [15, 23, 26, 43]. Related to this, amnesics exhibit a larger impairment in source memory than might be expected from their fact memory ability [37, 39]. In addition, when learning successive paired associate lists in which the same stimulus terms are paired with different response terms (AB–AC paradigm), amnesic subjects show a tendency to intrude first list responses into second list recall [20, 24, 47]. While these studies of temporal context are clearly of relevance, they can only provide indirect evidence about temporal duration judgements in amnesia.

The purpose of the present study was to compare time estimation in different groups of amnesic subjects, and, to discover whether their impairments were similar to those described in the subject H.M. [34]. A further goal was to examine the relationship between temporal duration judgements and other cognitive changes that often occur in amnesia. This provided the opportunity to determine whether impairments in temporal memory can be regarded as a core feature of anterograde amnesia or whether they might result from dysfunction in other brain regions, such as the frontal lobes [17]. For this reason we examined the relationship between the depth of amnesia, the extent of any temporal judgement deficits, and psychometric signs of frontal lobe dysfunction. Finally (Experiment 2), the subjects were tested on a version of the Fixed Interval operant task pioneered by comparative psychologists. Although this task has been used to examine the contribution of limbic brain regions to time estimation by animals [31] it has not, to our knowledge, been given to human amnesic subjects.

The initial test of duration estimation copied that used by Richards [34] to test H.M. In this the subjects are required to reproduce an interval of time demonstrated by the experimenter. This method avoids the need to “translate” the duration into verbal time units but it is dependent on the ability to make a comparison with some stored representation of the sample interval. As a consequence it is reliant on memory processes. Two further time production tasks were carried out in which the subject was presented with the time in seconds and asked to produce this interval. This method entails relating subjective time to clock time and so should be less dependent on memory processes. Productions were made with either “empty” or “filled” intervals.

**EXPERIMENT 1**

**Method**

The experiment was conducted with a group of seven subjects diagnosed as suffering from Korsakoff’s syndrome and nine Alcoholic Controls. A “temporal lobe” amnesic group consisting of three men who, had suffered viral encephalitis, was compared with 11 Normal Control subjects.

**Subjects.** Subjects were assessed with the WAIS and the NART [29] to evaluate IQ and premorbid IQ respectively, and with the Wechsler Memory Scale (WMS) and the Warrington Word and Face Recognition Test [44]. One subject in the Post-Encephalitic group (G.H.) who had a speech impediment did not attempt the NART.

The mean age of the three amnesics having suffered from viral encephalitis was 41 years, range 22–62. The psychometric profile of these subjects has already been published [10]. In brief, the mean scores for this group (ranges in parentheses) were as follows: WAIS full scale IQ (FSIQ) 98.0 (91–104), NART 107.5 (105–110), WMS 84.3 (76–97), Warrington words and faces 32.7 (32–33) and 31.3 (27–37), respectively.

The interval between the onset of the disease and testing ranged from 18 months, in the youngest subject, to 14 years in the oldest. All suffered from memory problems which had forced them out of work. A detailed case history of one of the subjects (B.D.), who appears to suffer from a semantic memory loss for living things, has already been
published [13]. In none of the cases was there precise information regarding the location and extent of brain damage.

The mean age of the 11 men in the normal control group was 46.6 years (range 20-59). Psychometric assessment was limited to the NART, and the mean full scale IQ estimate was 111 (range 99-119).

The mean age of the Korsakoff subjects (five men and two women) was 57.7 years (range 50-64) while that of the alcoholic group (eight men and one woman) was 50.6 years (range 43-68). Mean psychometric scores (ranges in parentheses) for the Korsakoff group were: WAIS FSIQ 95.1 (80-105), NART estimated FSIQ 104 (92-119), WMS 75.7 (65-81), and Warrington words and faces 28.3 (24-30) and 31.7 (24-38), respectively. For the Alcoholic Control group mean scores were: WAIS FSIQ 100.4 (88-116), NART FSIQ 108.4 (101-119), WMS 101.3 (91-114), and Warrington words and faces 44.8 (33-50) and 45.0 (36-49), respectively.

Tests of frontal lobe function were given to subjects in all four groups. These included the Wisconsin Card Sorting Test [14], Verbal Fluency [1], Design Fluency [18], picture arrangement [25], and the Block Design subtest of the WAIS—R in which subjects with frontal lobe damage often display inertia [1, 12]. Three subjects (one in the Korsakoff group and two in the Alcoholic Control group) were not available to carry out all of the frontal lobe test but the results suggested some frontal dysfunction in all of the amnesic subjects and several of the Alcoholic Control group. These are shown in Table 1.

Table 1. Scores on tests of frontal lobe function for the Korsakoff, Alcoholic Control and Post-Encephalitic subjects

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<td>34</td>
<td>37.5*</td>
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<td>80.4*</td>
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*Scores falling outside the normal range.

Cats.—Categories achieved in the WCST.
Persev. Resps.—Number of perseverative responses.

Procedure. The experiment took place over three sessions at weekly intervals. All subjects received the time reproduction condition during the first session, followed by the time estimations with filled and empty intervals presented in a counterbalanced order during the following two sessions. The time intervals for all conditions were 3, 6, 12, 24, 48 and 96 sec. Each interval was presented twice per session, once at the beginning of the session and once following performance of another task (psychometric tests or other experimental tasks). There was an interval, therefore, of approx. 20 min between each of the two presentations. The intervals were presented in random order for all subjects and were measured using a digital stop watch.

In the time reproduction condition the experimenter demonstrated an interval of time by saying “start” and “stop”. The subject was then asked to reproduce that interval by also saying “start” and “stop”. The subject was
asked not to count during any of the intervals and care was taken that no clocks or watches could be seen or heard by
the subject. The subject was not told the length of the interval but a notice with the words “I am timing” was
displayed whilst the interval was being demonstrated. The subject was shown a second sign “Tell me when to stop”
during the following test interval. For the time estimation conditions the subject was given the time in seconds and
asked to produce this interval. The experimenter told the subject to “start” and the subject was required to say “stop”
when the interval had elapsed. The “Tell me when to stop” notice was displayed along with the length of the required
interval in seconds. During filled intervals the subject started reading a printed passage as soon as the start of
interval had been indicated by the experimenter and continued reading throughout the interval. A different prose
passage of varying type face was used for each trial. Again the subject was asked not to count and all watches and
clocks removed from sight.

Results

Figure 1 shows the mean error from target irrespective of direction of the error (i.e. under or over estimation) for each time interval in each of the three experimental conditions. As can be seen the Korsakoff group made larger errors than their Alcoholic Control group at all time intervals in each of the conditions. They also made larger errors than the Post-Encephalitic group in all instances, except for the longest interval in the filled interval condition.

Analyses of variance with the factors group, condition and length of duration was carried out to compare each amnesic group with their control group. A reciprocal transformation of the data was used to uphold the homogeneity of variance assumption. This confirmed that the Korsakoff group were making larger overall errors than the Alcoholic Control group \[F(1, 14)=22.46, P>0.001\]. Both groups produced larger errors as the length of the interval increased but the interaction of group \(\times\) length of interval failed to reach significance \[F(5, 70)=2.17, P=0.067\]. There was a significant difference in performance on the different types of time estimation as shown by a main effect of condition \[F(2, 28)=4.71, P=0.017\], but the Korsakoff group were not differentially affected by type of time estimation. The differences between the types of time estimation were due to the groups making smaller errors on the reproduction condition than the other two conditions.

Although the Post-Encephalitic subjects appear to be performing similarly to their Control group at the shorter intervals, but with a tendency to make larger errors as the interval increased, no significant difference was found between the Post-Encephalitic group and the Normal Control group in overall error or in their error in relation to length of the interval (all \(F’s<1\)). There was also no difference in performance across experimental conditions.

Figure 2 depicts the mean estimated time plotted against true time for each group. This shows that during the shorter intervals the Korsakoff subjects were both under and over estimating time as their mean estimates appear to resemble closely those of the Alcoholic Control subjects, even though they were making larger errors (Fig. 1). With the longer intervals, however, the Korsakoff group showed a pronounced bias to underestimate the length of the interval. This bias was most apparent for the “reproduction” and “estimation with empty intervals” conditions. For two of the three conditions it can be seen that the Post-Encephalitic subjects were much more accurate as their estimations closely resembled a diagonal (which would represent complete accuracy). Like the Korsakoff subjects, however, there was some tendency to underestimate in comparison to the Normal Control subjects.

In order to assess the precision of the subjects’ estimations, that is, the consistency with which they estimated an interval on two trials, the difference between the estimates on the two trials at each interval was calculated and expressed as a ratio of the actual duration. An analysis of variance was then used to compare this consistency measure across groups,
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Fig. 1. The mean error from target in seconds for each time interval in each of the three experimental conditions, i.e. reproduction, estimation with empty intervals and estimation with filled intervals for the Korsakoff and Alcoholic Control groups (left side) and the Post-Encephalitic and Normal Control groups (right side).

Fig. 1. The mean error from target in seconds for each time interval in each of the three experimental conditions, i.e. reproduction, estimation with empty intervals and estimation with filled intervals for the Korsakoff and Alcoholic Control groups (left side) and the Post-Encephalitic and Normal Control groups (right side).

experimental conditions and intervals. These comparisons showed that the Korsakoff subjects were significantly less consistent than the Alcoholic Controls in their estimations \[ F(1, 14) = 6.85, P = 0.02 \]. They also showed that although both the Korsakoff and Alcoholic groups were more inconsistent as the interval increased \[ F(5, 70) = 6.63, P < 0.001 \], the Korsakoff subjects were differentially affected by length of the interval as shown by a significant group \( \times \) time interaction \[ F(5, 70) = 7.87, P < 0.001 \]. The Post-Encephalitic subjects, on the other hand, did not differ from their control group on any of the measures of consistency of estimation.

The error from target in each of the time estimation conditions and the total error from target over all conditions were correlated, using two-tailed Spearman rank order correlations, with performance on tests of frontal lobe function, and measures of memory and intellectual function for the Korsakoff and Alcoholic Control groups. In both groups
positive correlations were found between the cognitive estimation test and performance on the time estimations. In the Korsakoff group total error on the estimation with filled interval correlated positively with cognitive estimation errors [$r_s = +0.82, P = 0.044$] as did the total error over all three conditions [$r_s = +0.9, P = 0.015$]. In the Alcoholic Control group total error over the three conditions also produced a near significant positive correlation with cognitive estimation [$r_s = +0.75, P = 0.054$] as did total error on the estimation with empty interval [$r_s = +0.85, P = 0.016$]. None of the other tests of frontal lobe function produced any significant correlations in either group except for a negative correlation between the block design test and estimation with filled intervals in the Korsakoff group [$r_s = -0.9, P = 0.007$].

Performance on the time estimation tasks tended to show a negative relationship with memory function in the Korsakoff group and a positive relationship in the Alcoholic Control group. The WMS scores, in Korsakoff subjects, correlated negatively with the estimation
with filled interval \( r_s = -0.88, P = 0.008 \) and just failed to reach significance with the overall error \( r_s = -0.71, P = 0.06 \). Performance on the Warrington Recognition Memory test (total score for both words and faces) correlated negatively with the estimation with empty interval \( r_s = -0.84, P = 0.018 \), the estimation with filled interval \( r_s = -0.77, P = 0.042 \), and the total error for all three conditions \( r_s = -0.88, P = 0.010 \). The test of short term memory, digit span, also correlated negatively with the estimation with filled interval \( r_s = -0.83, P = 0.022 \). In summary, the better temporal duration judgements were made by those subjects who performed worst on the memory tasks. In the Alcoholic Control group, on the other hand, performance on the WMS correlated positively with the total error \( r_s = +0.66, P = 0.053 \) and the estimation with empty interval \( r_s = +0.87, P = 0.002 \). None of the correlations using the difference in WAIS—WMS scores were significant.

Because of the small group size correlations were not computed for the Post-Encephalitic subjects and no significant correlations were found in the Normal Control group between performance on time estimation and tests of frontal lobe function or intellectual function as measured by the NART.

**Discussion**

The Korsakoff amnesics were impaired in reproducing and producing intervals of time ranging from 3 to 96 sec whereas the Post-Encephalitic subjects were unimpaired in all measures of temporal estimation. This impairment in the Korsakoff group was not dependent upon severity of amnesia, indeed performance showed a negative relationship with tests of memory function. This finding was contrary to the positive relationship exhibited by the Alcoholic Control group between performance on the time estimations and tests of memory function. Disorders of temporal estimation could not be readily attributed to general frontal lobe dysfunction as there was no overall relationship between tests of frontal lobe function and time estimation. There was, however, a consistent positive correlation between time estimations and performance on the cognitive estimation test for both the Korsakoff and Alcoholic Control groups suggesting that time estimations may be dependent upon a specific process that may be partly served by the frontal lobes. It was found that the deficit in the Korsakoff subjects reflected both an under and over-estimation of the shorter intervals (up to 24 sec), but that they showed a consistent bias to underestimate longer intervals. Furthermore, as the length of the interval increased the Korsakoff subjects became significantly more inconsistent than their control subjects.

There was little evidence of the pattern of results shown by H.M. [34]. That is, of normal estimations for intervals up to 20 sec but impairments for intervals greater than 20 sec. The Korsakoff subjects were impaired at all intervals while the Post-Encephalitic subjects performed within the normal range. While both the Korsakoff and Post-Encephalitic subjects did appear to make larger errors as the length of the intervals increased, this interaction was not significant in either case. Furthermore, the Post-Encephalitic subjects, who are more likely to have damage in areas affected in H.M., did not differ significantly at any interval compared to their Control group. There remains, of course, the possibility that they may have shown an impairment at much longer intervals.

Although the experimental procedure in the reproduction condition was modelled on that of Richards [34] the results in the present experiment were analysed as absolute error from target. When the data were presented in a similar manner to that of Richards [34] (Fig. 2) it appeared that the Korsakoff subjects were producing accurate estimations for intervals of up to about 24 sec. This merely shows, however, that subjects were both over and
underestimating. Absolute error scores are more sensitive in detecting decrements in timing performance [5, 11] and it is possible that if the data from H.M. were analysed in terms of the error from target it would yield a different pattern.

To assess the consistency of the present findings Experiment 2 used an automated Fixed Interval (FI) procedure, a quite different method of time measurement. FI bears some similarity with the reproduction procedure used in Experiment 1 as it avoids the need to make a translation of a verbal time unit into duration measurement, a technique that produced the most accurate temporal estimations. Other advantages include the ability to give many more trials in a session at each time interval. Furthermore, as the FI is modelled on fixed interval procedures used with animals it provides an opportunity to compare amnesic subjects' temporal estimations with those of animals with specific brain lesions. Animal performance on FI schedules is characterized by a pause in responding at the start of the interval followed by an accelerated rate of responding terminating in the reinforcement (scalloping). While early human studies often failed to replicate this pattern of responding, a two-chain response procedure devised by LOWE, HARZEM and BAGSHAW [22] was successful in producing the scalloped pattern of responding in human subjects. In their experiment a response on one button gave access to a clock and a response on another button delivered reinforcement. The characteristic “scalloping” profile was then consistently found on the “clock button”. The present study utilized the two-chain response procedure by requiring subjects to respond on one button to gain information as to whether the interval had elapsed and on another to acquire the reinforcement (2p).

EXPERIMENT 2

Method

Subjects. The Korsakoff group was the same as that in Experiment 1 except for one subject who was unavailable for testing. This left a group of four men and two women, mean age 57.3 years (range 54–64). The Alcoholic Control group was also the same as that in Experiment 1 with the addition of a further male subject. The mean age for this group was 50.4 years (range 43–68). The Post-Encephalitic group remained unchanged but one subject in the Normal Control group was not available for testing. The mean age, therefore, of the Post-Encephalitic group was 41 years (range 22–62) and the Normal Control group was 49.2 (range 34–50). These changes to the groups did not appreciably alter the overall patterns of the psychometric test scores.

Apparatus. The experiment was run using a Toshiba T1000 portable computer linked to an external monitor (screen size 20 × 15 cm), an electronic coin dispenser, and two single key pads (7.5 × 5 cm) (buttons A and B) which were operated by the subject. A notice was attached to button A on which the words “press this button to find when the time is up” was displayed, and attached to key B was a notice showing the words “press this button to get a 2p”.

Procedure. Each subject took part in two sessions at weekly intervals, one session consisting of a FI of 15 sec and the other a FI of 30 sec. The order of the FI conditions was counterbalanced across subjects.

The subjects sat facing the monitor screen with the coin dispenser immediately to the right of it. Button A was placed in front of the screen and Button B in front of the coin dispenser. Subjects were then instructed that they would be given a number of intervals of time, all of the same length, and that the interval commenced when a box (white rectangle 4 × 7 cm on a black background) appeared on the screen and a short tone was heard from the computer. They were not informed of the length of the interval but were asked to try and find out when the interval had elapsed by pressing button A. They were instructed that a press to button A prior to the end of the interval would produce the words “Not Yet” on the screen (for 0.5 sec), but if the interval had elapsed they would see the word “Now” appear. On seeing the word “Now” a press to button B would produce a coin (2p sterling) from the coin dispenser which could be collected at the end of the session. They were told that they could press button A as often as they liked, but that they should press button B only once, and that they should aim to earn as many coins as possible. In addition to the coin reward, a successful press to button B produced a short cheerful tune from the computer, and the word “Correct” appeared on the screen. If button B had not been pressed by the end of a predetermined time limit (“limited hold”), the words “Sorry, too late” appeared on the screen accompanied by a deep tone from the computer. At the termination of the trial, either by a correct response on button B or a time out indication, the rectangle disappeared from the screen and was followed by a preset inter-trial interval.

A short practice session was given with an inter-trial interval of 2 sec and a limited hold of 8 sec for each FI
condition. Once the subject had received two coins this session was terminated and the experiment proper commenced. Seventy trials were given with an inter-trial interval of 2 sec and a limited hold of 5 sec for each condition. During the second half of each session eight probe trials occurred in the same predetermined random order for each subject on both conditions. In the probe trials the intervals were extended by 10 sec in the FI 15 and 20 sec in the FI 30. The limited hold period was the same as for normal trials.

Results

Performance on the Fixed Interval task was measured by calculating the mean number of responses made by each group in each 2.5 sec bin of the intervals. Efficient responding and accurate temporal differentiation is displayed by an increase in the number of responses as the interval approaches termination which can be compared to the "scalloping" produced by animals in fixed interval procedures. Each amnesic group's performance was then compared to that of their respective control group using analyses of variance with the factors group and bins. A log transformation of the data helped to uphold the homogeneity of variance assumption.

The responses of both control groups markedly increased towards the end of the FI intervals showing the accuracy of their temporal estimations (Figs 3 and 4). In contrast the Korsakoff group did not exhibit a marked scalloping effect (particularly in the FI 30 set), as their responses were more evenly distributed throughout the interval. Statistical analysis confirmed that the Korsakoff subjects were making more responses overall than the Alcoholic Control group in both conditions [FI 15 $F(1, 14)=9.51$, $P=0.008$; FI 30 $F(1, 14)=9.83$, $P=0.007$], while the increase in rate of responding with progression of the interval (i.e. scalloping) was greater in the Alcoholic Control group as shown by the group X bins interactions [FI 15 $F(7, 98)=4.76$, $P<0.001$; FI 30 $F(13, 182)=34.21$, $P<0.001$].

Although the Post-Encephalitic group showed efficient responding and a scalloped pattern of responses in the FI 15 set, responding on the FI 30 set was not as clear. This was due to one subject who responded at a steady rate throughout the interval, i.e. adopting a response based strategy rather than a temporally based strategy. One subject in the Normal Control group also adopted such a strategy but because of the larger group size this is not so apparent. The inset figures show the pattern of responses when these two subjects are excluded and indicate clearly the accuracy of responding in both groups. Analysis of variance confirmed that there were no significant differences between the Post-Encephalitic group and the Normal Control group in terms of the overall number of responses or the increase in rate of responding in either experimental condition.

To assess temporal discrimination the mean time to the median response was calculated for all trials in each condition, excluding probe trials (Fig. 5). This showed a tendency for the Korsakoff group to underestimate the length of the intervals with mean median response times of 12.8 sec (FI 15) and 23.0 (FI 30) compared to 16.4 (FI 15) and 30.0 (FI 30) in the Alcoholic Control group. Unlike the Korsakoff subjects, the Post-Encephalitic group produced more accurate median response times of 15.5 sec (FI 15) and 26.1 sec (FI 30) which were only slightly lower than those of the Normal Control group's times of 16.5 sec (FI 15) and 29.1 sec (FI 30). Student t-tests were carried out on the error from target of the median response times, the target being designated as the middle of the interval during which a reward could be obtained, i.e. 17.5 sec for the FI 15 and 32.5 sec for the FI 30. In both the FI 15 and the FI 30 the Korsakoff group had significantly lower median response times than the Alcoholic Control group [FI 15 $t(14)=3.87$, $P=0.002$; FI 30 $t(14)=5.01$, $P<0.001$]. The Post-Encephalitic median response times did not differ significantly from their Control group in either condition.
A further measure of efficiency in the FI schedule is the number of rewards obtained divided by the number of responses. In this case the highest level of efficiency would be 1, i.e. one reward per response and the lowest 0. As can be seen from Fig. 6 the Alcoholic Control subjects were responding much more efficiently than the Korsakoff subjects, particularly in the FI 30 condition. This was statistically significant using t-tests [FI 15 $t(14)=4.12, P=0.001$; FI 30 $t(14)=3.27, P=0.006$]. Although the Normal Control subjects were responding more efficiently than the Post-Encephalitic subjects this was not statistically significant.
Fig. 4. FI 30: The mean number of responses made by each group in each consecutive 2.5 sec bin during the FI 30 procedure (probe trials are excluded). The inset figures show the post-encephalitic data excluding subject G.H. and the normal control data excluding subject A.H. both of whom adopted response based strategies.

Probe trials, in which the interval was extended were included as an analogue of the “peak interval” procedure used with animals. These were not, however, analysed in detail as the peak in responding was attenuated by the fact that reward was eventually delivered. This is in contrast with the procedure used with animals whereby reward is not delivered and there is a falling off of responses with time, so producing a “peak”. In spite of this the pattern of responding of the Korsakoff subjects in both the FI 15 and the FI 30 was notably different from that of the Control groups in that they exhibited a steady response rate throughout the interval whereas the Control groups rate of responding increased as the interval progressed.
Fig. 5. The mean time to the median response for each group in the FI 15 (left side) and FI 30 (right side) conditions.

Fig. 6. The mean efficiency ratio (the number of rewards obtained divided by the total number of responses made during a session) for each group in the FI 15 (left side) and FI 30 (right side) conditions.

The mean response rate for the Encephalitic subjects also failed to show any increase with progression of the interval. This was due, however, to the one subject (G.H.) who adopted a response based strategy. When his responses were excluded from the data the pattern of responses of the remaining two subjects resembled that of the Control groups.

Spearman rank order correlations (two-tailed tests) between performance on the Fixed Interval tasks and performance on tests of frontal lobe function showed a positive relationship between perseverative tendencies and poor performance on the Fixed Interval in both the Korsakoff and the Alcoholic Control groups. In the Korsakoff group there was a positive correlation between perseverative responding on the Wisconsin Card Sorting test and poor performance on the FI 30 [r_s = +0.89, P = 0.018]. In the Alcoholic Control group the number of perseverative responses on the Design Fluency test correlated positively with poor performance on both the FI 15 and the FI 30 [FI 30 r_s = +0.80, P = 0.018; FI 30 r_s = 0.72, P = 0.044]. As in the time estimation experiment a negative relationship was found between Block Design and performance on the Fixed Interval in the Korsakoff group [FI 15
There was no indication in the Korsakoff group of the relationship found in Experiment 1 between cognitive estimation and time estimation, but in the Alcoholic Control group there was a nearly significant negative correlation between the FI 15 and cognitive estimates \( r_s = -0.69, P = 0.057 \) (i.e. the opposite to that found in Experiment 1).

As in Experiment 1 the Korsakoff subjects' performance on the FI test of time estimation produced a negative relationship with tests of memory function (WMS and IQ–MQ difference) although these just failed to reach significance \( r_s = -0.8, P = 0.06; r_s = +0.78, P = 0.06, \) respectively. No correlation was found in the Alcoholic Control data between FI performance and memory function.

**DISCUSSION**

The present study provides evidence of a dissociation between the judgement of temporal duration and memory function. This was most clearly shown by the Post-Encephalitic group who performed within normal limits on all of the temporal duration tasks yet were impaired on the standard memory tests. While it is possible that this group would have been impaired over longer intervals, their performance over the durations tested is in striking contrast to that of the Korsakoff subjects. Consequently, a deficit in time estimation, for at least these durations, cannot be considered a necessary feature of anterograde amnesia. Other support for a dissociation between memory and temporal estimation comes from the Korsakoff group. Although these amnesic subjects were impaired at making duration judgements using both the temporal estimation procedures and the Fixed Interval procedure, negative correlations were found between tests of memory function and temporal estimation for both procedures. It may also be relevant that the Korsakoff group performed better on the reproduction, rather than the production, task of Experiment 1: A result that at first sight seems counterintuitive as the reproduction task, which requires a representation of the interval to be held in memory, is likely to have a higher memory load. This finding, which accords with previous studies using reproduction tasks [4, 6], again points to the separation between temporal duration judgement and memory load.

The results of the present study were not in accordance with those of RICHARDS [34] who described how the amnesic subject H.M. could perform accurately on time estimations of intervals below 20 sec, but that after 20 sec he increasingly underestimated the passage of time. While the present Post-Encephalitic subjects showed no clear impairment either before or after 20 sec, the Korsakoff amnesics seemed to be impaired at all durations. One problem with the earlier study of H.M. is that the findings were not analysed as absolute error scores from the target time but calculated as mean estimates of each target time [34]. As a consequence, an individual who may both be wildly underestimating and overestimating the same time interval could falsely appear to be performing accurately. A similar problem occurs in a study of Korsakoff amnesics [19] who were reportedly able to estimate time intervals of up to about 30 sec. Indeed, when the present data were plotted in the same way it appeared that the Korsakoff subjects were making accurate time estimations at intervals below 20 sec and only after this were they impaired.

The apparent accuracy of the Korsakoff subjects when data were plotted as mean estimates is evidence that their impairment was not merely a result of response inhibition. This is because the subjects were responding later as well as earlier than the target time for the shorter intervals. It could be argued that a failure to inhibit responding and adopting a
response based strategy would be as efficient as a temporally based strategy in the FI procedure. This is true in terms of obtaining reward as, whichever strategy is used, a reward will be delivered at the appropriate time. However, in terms of response cost and effort, a temporally based strategy is more efficient. Furthermore, the responses of the subjects to the probe trials suggested that a temporally based strategy was indeed being used by all groups. This is because the response latency on the trial following a probe trial was significantly longer, particularly in the FI 15, suggesting that subjects were adjusting their response times in relation to the extended probe trials. Time outs, that is overestimation of the intervals and failure to gain a reward, also occurred more often after a probe trial in all groups.

It appears likely that temporal duration judgements and temporal order memory can be dissociated from one another. Although H.M. has a severe impairment in temporal estimation [31] he can perform at near normal levels on tests of recency and frequency [33]. Conversely, the Post-Encephalitic subjects in the present study were unimpaired on tests of temporal estimation but severely impaired on a test of recency memory (Shaw and Aggleton, in press). It has been proposed that amnesic impairments in recency memory are a result of damage to brain regions additional to those necessary to produce an amnesic syndrome. Possible candidates include the frontal lobes [39, 43] and the medial thalamus [42], and it is known that frontal lobe damage alone can produce deficits in tasks requiring sequential organization [28, 33]. It is of interest, therefore, to determine if the dissociation between temporal duration processing and temporal order memory can be ascribed to differences in frontal lobe functioning. Both Korsakoff and Post-Encephalitic subjects are known to suffer frontal injury [8, 16] and most of the amnesic subjects in this research showed some psychometric evidence of frontal dysfunction (see Table 1). While no generalized relationship could be found between tests of frontal lobe function and tests of temporal duration judgement, a striking correlation was found between the cognitive estimation test and the temporal estimation tests used in Experiment 1, and this appears to warrant further investigation with larger subject groups.

Impairments in cognitive estimation tasks have been attributed to the formation and utilization of cognitive plans or strategies for problem solving [38, 41], a function linked to the frontal lobes. This impairment in cognitive planning may, therefore, be partly responsible for the deficit in temporal estimation. It must, however, be of a fairly specific nature as many of the frontal lobe tests require such an ability, for example the WCST, but performance on the temporal estimation tests showed no relationship with other frontal lobe tests. This correlation between cognitive estimation and time estimation was not, however, apparent in Experiment 2 which used a Fixed Interval procedure. This highlights a qualitative difference between these two types of temporal estimation procedure and in fact no clear correlation was found between individual performance on these different tasks.

The temporal estimation tasks required the subject to monitor internal events whereas the Fixed Interval procedure required the subject to utilize external feedback to monitor the passage of time. It may, therefore, be that the cognitive estimation and the time estimation tasks both tap the ability to establish the necessary strategies to monitor internal cognitive events. The Fixed Interval task, on the other hand, showed a relationship to perseverative tendencies, suggesting that performance was dependent upon making external responses. The present findings also shed some light upon theories concerning the perception of time intervals. One such theory of temporal estimation proposes that duration judgements are solely dependent upon the sequential order of events within that duration [9, 27, 32]. Such a theory would predict a strong positive relationship between temporal order memory and
temporal estimation and a strong negative relationship between temporal estimation and severity of amnesia. Neither of these were found. Other evidence of a dissociation between temporal order and temporal duration has also been found in studies of normal subjects [2, 3].

An alternative model of time estimation that allows for a deficit in duration judgement to occur independently of impairments in memory function is derived from studies using animals [7]. This theory proposes an “internal clock” mechanism which consists of a pacemaker that generates pulses into an accumulator and a comparator that combines the value from the accumulator with a value held in reference memory, in order to make decisions about duration [7]. A breakdown of the system at any point would produce a disturbance in temporal estimation and although an impairment in reference memory could produce temporal estimation deficits this is not a necessary requisite of temporal dysfunction. Thus a problem in the pacemaker or accumulator could produce temporal deficits in the absence of a memory impairment. Although this theory accounts for much of the animal literature and, indeed, can account for the findings in the present study it does require some qualification when applied to human data. It does not, for example, take account of the many cognitive processes that can influence an estimation of duration such as mood, expectations, the types of processing occurring in and around the duration, and executive control such as planning and monitoring of strategies.

CONCLUSIONS

In conclusion, the ability to carry out temporal duration judgements need not depend on intact memory. Indeed, some severely amnesic subjects were able to carry out time estimation tasks as well as their control subjects, and, in those amnesics who did show an impairment in temporal estimation, this deficit showed no direct relationship with their memory ability. The findings do not support models of time estimation that depend upon memory for events within the duration, but favour “internal clock” models that propose an independent internal timing mechanism that is responsive to cognitive factors and external events but is not dependent upon them. The results also suggest that the influence of certain cognitive factors upon time estimation may be related to frontal lobe function. Thus there were striking correlations in Experiment I between temporal estimation and cognitive estimation, suggesting the existence of common cognitive demands between being asked to estimate a time duration and estimating seemingly quite different items such as weight, height and speed.

REFERENCES