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A method for measuring human behavioural and physiological responses at different stress levels in a driving simulator

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Summary

1. A method is described by which a car simulator can be used to measure, simultaneously, motor-perceptual performance and physiological responses of human subjects under different levels of task difficulty or stress.

2. Motor-perceptual performance was measured in terms of reaction times taken by subjects to carry out steering, braking and operation of traffic indicators in the simulator. Subjects were instructed to carry out the different driving manoeuvres by means of a command panel containing five coloured lights. Three levels of task difficulty or stress were devised. In level 1 only the light signals were used. In level 2 the driving simulator film was shown and all of the light signals reinforced the movements of the car in the film. Level 3 was similar to level 2, with the exception that whilst some of the light signals reinforced the movements of the car, others deliberately conflicted with it.

3. Physiological responses measured were heart rate, blood pressure, respiration and calf blood flow. Personality was also measured by means of the Cattell 16 personality factor questionnaire.

4. Analysis of variance of the performance of 15 subjects showed significant variation between the three task levels ($P = < 0.001$ for steering reaction times; $P = < 0.01$ for brake and indicator reaction times). In all cases the reaction times were longest for level 3, indicating that this was the most difficult task. The number of anticipated responses to steering, braking and traffic indicator signals was highest in level 2, while the number of corrections to steering and braking responses was lowest in level 2. None of these differences was statistically significant.

5. Of the physiological variables, the heart rate showed a progressive increase from task levels 1 to 3 but only those between levels 1 and 3 were statistically significant ($P < 0.05$).

6. The results are discussed in relation to the validity of the method. It is concluded that by means of this method it is possible to produce controlled and reproducible degrees of stress and under conditions which are also suitable for the investigation of pharmacological agents upon it.

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Introduction

This paper describes a method by which a car simulator can be utilized to measure motor-perceptual performance and physiological responses of human subjects simultaneously under various conditions. To date, the method has been used to measure the responses of human subjects exposed to stress in the form of driving tasks of varying difficulty, together with the effects upon them of smoking. In addition, other factors such as personality can be measured and correlated with physiological and behavioural responses and these results are reported separately (Ashton, Savage, Telford, Thompson & Watson, 1972).

The Link Driver Trainer, a commercially available driving simulator, was substantially modified and used in conjunction with conventional physiological transducers and recording equipment. The principle of using a car simulator for the measurement of drug effects in man is not new (see, for example, Marquis, Kelly, Miller, Gerrard & Rapoport, 1957 ; Drew, Colquhoun & Long, 1958 ; Loomis & West, 1958a & b ; Hughes, Cramer & Knight, 1967) and recently, Goldman, Comerford, Hughes & Nyberg (1969) used the standard Link Driver Trainer to investigate the effects of alprenolol with and without ethyl alcohol upon driving performance. However, the method described in this paper has the considerable advantage that it makes possible the simultaneous measurement of performance and physiological changes in human subjects under realistic conditions, where the level of task stress is reproducible and can be varied in degree.

Methods

Brief outline of experimental procedure

Each subject was required to carry out certain driving operations at three levels of task difficulty (levels 1, 2 and 3), whilst seated in a car simulator. For each driving manoeuvre, the subject received instructions by means of a series of coloured light signals mounted on a command panel above the dashboard. Behavioural and physiological responses of the subject were recorded in an adjacent control room.

Laboratory layout

Figure 1 shows how the apparatus was installed in two adjacent rooms. In one room, the subject sat in the car simulator and was connected to appropriate recording electrodes and transducers. Cables linked the simulator, electrodes and transducers to recording equipment placed in the adjacent room, operated by personnel in charge of the experiment. Throughout each experiment the subject could be observed directly through a ' one-way ' glass screen and also indirectly via closed circuit television ; two-way speech communication was possible by means of intercom equipment. All necessary connexions between the two rooms passed through a small hole in the connecting wall. An air conditioner maintained the temperature of the subject's room at $21{\cdot}5 \pm 1{\cdot}7°$ C.

Procedure carried out by subject

The 15 subjects were volunteers, 9 males and 6 females with a mean age of 20·8 years (range 19–26 years) and with an average of 3 years driving experience.

All subjects were non-smokers. They were asked to carry out five procedures in the following order:

1. To complete a questionnaire to establish the subject's driving experience and medical history.

2. Each subject then sat in the car simulator and recording electrodes for ECG and respiration; blood pressure cuffs and blood flow transducers were fixed in position.

3. Each subject then completed a Cattell personality inventory which measures 16 primary and 4 second order personality characteristics. This occupied about 30 min and also provided sufficient time for each subject to become familiar with the laboratory surroundings.

4. The driving task was then explained to each subject. The command panel

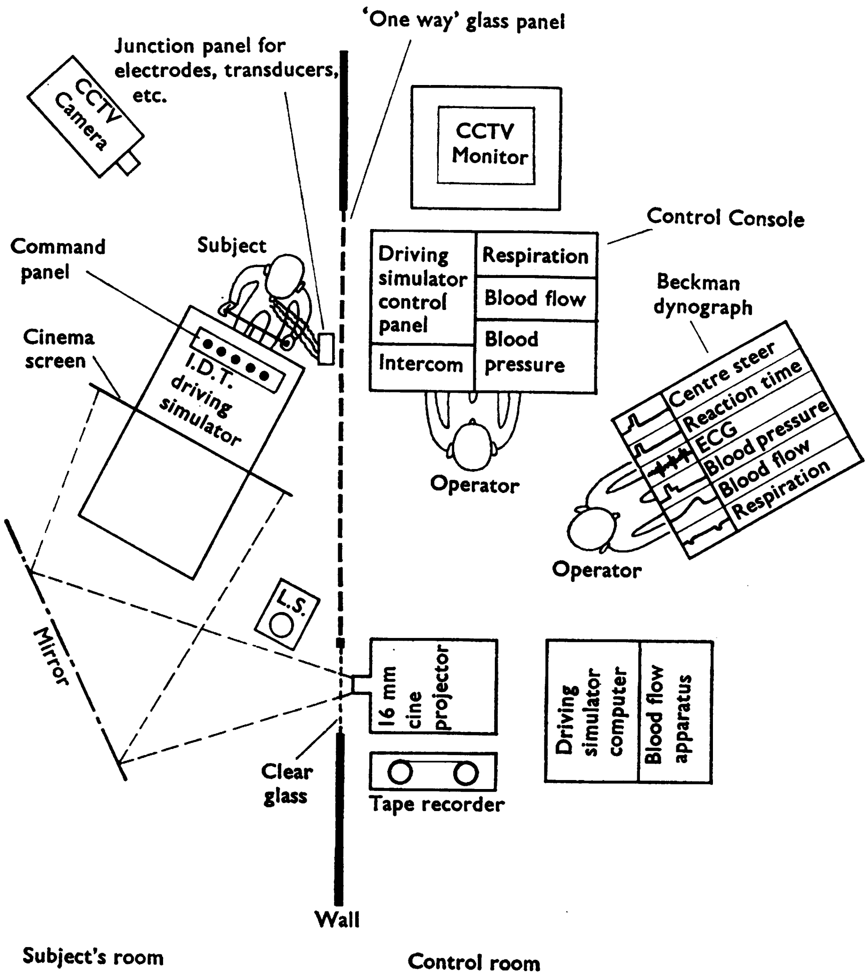

FIG. 1. Diagram showing layout of apparatus in subject's room (left) and control room (right). For the sake of clarity, the connecting cables between the different items of apparatus have not been shown. L.S. = loudspeaker.

COMMAND PANEL

1. Command signal lights	green	amber	red	amber	green
2. Meaning of signal	Switch on left traffic indicator	Light, medium or hard steer left*	Light, medium or hard brake*	Light, medium or hard steer right*	Switch on right traffic indicator
3. Action which must be taken by subject to extinguish signal light	Switch on left traffic indicator	Steer left until light extinguished	Press brake pedal until light extinguished	Steer right until light extinguished	Switch on right traffic indicator
4. Incorrect responses possible	No action taken	1. No action taken 2. Oversteering on light or medium steer 3. 2 with correction 4. Anticipatory response 4. Off centre on the opposite side to that involved in the next manoeuvre	1. No action taken 2. Overbraking on light or medium brake 3. 2 with correction	1. No action taken 2. Oversteering on light or medium steer 3. 2 with correction 4. Anticipatory response 5. Off centre on the opposite side to that involved in the next manoeuvre	No action taken

* For full explanation see text.

FIG. 2. Scheme showing (1) the five signal lights of the command panel, (2) the meaning of each signal, (3) the correct action which must be taken by the subject in order to extinguish the signal and (4) the possible incorrect responses to each signal. Note that the steer and brake signals each call for one of three possible responses, the correct one of which can only be determined by trial and error.

(Fig. 2) contained five coloured signal lights which represented five different commands, namely, brake, left or right steer and left or right traffic indicator. The lights were switched on singly for set periods of time and the subject's task was to carry out the correct driving manoeuvre as quickly as possible and thereby extinguish the appropriate light. The command signal for the left or right traffic indicator simply required the corresponding trafficator to be switched on in order to extinguish the command light. On the other hand, the brake and left and right steer signals were more complicated. The appearance of one of these signals (brake, left or right steer) called for one of three possible degrees of response, the correct one of which could only be discovered by trial and error. Thus, illumination of the brake signal required either a light, medium or hard brake; similarly the steer signals called for either light, medium or hard steer in the left or right direction. In each instance, the only indication to the subject that the correct response had been carried out was the extinction of the appropriate light. If the subject over-responded this was indicated by the reappearance of the particular light signal. For example, if the brake command signal called for a light brake response but actually evoked from the subject a medium brake response, the command signal would first extinguish but then reappear; only after pressure to the brake pedal had been reduced sufficiently to apply the correct pressure would the brake light signal be re-extinguished.

In level 1 the subject was shown the light signals alone, while in levels 2 and 3 a film was shown at the same time as the signals were displayed on the command panel. Under these conditions the subject was asked to drive to the film, but always to give precedence to the light signals. In level 2 all the signals reinforced the movements of the car, whereas in level 3 only some of them did; the remainder conflicted. The film sequence was originally photographed in busy traffic conditions and was accompanied by appropriate traffic noise reproduced by a loud speaker in the subject's room. The duration of the film was 20 min and it was shown twice to each subject (levels 2 and 3).

5. The three driving tasks of varying difficulty, levels 1, 2 and 3, were then presented to each subject in randomized order. During each of these 20 min tasks, the subject's responses to a total of 122 light signals were recorded simultaneously with those of ECG, blood pressure, limb blood flow and respiration. During a five minute period at the end of each level, physiological measurements were made under resting conditions and the subject was warned to expect these.

Apparatus

A standard version of the Link Driver Trainer (Indoor Driver Trainers Ltd.) was modified as follows:

(i) In place of the standard instructional films, a special 16 mm colour film of 20 min duration was made by the Road Research Laboratory (for details see under section headed 'Driving simulator control system').

(ii) A special command light panel was constructed which contained 5 coloured lights (see Figs. 1, 2 and 3). These were connected to the existing relay circuits of the simulator so that each light was switched on by a particular driving instruction recorded on the film in the form of a magnetic code.

(iii) A transparent cinematograph screen was mounted above the driving console and the film back-projected on to it via a mirror (see Fig. 1). The view seen by the subject seated in the driving simulator was that taken by the film camera which had been carefully positioned in the driver's seat of the special film car (a Humber ' Snipe ' with left hand drive) owned by the Road Research Laboratory. Thus during film projection the subject was given the impression of looking out of the windscreen of a car moving in busy traffic.

Recording system

The results of each experiment were recorded on six channels of a Beckman eight channel Dynograph. The output from each transducer and set of electrodes was fed either directly, or indirectly via other equipment, to one of the channels and displayed by pen galvanometers writing on moving paper. Details of each channel are as follows (see also Fig. 1):

Channel 1: Centre steer was indicated by the movement of a pen connected to rotating contacts mechanically linked to the steering wheel. On this record the pen moved between the two positions of 'on centre' and 'off centre' and thereby indicated from what position of the steering wheel any driving manoeuvre had started.

Channel 2: Reaction times of the subject during traffic indicator, steering and braking responses were recorded by the stepwise movements of a pen connected to a series of switches linked to the traffic indicator, steering wheel and brakes. In the case of steering it was possible to measure not only the total reaction time, but also its two components, action time and response time (see Fig. 3).

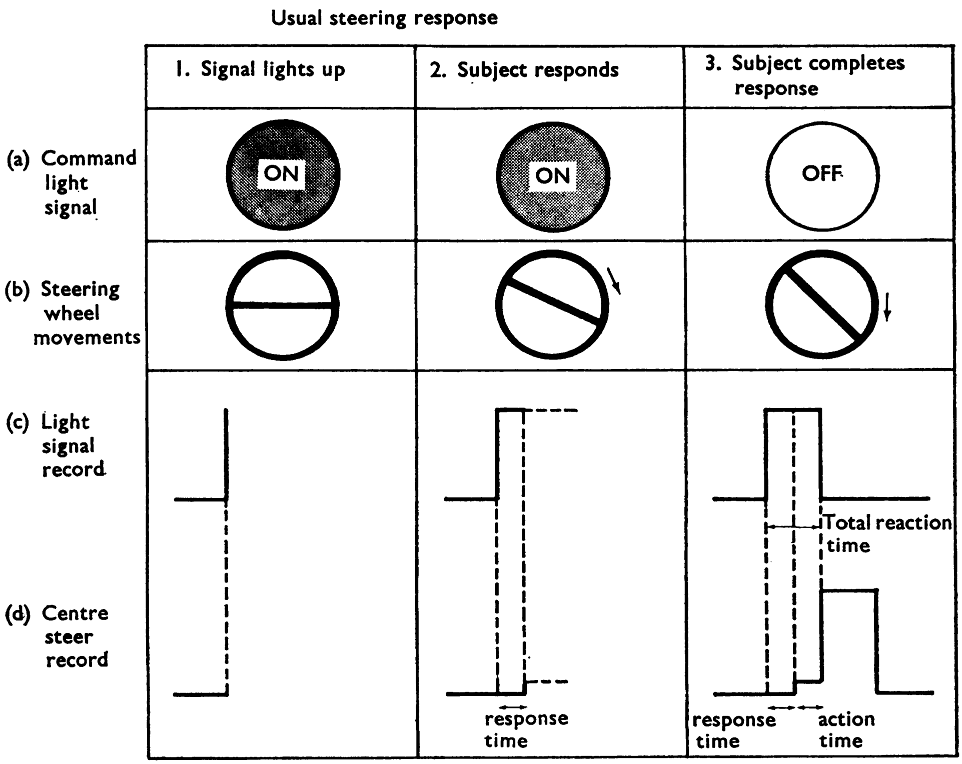

FIG. 3. Diagram to illustrate the relationship between (a) the command light signals and (b) the movements of the steering wheel, with the recordings of (c) the light signal channel and (d) the centre steer channel during a usual steering response. The diagram indicates the excursions of the pen recordings from which the response and action times are measured (see also Fig. 5 for actual record).

Channel 3: ECG was recorded by means of three Beckman skin electrodes fixed to the skin over the upper end of the sternum.

Channel 4: Blood pressure was recorded by means of a special inflatable cuff placed around the left upper arm and connected to a Godart Haematonograph. The blood pressure readings could be taken direct from the meters on the Haematonograph, but the output was also fed onto the pen of channel 4.

Channel 5: Limb blood flow was measured by means of venous occlusion plethysmography with a Witney type mercury-in-rubber strain gauge (Devices) placed around the left calf. An inflatable cuff was placed around the left thigh and this was inflated semi-automatically from an apparatus in the control room (see Fig. 1).

Channel 6: Respiration was recorded by means of impedance plethysmography (E & M Instrument Co.) using two Devices electrodes attached to the skin overlying the left and right tenth intercostal space.

Driving simulator control system

The driving simulator was controlled by a series of coded signals recorded on 16 mm film. These signals were decoded and then made to operate the lights on the command panel (see Figs. 2 and 3). In level 1 (signals without film) the codes

TABLE 1. *Stress levels*

	Level 1	Level 2	Level 3
Duration (min)	20	20	20
Use of film	None	+	+
Reaction times:			
Steering	+	+	+
Brakes	+	+	+
Relation between car movement in film and command signal lights	Not applicable	Always reinforced	Sometimes reinforced, sometimes conflicted
Appropriate traffic noise	—	+	+
Physiological measurements made during task and rest periods	+	+	+

Table 1 shows the features of the experiment pertinent to the three stress levels.

were recorded on 16 mm perforated magnetic tape. In levels 2 and 3 (signals with film) each code was recorded on the magnetic stripe of 16 mm film and was thereby synchronized with a particular sequence of the film. In all three levels each code was followed by a cancelling code which occurred either 2·5 s after all signals which reinforced the film (levels 1 and 2; some of level 3), or 3·5 s after those signals in level 3 which conflicted with the film. Each cancelling code reset the apparatus ready to receive the next signal, whether or not the subject had responded to the previous signal.

Timing of physiological recordings

Of the physiological recordings, ECG and respiration were continuous, whilst blood pressure and blood flow were intermittent and operated semi-automatically. Since the latter two recordings were subject to movement artefact, each measurement was carefully timed to take place during an interval when no signals occurred.

Note on measurement of reaction times and physiological responses from records

All reaction times were read off directly from the records (see Figs. 3 and 5). It was also possible to determine from the records any anticipated or corrected responses. For braking and indicator responses 'minimum reaction times' were calculated from the mean results of a small number of separate experiments in which each subject, seated in the simulator with both hands on the steering wheel and the right foot on the accelerator pedal, responded as quickly as possible to appropriate light signals. From these results it was determined that a brake reaction time of less than 0·5 s or an indicator reaction time of less than 0·2 s was not possible unless the subject had anticipated these responses (in advance of the signal) by having placed the right foot on the brake pedal or the right hand on the indicator switch, respectively. Anticipated steering responses could also be detected from the tracings by noting the position of the centre steer record; if this was 'off centre' before the appearance of a steering signal, this clearly indicated that the steering response had been anticipated.

Corrected responses were clearly identifiable from the light signal record; an

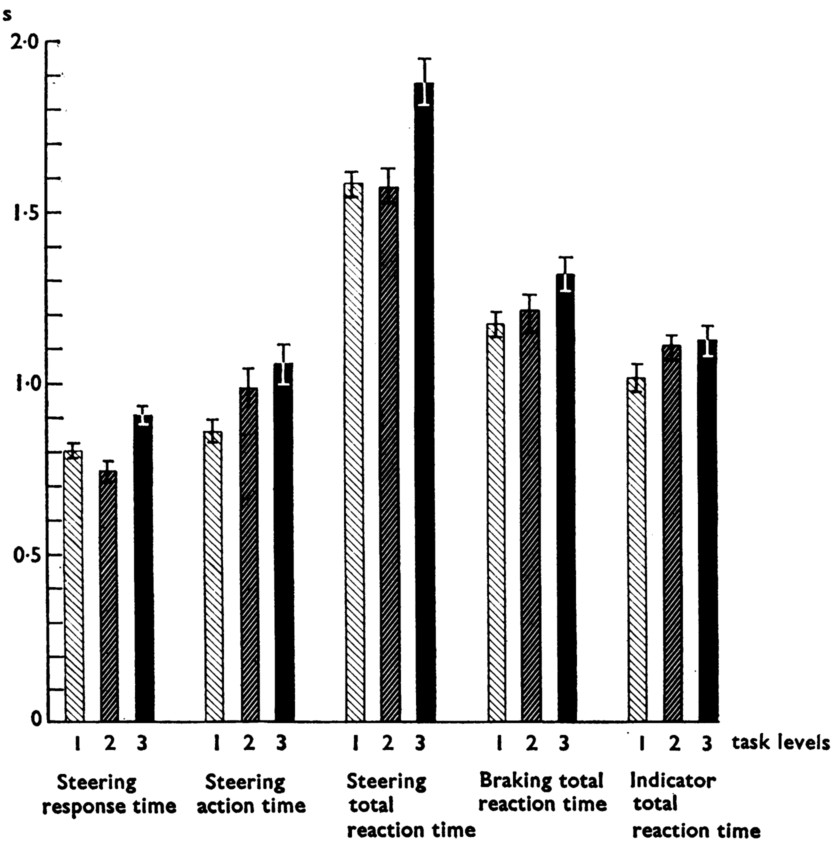

FIG. 4. Histogram of mean reaction times (and standard error of the mean) of 15 normal subjects for steering, braking and indicator responses at three levels of task difficulty. (Data from Table 2).

example is illustrated in the middle of the group of three light signal records shown in Fig. 5.

To measure pulse rate (in the form of ECG) and respiration rate, each continuous record was sampled for a period of one minute during every fifth minute. The mean heart rate or respiration rate was therefore the mean value calculated from these individual readings. For blood pressure and blood flow measurements the mean value of the individual readings over the period indicated in the text was calculated.

Results

The results of the measurements described above on the 15 normal subjects were analysed to see if the assumed differences in task level difficulty were associated with differences in performance or physiological responses.

Performance

Measurement of the responses showed significant differences between the three task levels. The results are shown in Table 2 which gives the means, standard deviations, and analyses of variance for steering, braking and indicator responses. The results for slight, medium, and hard steering were pooled to give a single

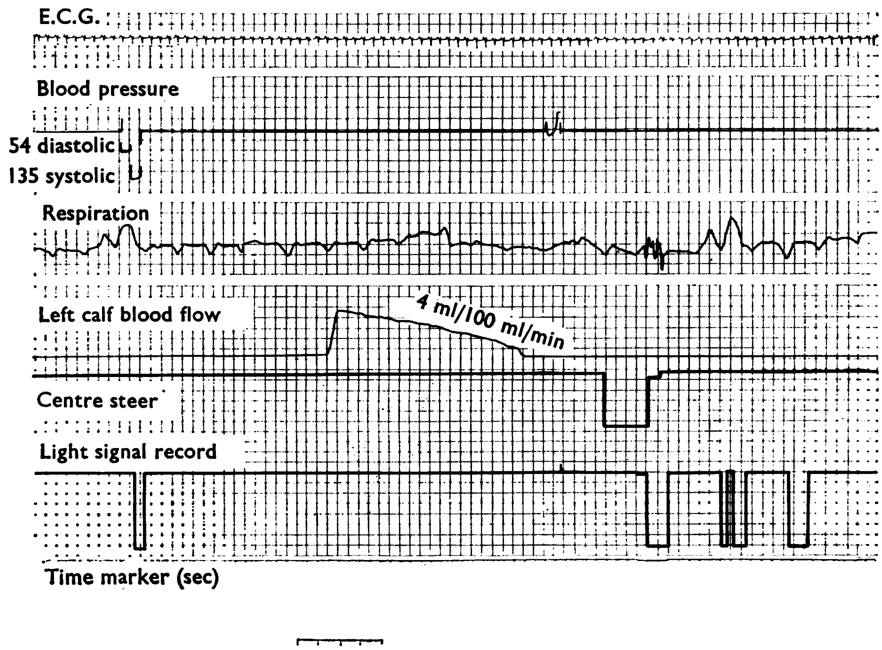

FIG. 5. Specimen record of electrocardiogram (ECG), blood pressure, respiration (inspiration downwards), left calf blood flow, centre steer and light signal records made during an experiment; this record reads from right to left. For the purposes of reproduction the record has been retraced and unused areas of chart paper between the individual records have been removed to make the figure more compact. There is an artefact in the blood pressure record which is also detectable as a spike in the light signal record. For further details see text and also Fig. 3 (where the light signal and centre steer records are shown inverted).

measure of steering and the braking responses were pooled similarly [See also Fig. 4 (histograms)].

(a) *Steering responses* (see Fig. 3)

Response time. This showed a significant difference between the three task levels ($P<0{\cdot}001$). The mean response time was longest for task level 3, indicating that this was the most difficult task. The mean response time for level 2 was, however, slightly less than for level 1.

TABLE 2. *Reaction times (in seconds) for steering, brakes and indicators for* 15 *subjects performing task levels* 1, 2 *and* 3

Steering				
Response time				
	Level 1	Level 2	Level 3	
Mean	0·8021	0·7436	0·9048	
Standard deviation	0·0761	0·1044	0·1153	
Variance source	Degrees of freedom	Mean square variance	F	*P*
Between levels	2	0·0999	12·6455	<0·001
Subjects	14	0·0142	1·7972	n.s.
Residual	28	0·0079		
Steering				
Action time				
	Level 1	Level 2	Level 3	
Mean	0·8632	0·9848	1·0570	
Standard deviation	0·1244	0·2154	0·2475	
Variance source	Degrees of freedom	Mean square variance	F	*P*
Between levels	2	0·1438	6·7196	<0·01
Subjects	14	0·0805	3·7616	<0·01
Residual	28	0·0214		
Steering				
Total reaction time				
	Level 1	Level 2	Level 3	
Mean	1·5812	1·5758	1·8763	
Standard deviation	0·1276	0·1972	0·2445	
Variance source	Degrees of freedom	Mean square variance	F	*P*
Between levels	2	0·4434	25·1931	<0·001
Subjects	14	0·0798	4·5340	<0·001
Residual	28	0·0176		
Brakes				
	Level 1	Level 2	Level 3	
Mean	1·1680	1·2034	1·3189	
Standard deviation	0·1326	0·2116	0·1857	
Variance source	Degrees of freedom	Mean square variance	F	*P*
Between levels	2	0·0934	8·0517	<0·01
Subjects	14	0·0737	6·3534	<0·001
Residual	28	0·0116		
Indicators				
	Level 1	Level 2	Level 3	
Mean	1·0132	1·1001	1·1200	
Standard deviation	0·1469	0·1352	0·1705	
Variance source	Degrees of freedom	Mean square variance	F	*P*
Between levels	2	0·0484	8·0666	<0·01
Subjects	14	0·0569	9·4833	<0·001
Residual	28	0·0060		

Action time. For this measure there was again a significant difference between levels ($P<0{\cdot}01$) and also between subjects ($P<0{\cdot}01$). In this case the mean action time increased progressively from levels 1 to 3.

Total reaction time. The variances between the three levels was significantly different for total reaction time ($P<0{\cdot}001$) and the mean total reaction time in level 3 was again the longest. There was little difference between the mean total reaction times for levels 1 and 2. There was also significant variation ($P<0{\cdot}001$) between the subjects.

(b) *Brake reaction times*

The mean reaction time showed a consistent and significant ($P<0{\cdot}01$) lengthening from level 1 to level 3. There was also a significant difference between subjects ($P<0{\cdot}001$).

(c) *Indicator reaction times*

Difference between levels for this response were also significant ($P<0{\cdot}01$) and there was a consistent lengthening in mean reaction time from level 1 to level 3. There were also significant differences between subjects ($P<0{\cdot}001$).

The results for performance indicate that the level 3 task was more difficult than the other two tasks as measured by the significantly longer reaction times for all the responses measured in the car simulator. There was, however, little difference in performance between level 1 (signals but no film) and level 2 (signals and corresponding film). For future experiments, using drugs, it was therefore decided to utilize levels 2 and 3 only as tasks in which the degree of stress (task difficulty) could be varied as shown by the above results in normal subjects.

(d) *Corrected responses and anticipated responses*

Table 3 shows the mean number of corrections and anticipations made by the subjects during levels 1, 2 and 3. Incorrect steering and braking responses could be corrected and figures shown represent the combined means of these values. Level 2 showed the smallest number of corrections and level 1 the highest. All three responses could be anticipated and the figures in Table 3 are the combined means of steering, braking and indicator responses. Level 1 showed the smallest number of anticipations and level 2 the highest.

Physiological responses

Four physiological variables were measured: heart rate, calf blood flow, blood pressure and respiration rate. Of these, the heart rate showed a progressive increase from task level 1 (mean 81·23 beats/min) to level 2 (mean 83·74 beats/min) and to level 3 (84·35 beats/min). Only the differences between levels 1 and 3 were significant ($t=2{\cdot}1915$; $P<0{\cdot}05$).

Blood flow, blood pressure and respiration, while driving and watching the film were not significantly different from the values recorded during the level 1 task.

TABLE 3

	No. of corrections (combined means of steers and brakes)	No. of anticipations (combined means of steers, brakes and indicators)
Level 1	12·53	1·2
Level 2	7·73	17·2
Level 3	11·93	11·4

Personality characteristics of 15 non-smokers

The Cattell 16 personality factor questionnaire showed that all subjects fell within the normal range on all primary and second order personality dimensions.

Discussion

In the field of human psychopharmacology, there is an urgent need for the development of objective methods by which to test the effects of centrally active and other drugs in man. For example, large numbers of people smoke cigarettes, but few satisfactory attempts appear to have been made to measure objectively in a real-life situation the effects of smoking on stress and to correlate these results with other factors such as physiological responses and personality.

As the first step in devising a suitable method of measuring drug responses, it is necessary to expose subjects to carefully controlled and reproducible conditions. It is exceedingly difficult to satisfy these criteria under natural conditions and so in the present study, a group of subjects who held a driving licence were asked to operate a driving simulator. Thus, the conditions used were a compromise between a natural situation and an artificial one ; the subjects carried out a familiar task under controlled laboratory conditions. It is important to appreciate that the results of these experiments should not be applied directly to the real driving situation, although it is possible that they may have some relevance to it.

Behavioural responses were determined by measuring the reaction times to each driving task and at varying levels of difficulty. The overall pattern of the total reaction times suggests that there is a direct relationship between the magnitude of these and the complexity of a task. An increase in the level of stress or task difficulty appeared to increase the duration of the total reaction time.

The steering response was also analysed in greater detail by examining the two components of which it consisted, namely, the response and action times. The values for these differed significantly over the three task levels ($P<0{\cdot}001$ and $P<0{\cdot}01$ respectively). The steering response time was shortest not for level 1, but for level 2 and longest for level 3. A likely explanation for this result is that in level 2 the presence of the film assisted the subject to make the correct steering manoeuvres because each driving task in the film always corresponded with an appropriate light signal and so made the latter more predictable. There is evidence to show that as the predictability of a signal increases, especially in a constant environment, the response time to it shortens (Broadbent, 1964 ; Nicely & Miller, 1957 ; Blair & Kaufman, 1959). On the other hand, in level 3 the presence of a proportion of light signals which conflicted with the film reduced the predictability of stimuli to below that in level 1 (where since the film was absent conflict could not occur) with the result that the mean steering response times were significantly increased.

Steering action time, that is the time taken by the subject to complete the required steering manoeuvre, became progressively longer with increasing task difficulty. Thus, the pattern was not the same as that of the steering response times and suggested that the combination of light signals and complementary film (level 2) produced different effects on the steering action time. Whereas in level 1 the subject was able to devote full attention to the light signals, in levels 2 and 3 attention was divided between the light signals and the film. This might tend to lengthen action time because under these conditions the appearance or disappearance of a light signal could be missed due to momentary diversion of attention.

Analysis of the number of anticipations and corrections recorded in the three levels illustrated the subtle distinction between the anticipatory and predictive powers of the film stimuli on the responses of these subjects. Thus compared to level 1, the reinforcing effect of the film in level 2 resulted in a fourteenfold increase in the number of anticipations, whilst the number of corrections was reduced by over a third. On the other hand, in level 3 the presence of the film with which the light signals sometimes corresponded and sometimes conflicted, increased the number of anticipations over ninefold without causing any substantial reduction in the number of corrections, compared to level 1.

The added facility by which it was possible for the subject to correct a steering or braking manoeuvre and also for this to be recorded extended the usefulness of the driving simulator. It increased the degree of simulation by introducing a 'closed servo-loop' component in which the subject was not only able to observe the effects but also to delicately adjust his responses on steering, indicator and brakes. The remainder of the system formed an 'open servo-loop' because the movement of the car in the film could not be influenced by the subject's responses. Simulators with fully closed servo-loop systems have been devised, but they are very complex technically and of prohibitive cost. The relatively simple adaptation of the present apparatus made it possible to study a more complex and sophisticated behavioural system which may well be altered by drugs having little or no effect on simpler all or none responses.

Of the physiological responses measured, the only significant effect was seen in heart rate which showed an increase with increasing task difficulty, suggesting that the degree of 'physiological stress' increased from task levels 1 to 3.

Thus the results of these experiments show that in spite of its limitations the method is valid and reproducible and the tasks may be regarded as of different difficulty levels. The results obtained with it in testing the effects of smoking are reported in a separate paper (Ashton, *et al.*, 1972).

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REFERENCES

ASHTON, HEATHER, SAVAGE, R. D., TELFORD, ROSEMARY, THOMPSON, J. W. & WATSON, D. W. (1972). The effects of cigarette smoking on the response to stress in a driving simulator. *Br. J. Pharmac.*, **45**, 546–556.

BLAIR, W. C. & KAUFMAN, H. M. (1959). *Command control.* I: Multiple display monitoring; II: Control–display spatial arrangement. General Dynamics Corporation, Electric Boat Division, Groton, Conn. Report No. SPD 59–082.

BROADBENT, D. E. (1964). Vigilance. *Br. med. Bull.*, **20**, 17–20.

DREW, G. C., COLQUHOUN, W. P. & LONG, M. A. (1958). Effects of small doses of alcohol on a skill resembling driving. *Br. med. J.*, **5103**, 993–9.

GOLDMAN, V., COMERFORD, B., HUGHES, D. & NYBERG, G. (1969). Effect of β-adrenergic blockade and alcohol on simulated car driving. *Nature, Lond.*, **224**, 1175–1178.

HUGHES, D. T. D., CRAMER, F. & KNIGHT, G. J. (1967). Use of a racing car simulator for medical research. *Med. Sci. and the Law*, **I**, 200–204.

LOOMIS, T. A. & WEST, T. C. (1958a). The influence of alcohol on automobile driving ability. *Quart. J. Stud. Alcohol*, **19**, 30–46.

LOOMIS, T. A. & WEST, T. C. (1958b). Comparative sedative effects of barbiturate and some tranquilliser drugs on normal subjects. *J. Pharmac. exp. Ther.*, **122**, 525–531.

MARQUIS, D. G., KELLY, E. L., MILLER, J. G., GERRARD, R. W. & RAPOPORT, A. (1957). Experimental studies on behavioural effects of meprobamate on normal subjects. *Ann. N.Y. Acad. Med.*, **67**, 701–710.

NICELY, P. E. & MILLER, G. A. (1957). Some effects of unequal spatial distribution on the detectability of radar targets. *J. exp. Psychol.*, **53**, 195–198.

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