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A Note on the Chronometric Analysis of Cognitive Ability: Antarctic Effects[1]

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Systematic increases in item-completion time over successive items of a "mental paper folding" task were stable with repeated administrations of the task. Rate of change in processing time was suggested as a sensitive measure of the effects of situational variables on cognitive performance, unconfounded by sample-specific effects. As an example, rates of change in item-completion time were compared for police recruits and personnel located at Scott Base, Antarctica, and for Scott Base personnel before and after wintering over. An increase in the rate of change in processing time under Antarctic conditions was found, and wintering over increased overall item-completion time.

Abilities measured by psychometric tests of intelligence or specific aptitudes have much in common with the processes studied in cognitive psychology, although it is only recently that the theoretical substrate for cognitive processes has been extended to the analysis of individual differences (Hunt, 1978). For example, Jackson and McClelland (1979) found that fast readers had faster reaction times than average readers on several tasks tapping the speed of encoding visual information such as matching nominally identical letters (Posner, 1969). The general approach involves correlating performance on the many specific tasks already subjected to considerable theoretical treatment in cognitive psychology with individual differences assessed by more traditional means (Sternberg, 1981).

The contemporary focus of cognitive psychology on "chronometric analysis" (Posner, 1978), together with its impact on theoretical analyses of individual differences (Hunt, 1978), suggests a single general dimension for differences in individual ability, namely speed of information processing. The analysis of information processing time may represent a useful strategy for the measurement of individual cognitive ability.

Our intention is to illustrate one particular advantage of chronometric analysis of cognitive ability. Ability tests are frequently used to determine the effects of situational variables on performance. But the effects of these variables will often be confounded with other factors such as order effects or effects resulting from the non-random selection of subjects exposed to the situational variables of interest (e.g. Antarctic conditions). The advantage of chronometric analysis is that it allows separation of overall differences in ability from differences in the extent of change in performance when task parameters are varied. Typically a performance task will involve several items or trials and a single accuracy measure is derived from frequency correct over all trials. If task-completion time is recorded on each trial, two additional measures are afforded: total time over trials and rate of change in completion time per trial. Whereas total time or accuracy measures may reflect the influence of confounded variables, rate of change in information processing speed may be uniquely sensitive to situational variables.

In the present study we examined the stability of processing speed over time in a

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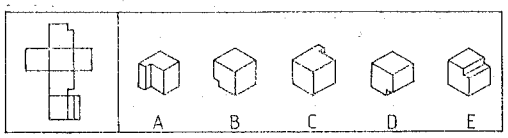

Figure 1. Example of an item from the "mental paper folding" task.

sample of police recruits, and also the way in which processing speed was influenced by Antarctic conditions. Our data illustrate the way in which the extent of change in processing speed as items of a cognitive ability task progress may be used to assess the effects of situational variables on performance. The task we chose was the "mental paper folding" task from the Space Relations subtest of the Differential Aptitude Tests (DAT) (Bennett, Seashore & Wesman, 1959). A sample item is illustrated in Figure 1. The task may be seen to involve two distinct components. First, the two-dimensional figure must be "mentally folded" to form a three-dimensional representation. The time required to produce the folded version is likely to increase as the figure becomes more complex. Second, the folded version must be compared with each of the five comparison figures which themselves vary in orientation. Following Shephard and Metzler's (1971) demonstration of a linear relation between same-different response latency and disparity in degrees of rotation of three-dimensional figures, we might suppose that judging the folded figure against each comparison figure requires a "mental rotation" which itself takes time. To summarize, the task illustrated in Figure 1 requires a finite time to perform, and that time we surmize to depend directly upon the general complexity of the two-dimensional array.

On the basis of preliminary work with a few subjects in which times to complete DAT items were recorded, 40 items such as those in Figure 1 were selected from the DAT. These items were grouped in four *forms,* each comprising 10 items of comparable difficulty (in terms of time to completion) across forms and increasing difficulty as items progressed within forms. (It should be noted that our forms did not correspond to the original "Forms" of the DAT. Indeed, the DAT items were simply intended to provide useful stimulus material.) Subjects were given brief instructions to decide which of the three-dimensional comparison figures of an item could be made by folding the two-dimensional pattern, and that completion of each item would be timed to a maximum of 60 seconds. Most subjects completed each item within the 60-sec limit. For each item the maximum number of possible correct comparison figures varied between 1 and 5 with a mean of 2.6 per item. (Our accuracy measure was simply frequency of comparison figures correctly identified, whereas an apparently arbitrary correction is used in the DAT, namely frequency correct minus frequency of errors for each item.) Because completion-time per item was recorded independently of the number of alternatives correctly identified per item, our two performance measures, total accuracy over the items of a form and total item-completion time, were procedurally independent measures.

Each of 24 police recruits (mean age 23) was tested individually on four occasions spaced one week apart. In order to counterbalance forms and their order over test occasions, each subject was administered all four forms over the four test sessions, and the order of presentation of forms over tests was determined by the rows and columns of a Latin square such that over subjects each of the four forms was preceded by each other (in the preceding test session) equally often.

Table 1 presents traditional measures of performance on the task, namely, mean frequency of correct responses and mean total completion times for the 10 items of each form, averaged over the forms for each administration. Table 1 shows that as successive administrations (test sessions) progressed, accuracy systematically increased ($F\ 3, 69 = 6.71$, $p < .01$) and mean total completion time showed a systematic but insignificant decrease ($F < 1$). These changes in performance with repeated exposure to the various forms of the test can be regarded as a general practice or positive transfer effect.

Table 1: *Mean total correct responses and mean total completion times (sec) averaged over forms for each test administration.*

Administration	1	2	3	4
Correct Responses	14.83	17.96	18.08	19.37
Completion Time	265.2	260.8	248.9	243.0

As an example of the way in which the response accuracy measure may allow confounding between situational and sample-specific factors, the Otis IQ for the 24 recruits was correlated with mean response accuracy over all four forms ($r = .402$, $p < .01$). Comparisons between samples based on accuracy measures may therefore be confounded with IQ differences between samples. Although the Otis IQ was unrelated to total completion time ($r = -.08$), a confounding between IQ differences and total completion times is also possible.

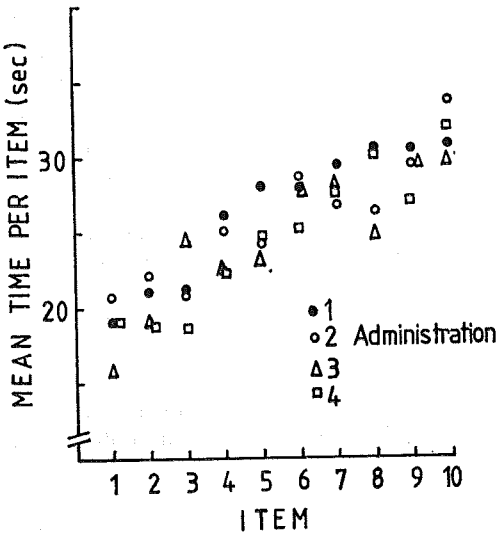

Figure 2. Mean item-completion times for successive items over four administrations (for 24 police recruits).

In Figure 2, mean completion time per item averaged over items of the four forms is shown plotted for each item separately for each of the four test administrations. As items progressed within a form, there was a systematic (and nearly linear) increase in the time required to complete each item. This increase primarily results from a progressive increase in item difficulty, and its monotonicity is the direct consequence of having arranged items within a form in order of increasing difficulty. The important feature of the Figure 2 data is that the *slope* of the linear function describes the *extent of change* in performance with successive items. This change may be used as a baseline against which the effects of situational variables may be compared. Further, the separate functions for the four administrations of the various forms of the test clearly overlap, demonstrating that the extent to which performance changes with successive items remained relatively stable with repeated administrations.

By collapsing total completion times and total correct responses for each of the four forms of the test over administrations it was possible to correlate performance on one form with performance on each other form. Table 2 gives inter-form correlations for response and time measures. Interestingly, correlations based on times are overall higher than those based on responses. A measure of alternate-form reliability was derived from the Spearman-Brown Prophecy Formula, employing mean inter-form correlations. For responses, the reliability coefficient was $r_{kk} = .687$, and for times, $r_{kk} = .865$. For the particular versions of the mental paper folding task we used here, therefore, test reliability was particularly high when measured in terms of task-completion time. The relative independence of time and response accuracy as performance measures was indicated by the fairly low (yet significant) product-moment correlations between total completion time and total correct accuracy. For Forms A, B, C, and D respectively, these correlations were .298, .207, .130, and .128, each based on the data for the 24 recruits.

Next we illustrate how the extent of change in processing speed over successive items (Figure 2) may be used to assess the effects of situational variables. Form A of the mental paper folding task was administered to 15 scientists, technicians and support per-

Table 2: *Inter-form product-moment correlations based on total correct responses and total completion times ($N = 24$)*

Correct Responses				
	Form A	Form B	Form C	Form D
Form A		.401	.280	.413
Form B			.497	.071
Form C				.463
Form D				
Completion Times				
	Form A	Form B	Form C	Form D
Form A		.647	.760	.668
Form B			.626	.382
Form C				.608
Form D				

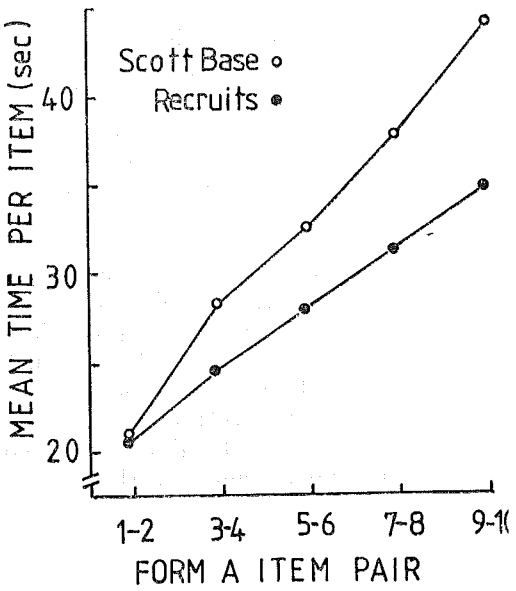

Figure 3. Mean item-completion times for successive item pairs of Form A for 24 police recruits (filled circles) and 15 Scott Base personnel (open circles).

sonnel at Scott Base, Antarctica (mean age 28), under much the same conditions as it was administered to the police recruits at Trentham, N.Z. Figure 3 shows the mean item-completion time plotted for successive pairs of the Form A items for both police recruits and Scott Base personnel. The data for the recruits (from Form A) is a subset of those presented in Figure 2 and accordingly shows the same linear increase in completion time with successive items. The function for the personnel located at Scott Base is also linear in form, but has an overall steeper slope, indicating that the extent of increase in information processing time is greater than for the recruits. Whereas an overall increase in processing time might result from factors specific to the especially-selected Scott Base personnel (or recruits), a change in the "extent of increase" index is the more likely result of working in the relatively isolated Antarctic conditions.

The greater rate of change in processing time for Scott Base personnel was indicated by a significant interaction between groups and items (F 4, 148 = 2.42, $p < .05$). The overall completion times for the Scott Base group were not significantly longer than for the recruits (F 1, 37 = 2.53, $p > .05$), although the general increase in item-completion time with successive items was highly reliable (F 4, 148 = 42.94, $p < .001$). The result is consistent with anecdotal reports of "mental slowing down" that occurs under Antarctic conditions (Taylor, 1980). The extent to which item-completion time progressively lengthens with successive items gives an index of the influence that task parameters, such as complexity and orientation differences, may have on processing speed. Accordingly, the increase in rate of change in completion time for the Scott Base group indicates an impairment of rate of information processing by (as yet unspecified) factors associated with working under Antarctic conditions.

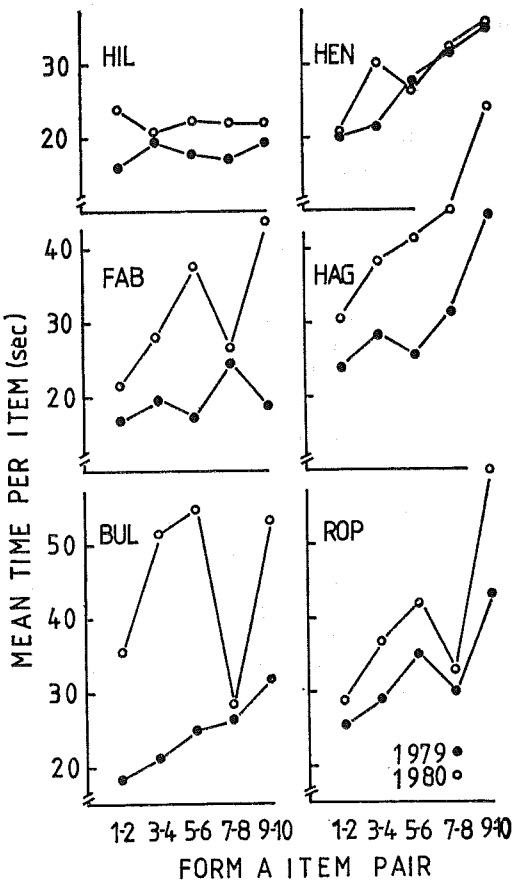

Figure 4. Mean item-completion times for six individuals before (August 1979, filled circles) and after (August 1980, open circles) wintering over at Scott Base, plotted as a function of successive item pairs of Form A.

Further illustration of our analysis of the effects of Antarctic conditions on processing time is offered by the data in Figure 4. Here the item-completion times for Form A are plotted as in Figures 2 and 3 for six individuals who had spent the winter at Scott Base. The function obtained before the wintering-over period (filled circles) shows the same general increase over items as in the previous figures. The function obtained one year later for the same individuals, although irregular in form, evidences a greater extent of "mental slowing down". Following wintering-over, item completion time was overall longer than a year earlier (F 1, 5 = 8.48, $p < .05$) and the general increase in item-completion time with successive items was reliable (F 4, 20 = 10.10 $p < .001$). The interaction between pre- and post-wintering conditions and item progression was however weak (F 3, 20 = 2.43, $.10 > p > .05$). A stronger interaction (or perhaps stronger monotonicity in the data of Figure 4) would verify extent of change in processing time as a sensitive measure of the effects of wintering-over in Antarctica. The overall increase in time following wintering-over did not reflect a change in accuracy, but may reflect the influence of some (unidentified) variable confounded with wintering-over effects. Pre- and post-wintering-over accuracies were not different and were highly correlated ($r = .93$).

Both examples we presented suggest that Antarctic conditions may conduce to cognitive impairment. The comparison between Scott Base personnel and police recruits revealed a differential rate of change in processing time for the two groups. The same interaction for the comparison between before and after wintering-over was weak, although overall longer completion times were recorded after wintering-over. The few previous studies provide no evidence for a general decrement in cognitive performance under Antarctic conditions (Gregson, 1978), perhaps owing to the relative insensitivity of measures employed. Chronometric analysis in cognitive research has justified time as a sensitive dependent variable. Further, rate-of-change measures derived from the manipulation of task parameters offer a powerful means of assessing the effects of situational variables on cognitive abilities. Here we suggested that Antarctic effects on cognitive performance may be elucidated through chronometric analysis, but we have yet to identify the specific aspects of contemporary working conditions in Antarctica which might be expected to alter cognitive performance.

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