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Effects of Prolonged Driving on Time Headway Adopted by HGV Drivers

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Truck driver safety was studied under conditions of prolonged normal driving, prolonged continuous convoy driving, and continuous convoy driving under conditions of task uncertainty. In all experiments drivers were required to drive an experimental truck for 4 consecutive days. Dependent variables were driver performance, self-ratings, and endocrine changes. Apart from changes over time, when possible the effects of age and time of work period onset were determined. (Continued)

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Symptoms of fatigue were most typical of the end of the driving shift, becoming evident from about the 9th hour of driving, and were particularly characteristic of older drivers on a shift finishing at 02.30 hours. Nevertheless, the requirement to drive 11 hours per day for 4 consecutive days did not lead to conspicuous deterioration in driving performance under normal driving conditions. Even prolonged continuous convoy driving did not produce impairment but elicited compensatory adjustments toward the end of the late shift. Finally, task uncertainty was not found to induce earlier fatigue. Drivers appeared to adjust to this condition by covertly anticipating a demand in excess of actual requirement.

A behavioural analysis of the driving task is proposed, and amongst other features its implications for driver fatigue and traffic accidents are discussed.

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EFFECTS OF PROLONGED DRIVING ON TIME HEADWAY ADOPTED BY HGV DRIVERS

EXECUTIVE SUMMARY

This study was concerned with the effects of prolonged driving on heavy goods vehicle (HGV) drivers and in particular with the time headways drivers adopt in following situations. It incorporated a replication of the late shift of an earlier study that had very few observations for some of the driving periods studied because of the paucity of naturally occurring sequences of vehicle following. Additional following was contrived in the present study by using a second vehicle that intercepted the experimental HGV at intervals.

Subjects were six volunteer professional truck drivers, each paid $160 for participating in the project. They were required to drive an instrumented 7-ton Bedford rigid van-type truck for 11 hours from 15.00 hours to 02.30 hours on each of 4 consecutive days over a preselected route of approximately 300 miles. Driving was continuous except for a 30-minute meal break after 5.5 hours and a 5-minute break during each 5.5-hour period. Time headway for all following episodes was continuously recorded, sampled, and analysed as described in Fuller, McDonald, Holahan, and Bolger (1978). Also obtained were subjects' hourly self-ratings of performance, motivation, and fatigue; a daily profile of sleep quality and drug usage; and pre-post samples of five endocrine hormones.

It was found that drivers tended to adopt shorter headways on the late shift, and this effect is interpreted by reference to drivers' expectations of sharp velocity decreases in the leading vehicle. A close association between time headway and time headway variability was also found. It is argued that this is caused by differences in ease of detection of distance change, in requirements to respond to lead vehicle speed variations, and in the stability of the lead vehicle velocity.

Overall, no detrimental effects of prolonged driving were found, although subjects' ratings and the endocrine assay results provided some tentative evidence that the older drivers were less able than the younger drivers to accommodate to the task demands of the late shift.

EFFECTS OF PROLONGED DRIVING ON TIME HEADWAY ADOPTED BY HGV DRIVERS

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INTRODUCTION

The aim of this study was to replicate, with slight modification, part of an earlier study that attempted a preliminary exploration of the relationship between prolonged driving and time headway in heavy goods vehicle (HGV) drivers (see Fuller, 1978, 1979; McDonald, 1978). In that study, 12 professional HGV drivers drove an instrumented 7-ton Bedford rigid van-type truck for 11 hours on each of 4 consecutive days over a preselected route of approximately 300 miles repeated each day. Time headway adopted by the drivers each time they followed another vehicle (a following episode) was monitored and recorded using a closed circuit television system mounted on the experimental HGV (Fuller et al., 1978). Drivers were assigned to one of two age groups and within each group allocated at random to one of two driving shifts that started at either 09.00 hours or 15.00 hours. In addition to the recording of time headway and its variability, subjects' own ratings of performance, fatigue, and motivation and a profile of endocrine measures were obtained.

Although no detrimental effects of prolonged driving on performance were found, some apparently time-related changes were observed. Shortest mean time headways occurred in the 2nd and 5th hours of driving on both shifts. In addition, the accumulation of hours of driving was generally associated with a decrease in the variability of time headway, indicating a more stable following performance over time.

One difficulty encountered in that initial study was the paucity of naturally occurring following episodes, particularly during the later driving shift (15.00 to 02.30 hours). Because of the consequent unreliability of the headway samples, no analysis of time headway was attempted for Hours 4, 8, 9, and 10. This study attempted to overcome that problem by replicating the late shift of the earlier study with a modification that ensured that reliable samples of following behaviour would be obtained, especially after Hour 3. In this replication, a second vehicle intercepted the experimental HGV at random points along the scheduled route to impose a following requirement on the HGV driver.

METHOD

With the exception of the introduction of a second vehicle to create additional following episodes, the method of the earlier study was followed.

Subjects

Subjects were six volunteer professional HGV drivers, each paid $160 for participating in the study. They were divided into two age groups; the younger group had a mean age of 25.3 years (sd = 5.0) and the older group had a mean age of 43.6 years (sd = 13.3). These compare with means of 28.8 years and 41.3 years in the original study.

Driving Task

Each subject was required to drive an instrumented 7-ton Bedford rigid van-type truck for 11 hours on each of 4 consecutive days over a preselected route of approximately 300 miles of main roads, repeated on each day. The route consisted of two loops out of and returning to Dublin, the same loop being driven first on each day. The route as a whole was novel for the drivers, although most of the roads involved were familiar to all of them. The driving was continuous except for a 30-minute meal break after 5.5 hours and one 5-minute break during each 5.5-hour block to refuel a petrol-driven AC generator that powered the research instrumentation. All subjects drove a shift starting at 15.00 hours and ending at 02.30 hours.

Performance Measures

The driving performance of interest was mean time headway and its variability, monitored and recorded using a closed circuit television system described in detail in Fuller et al. (1978). Provision was also made for recording vehicle braking to assist in comparing the task demands of the two 5.5-hour blocks of driving. Also recorded at the start of each session were the duration and quality of the subject's sleep the previous night, the subject's consumption of drugs and medicines, and the subject's feelings during the previous hour. This information was obtained to provide a check on the comparability of the different days on which each driver participated. At the end of each 5.5-hour session, self-ratings of performance, motivation, and fatigue were obtained by administering a checklist to drivers that required them to rate a number of variables on a 5-point scale for approximately each hour of driving.

Endocrine Measures

Two 20-ml blood samples were taken from each subject immediately before and after driving each day and a daily 11.5-hour urine sample was collected during the driving period. Samples were also collected at corresponding times on the day immediately preceding the experiment to provide a simple control measure. The samples were assayed for blood cortisol, testosterone, and prolactin and urine adrenalin and noradrenalin. The results from this analysis are presented and discussed in relation to the original study elsewhere (Cullen, Fuller, & Dolphin, 1979) and will not be treated in detail here.

Contrived Following Episodes

In the previous study it was found that after the 3rd hour of driving the frequency of naturally occurring following episodes was inadequate for reliable analysis. Therefore, beginning with the 4th hour, additional following episodes were created by a second vehicle that intercepted the HGV at random points during each hour. The vehicle used was a 15 cwt. Volkswagen van, always driven by the same driver.

For each episode the leading vehicle appeared on the road well ahead of the experimental HGV and then permitted the latter vehicle to catch up. This procedure resulted in a 132% increase in the number of observations of time headway obtained compared with the observations of the late shift of the earlier study. The frequency distribution of observations by hour for each study is presented in Table 1. The amount of time each driver spent following increased from approximately 12 minutes per day in the first study to 30 minutes per day in the current one.

Table 1

Number of Time Headway Samples per Hour for Late Shift

Study	Hour 1	2	3	4	5	6	7	8	9	10	11
Original	1,530	746	259	89	230	556	25	33	3	56	61
Present	875	1,651	629	432	1,156	1,162	512	496	850	545	751

Procedure

Each subject went to the Biological and Medical Research Institute at St. James' Hospital, Dublin, at 15.00 hours for 5 consecutive weekdays. On Day 1 the first blood sample was taken. The subject was instructed in detail on the complete procedure for the remainder of the experiment, was asked to complete a short form of the Eysenck Personality Inventory, and was also given a brief "check-out" on the controls of the experimental vehicle. He was then given two bottles to collect his urine for the next 11.5 hours and asked to return to the Institute for a further blood sample at 02.30 hours. Thus Day 1 was used both to familiarise the subject with experimental procedure and to obtain reference baseline values for the endocrine analysis.

On Days 2 through 5, the general procedure was the same as for Day 1, but in addition the subject carried out the driving task described earlier and completed an additional questionnaire that related to his reactions to the experiment as a whole.

The subject was told that he would encounter a white Volkswagen van driven by a member of the research team at odd times during his shift to increase the traffic density he experienced. He was told to treat the van as he would any other vehicle on the road. At no point in the study was the driver informed that his following performance was under observation. He was told that the television cameras mounted in the HGV were there "to record traffic conditions" and the main purpose of the study was "to explore the effects of prolonged driving on hormone secretion." This maintained the unobtrusiveness of the time headway measurement.

Data Sampling

As in the earlier study, the main dependent variables examined in this experiment were the driver's time headway and its variability. A subsidiary dependent variable, also reported here, was the driver's subjective evaluation of his performance, fatigue, and motivation to continue driving.

The time headway recording system was operated with a distance headway threshold of 190 feet, which corresponded to a time headway of approximately 2.4 seconds at 55 miles per hour (maximum speed of HGV), 3.2 seconds at 40 miles per hour (maximum legal speed of HGV), and 10.0 seconds at 13 miles per hour. Videorecords were obtained of all traffic situations in which the distance to a leading vehicle either decreased or remained stable. These records of following episodes were sampled at a mean rate of once every 5 seconds, and instantaneous speed and distance headway values were transferred to record sheets.

Sequences with time headway greater than or equal to 10 seconds were excluded as not constituting true following episodes. Similarly excluded were sequences in which there were both a progressive decrease in distance headway and a progressive speed decrease to a speed of less than 10 miles per hour. By this procedure it was hoped to eliminate from the analysis all situations in which the experimental vehicle approached a stopped, stopping, or very slow front vehicle (as, for example, in a typical traffic jam or crawl). Recorded speed and distance headway values were processed by an IBM 360 model 44 computer, programed to convert them to units of time headway in seconds and to compute means and standard deviations of time headway for each hour of driving separately for each subject.

Statistical Design

In order to compare the results for the late driving shift studied here with those for the early driving shift reported in the previous experiment, the performance data for the two shifts were combined for statistical analysis. This procedure had the added advantage of enabling the use of performance data obtained in Hours 4, 8, 9, and 10 of the original early shift but not reported or analysed at that time because of the inadequacy of the corresponding data samples for the original late shift. In conformity with the earlier study, the two 30-minute blocks of driving in Hour 6, separated by the 30-minute meal break, were treated as separate levels of the Hours factor in a factorial analysis of variance. It should be noted that the effect of this procedure is to weigh the values for each of the separate halves of Hour 6 equally with the values for each other whole hour. Thus the general design of the statistical analysis of the performance data was a 2 x 2 x 4 x 12 factorial analysis of variance with Age, Shift, Days, and Hours as main factors and repeated measures on the last two factors.

In the original experiment subjects' ratings of performance, fatigue, and motivation were not affected by sampling inadequacies in the same way as were the data on driving performance. Those self-ratings have been reported fully in Fuller (1978). It was decided to leave those results intact and analyse the current data as a discrete experiment. However, comparisons are drawn with the results of the original study where appropriate.

RESULTS

Braking Frequency

As reported in the earlier study, drivers depressed the foot brake significantly more frequently during the first half of each 11.5-hour day than during the second half ($t = 16.22$, $df = 5$, $p < .01$, two-tailed). Mean values for both studies are presented in Table 2. This result possibly reflects the diurnal variation in urban and rural traffic density and suggests that the task demands on drivers were not necessarily the same for both halves of each shift. This putative difference should be borne in mind when considering the time headway performance results.

Table 2

Mean Frequency of Foot-Brake Applications by Session Half

Study	Session half: First	Session half: Second
Original		
Early shift	99.6	70.8
Late shift	97.8	49.0
Present		
Late shift	116.6	60.8

Time Headway

The mean time headway values for each subject for each hour of each day's driving were submitted to a four-factor factorial analysis of variance with Age (2 levels), Shift (2 levels), Days (4 levels), and Hours (12 levels) as main factors and repeated measures on the last two factors. The results of this analysis are presented in Table 3, which shows that there is a significant main effect for shift and a significant first-order interaction between shift and hours. Taking the shift effect alone, mean time headway was shorter in the late shift (1.97 seconds) than in the early shift (3.01 seconds). However, this effect is clearly not independent of hours. The means for the shift x hours interaction are presented in Table 4. For making comparisons amongst pairs of means, Tukey's HSD test was applied (Kirk, 1968, pp. 88-90), yielding $HSD = .80$ ($p < .01$, two-tailed). The shift effect was found to be reliable for all hours except Hours 1 through 3.

A graph of these results is presented in Figure 1. It may be seen that the patterns of hourly variation for the original early shift and the current late shift have much in common. However, there is apparent a much stronger linear relationship between hours of driving and time headway in the late shift ($r = -.51$, $p < .05$, one-tailed) than in the early shift ($r = +.30$, n.s.). It is also to be noted that the hours effect found in the previous study, although still apparent, is no longer reliable.

Table 3

Analysis of Variance for Time Headway

Source of variation	SS	df	MS	F
Between subjects	272.83	11		
A (age)	1.64	1		
B (shift)	156.75	1	156.75	10.99*
AB	.38	1		
Subj. w. groups	114.05	8	14.26	
Within subjects	309.83	564		
C (days)	4.09	3		
AC	.12	3		
BC	1.04	3		
ABC	3.18	3		
CX Subj. w. groups	50.06	24	2.09	
D (hours)	2.93	11		
AD	6.48	11		
BD	14.45	11	1.31	2.67**
ABD	2.93	11		
DX Subj. w. groups	43.13	88	.49	
CD	18.10	33	.55	1.20
ACD	14.23	33		
BCD	17.36	33		
ABCD	11.09	33		
CDX Subj. w. groups	120.62	264	.46	

*$p < .05$.

**$p < .01$.

Table 4

Time Headway Means by Shift and Hour

	Hour											
Shift	1	2	3	4	5	6_1	6_2	7	8	9	10	11
Early	3.17	2.48	2.76	3.34	2.71	3.08	3.09	2.83	3.41	3.24	3.10	2.90
Late	2.58	1.84	2.16	2.18	1.48	2.15	2.08	1.82	1.98	1.81	1.54	1.96

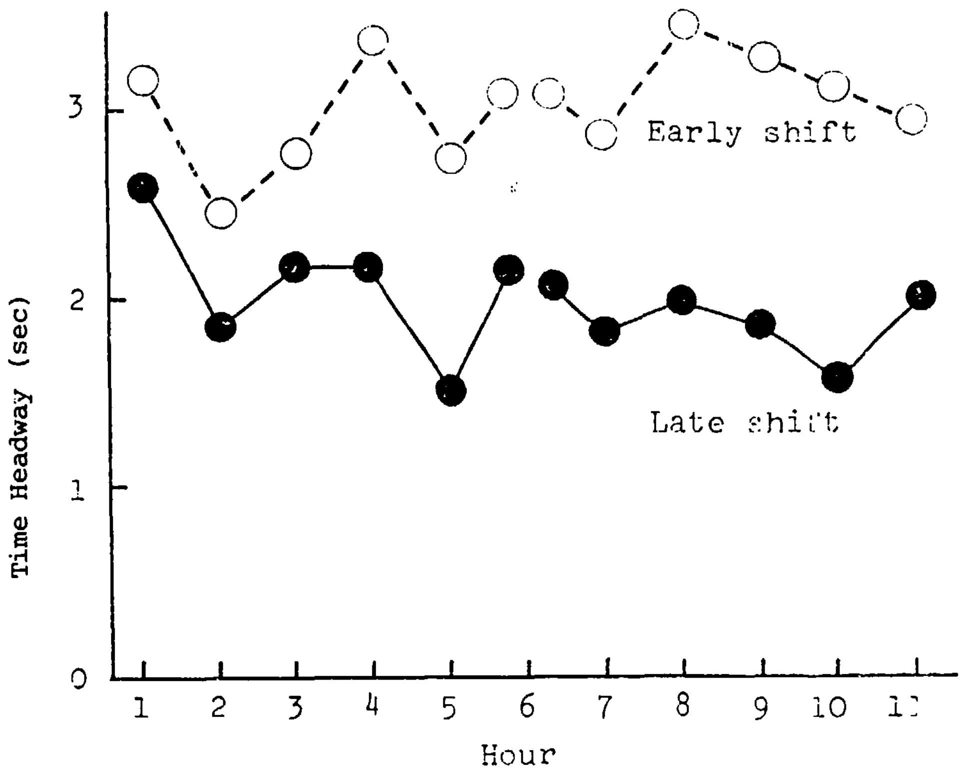

Figure 1. Mean time headway by hour.

Time Headway Variability

Standard deviations of time headway for each subject for each hour of each day's driving were submitted to the same four-factor factorial analysis of variance as were the time headway means. The results are presented in Table 5. There was a significant main effect for hours, and Tukey's HSD test revealed headway variability for Hour 1 to be greater than for Hours 3 through 5, 6_2, and 7 through 10 (HSD = .32, $p < .01$, two-tailed). However, this effect was not independent of shift, so the means for this interaction, presented in Table 6, were also analysed using Tukey's HSD test. The critical mean difference was found to be HSD = .46 ($p < .01$, two-tailed) and comparison of pairs of means revealed that the difference between Hour 1 and the other hours was reliable only for the late shift. For this shift, variability in Hour 1 was significantly greater than in Hours 4, 5, and 7 through 10 (also Hour 3 > Hour 10). For the early shift, the mean for Hour 1 was reliably greater than for Hour 3 only. To make these comparisons more visible, the means are presented graphically in Figure 2.

It may be noted that time headway variability was generally lower for the late shift than for the early shift, especially after the first 3 hours. Although the main effect for shift failed to reach significance ($.05 < p < .10$), a significant second-order interaction for age, shift, and days was found. The means for this interaction are presented in Table 7. Tukey's HSD test yielded HSD = .35 ($p < .01$, two-tailed) and a comparison of means revealed

Table 5

Analysis of Variance for Time Headway Variability

Source of variation	SS	df	MS	F
Between subjects	18.94	11		
A (age)	.06	1		
B (shift)	7.24	1	7.24	4.99
AB	.02	1		
Subj. w. groups	11.62	8	1.45	
Within subjects	88.76	564		
C (days)	.18	3		
AC	.05	3		
BC	.48	3		
ABC	1.68	3	.56	5.09**
CX Subj. w. groups	2.54	24	.11	
D (hours)	9.10	11	.83	5.19**
AD	2.19	11		
BD	4.71	11	.43	2.69**
ABD	1.34	11		
DX Subj. w. groups	13.89	88	.16	
CD	4.42	33		
ACD	4.16	33		
BCD	3.93	33		
ABCD	2.99	33		
CDX Subj. w. groups	37.10	264	.14	

$^{**}p < .01$.

Table 6

Time Headway Variability Means by Shift and Hour

Shift	Hour 1	2	3	4	5	6_1	6_2	7	8	9	10	11
Early	1.15	.95	.67	.78	.83	.93	.86	.89	.98	1.01	.86	.95
Late	1.09	.83	.88	.57	.48	.69	.66	.60	.58	.58	.40	.82

that time headway variability was greater for the older group of drivers on Days 1 and 4 of the early shift than on the same days of the late shift. It was also greater than for the younger group of drivers on Days 2, 3, and 4 of the late shift. This result may simply indicate that the older drivers were especially variable in headway performance on the first and last days of the early shift, but an alternative interpretation is that the result reflects a tentative shift effect, surfacing at some of the points in the interaction matrix. If one compares early and late shift values for each age group and day in Table 7, the values for the late shift are consistently lower.

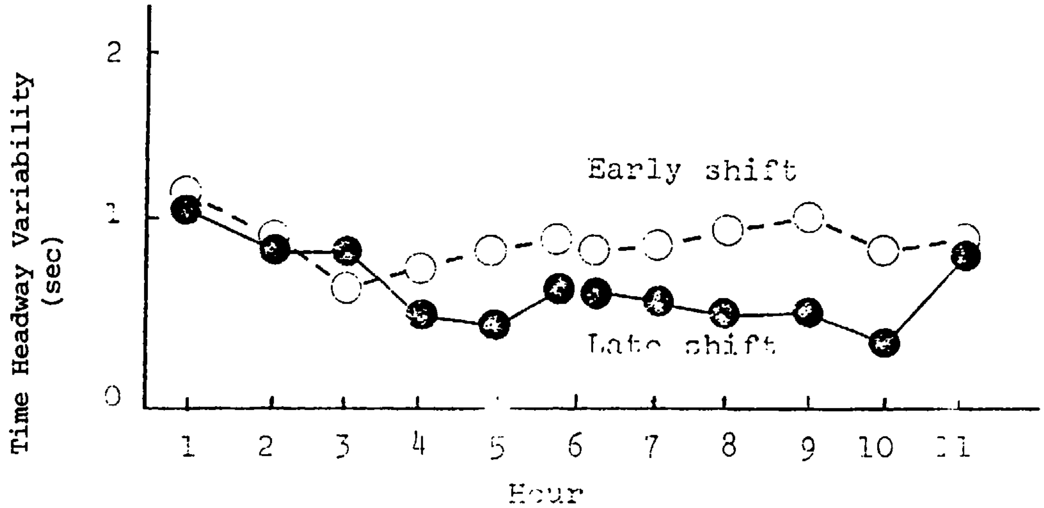

Figure 2. Time headway variability by hours.

Table 7

Time Headway Variability by Age, Shift, and Day

Age group	Day 1	2	3	4
Younger				
Early shift	.85	.92	.88	.90
Late shift	.78	.65	.64	.65
Older				
Early shift	1.02	.87	.80	1.01
Late shift	.60	.75	.75	.65

The data for time headway variability were also examined to determine the relationship between variability and hour of driving. The Pearson correlation coefficient for the early shift was r = +.05 (n.s.) and for the late shift

$r = -.56$ ($p < .05$, two-tailed). Thus, as for the time headway results, there is a much stronger relationship between hours of driving and performance on the late shift than on t..e early shift.

Relationship Between Time Headway and Time Headway Variability

Because of the clear relationship between both performance variables and time driving on the late shift, an analysis was carried out to determine the relationship between each pair of variables while holding the other variable constant. The results of this procedure are presented in Table 8. It may be seen that when each performance variable is correlated with time driving while holding the other performance variable constant the relationship between performance and time diminishes, yet both performance measures are still closely associated independently of the time factor. It thus appears that in the late shift both time headway and its variability are interrelated--shorter headway means less variability--but apart from this some factor or factors must be operating to produce a general decrease in one or both measures together over time. Incidentally, it may be noted that the partial correlation coefficient for the performance variables independent of time for the early shift was $r = +.30$ (n.s.).

Table 8

Correlation Coefficients for Time Headway, Time Headway Variability, and Time Driving on the Late Shift

	Confounded		Partial	
	Time headway variability	Time	Time headway variability	Time
Time headway	.77**	-.51*	.68*	-.15
Time headway variability		-.56*		-.31

*$p < .05$.

**$p < .01$.

Drivers' Ratings of Performance, Fatigue, and Motivation

Self-Ratings and Objective Performance Measures. An initial analysis was carried out to determine the relationship between drivers' own ratings of ability and riskiness and the objective measures of time headway and time headway variability. Two of the six subjects never reported any decrement in driving ability; they regularly rated themselves as "very good," at the extreme of the 5-point rating scale (interpreted to the subjects as "equivalent to your best"). The other four subjects reported a total of 37 hours (23%) of decreased driving ability: 32 hours were rated as "quite good" and 5 hours as "moderately good." For purposes of analysis these two categories were combined. The means for time headway and time headway variability for each subject for the hours for which a decrease in ability was reported were compared with the means for all other hours (in which driving ability was rated as the driver's best). The results are presented in Table 9. From inspection of this table it is clear that there is no relationship between mean time headway or its variability and ratings of driving ability.

Table 9

Time Headway and Time Headway Variability Means for Hours for Which Subjects Rated Changes in Driving Ability

	Reported driving ability			
	No decrement		Decrement	
Subject	Time headway	Time headway variability	Time headway	Time headway variability
S_2	2.00	.64	1.77	.36
S_3	2.31	.70	2.60	1.16
S_4	1.84	.66	1.76	.44
S_5	1.84	.59	1.86	.57
$\bar{X}$	2.00	.65	2.00	.63

In rating riskiness of driving, subjects admitted to deviating from the scale position of "not at all risky" only very rarely. No subject rated himself as more than "slightly risky," and only 4 out of a total of 240 ratings were in this category. Time headway means for these four occurrences were 2.04, 1.60, 1.15, and 2.63. The corresponding means of time headway variability were 1.30, .74, .13, and 1.45. These results are intriguing when compared with the results of the earlier study, in which drivers were more than three times as likely to report that their performance deviated from being not at all risky. In the current study, subjects generally drove with a shorter time headway, particularly after the 3rd hour on the road. This would seem to indicate, assuming the validity of subjective reports, that shorter time headway is not necessarily perceived as implying increased riskiness.

One is led to the conclusion that there is no evidence to support the view that drivers' evaluations of their own performance are associated with general levels of time headway and its variability. This corroborates the conclusion of the earlier study.

Effects of Time-on-Task. To provide an estimate of the relationship between hours of driving and ratings of performance and fatigue, mean scores for each age group on each rating dimension were obtained for half-sessions (combining data for days). The resulting values for each half-session are presented in Table 10. It may be seen by inspection that there were no marked changes in ratings from one part of a shift to the next for either age group.

However, there is some slight indication that drivers are likely to feel more drowsy in the second half of a session, an effect that was reported for the late shift of the original study. There is also evidence that drivers feel less bored during the second half of a session.

Table 10

Mean Self-Ratings for Each Half-Session

	Age group			
	Younger		Older	
Rating dimension	1st session half	2nd session half	1st session half	2nd session half
Driving ability	4.84	4.82	4.78	4.87
Observation	5.00	4.98	4.80	4.93
Control	4.87	4.98	4.98	5.00
Decision making	4.92	4.98	4.98	5.00
Courtesy	5.00	5.00	4.92	4.92
Riskiness	1.03	1.00	1.02	1.02
Drowsiness	1.03	1.12	1.17	1.32
Boredom	1.45	1.28	1.30	1.07
How quickly time passed	4.75	4.53	4.85	4.77
Irritation	1.33	1.45	1.53	1.50
Exhaustion	1.00	1.03	1.03	1.25
Physical discomfort	1.20	1.60	1.62	1.68
Awareness of what doing	4.97	4.93	4.83	5.00
Awareness of time passing	1.12	1.00	1.35	1.21
Probability of reporting daydreaming	.30	.30	.40	.42

Note. 1 = low; 5 = high.

These results were analysed further by session hour. Although there was no significant relationship between hours of driving and boredom, both age groups showed a significant relationship between hours of driving and drowsiness (r_{young} = .61, $p < .05$, one-tailed; r_{old} = .64, $p < .05$, two-tailed). Also, during the last hour of each half-session of driving, subjects tended to report both more drowsiness (Wilcoxon test, $T = 6.5$, $N = 9$, n.s.) and more boredom (Wilcoxon test, $T = 0$, $N = 8$, $p < .01$, two-tailed), although these differences were very slight (see Table 11).

A Wilcoxon test revealed that driving after sunset was not rated significantly more boring than driving during daylight ($T = 11$ $N = 6$, $p > .05$), a result that fails to replicate a finding of the earlier study. This may perhaps have been due to the design modification that "imposed" following manoeuvres on subjects. However, as in the previous study, no relationship was found between boredom ratings and subjects' extraversion scores (r_s = +.70, df = 4, $p > .05$). The methods used by subjects to combat boredom are described in Table 12, which also offers a comparison between the results of both studies. It may be noted that singing and whistling account for more than 40% of reported methods. Although smoking is reported more frequently in the present study, the overall distribution of frequencies is quite similar for both experiments.

Table 11

Mean Self-Ratings for Drowsiness and Boredom: Last Hour per Half-Session vs. Previous Hours

	Half-session			
	First		Second	
Rating dimension	Previous hours	Last hour	Previous hours	Last hour
Drowsiness				
Younger group	1.00	1.17	1.06	1.33
Older group	1.06	1.58	1.27	1.50
Boredom				
Younger group	1.29	2.08	1.17	1.25
Older group	1.25	1.50	1.02	1.25

Table 12

Methods Used to Combat Boredom

	Study	
Method	Original	Present
Singing	30	25
Whistling	10	18
Smoking	14	28
Chewing gum	9	7
Observing road more closely	11	6
Looking out window	3	1
Daydreaming	8	6
Thinking about things	1	4
Other	14	5

Note. Figures represent percentage of drivers who reported using a given method.

Returning to Table 10, inspection reveals further slight but nevertheless suggestive rating differences over time. Older drivers report an increase in exhaustion in the second half of a session (Wilcoxon test,[1] $\underline{T} = 0$, $\underline{N} = 8$, $\underline{p} < .01$, two-tailed). They also appear to be more aware of time passing, especially during the first half-session, but this is entirely due to the ratings of only one of the drivers. The younger drivers show an increase in physical discomfort from the first to second half of the driving day, at which time they report a level more consistent with that of the older drivers (Wilcoxon test, $\underline{T} = 0$, $\underline{N} = 7$, $\underline{p} < .02$, two-tailed).

Effects of Days. To determine the effect of days on ratings, mean group values for each variable and for each day were obtained. Variables showing any apparent change are presented in Table 13. Where inspection indicated a relatively large or consistent effect having implications for driver riskiness or fatigue, further statistical analysis was undertaken. For driving ability, a Wilcoxon test (treating hours as independent observations) revealed a significant increase in the quality of performance on Days 3 and 4 compared with the first 2 days for both the younger and older groups (respectively $\underline{T} = 0$, $\underline{N} = 10$, $\underline{p} < .05$, two-tailed; $\underline{T} = 1$, $\underline{N} = 8$, $\underline{p} < .05$, two-tailed). This finding was supported further by slight and statistically unreliable increases after the first day in ratings of road observation and control of the vehicle. It is also consistent with results in the earlier experiment for the younger group, who rated driving ability as better for the second 2 days of both shifts.

A Sign test (treating hours as independent observations) showed Days 3 and 4 to have significantly higher drowsiness ratings than Days 1 and 2 for the older group ($\underline{L} = 0$, $\underline{T} = 8$, $\underline{p} < .008$) but not for the younger group. Over time there was a slight decrease in irritation ($\underline{r} = +.25$, $\underline{p} > .05$) and, for the first and last days, time was rated as passing more slowly (Wilcoxon test, $\underline{T} = 0$, $\underline{N} = 6$, $\underline{p} < .05$, two-tailed) and physical discomfort was rated as greater (sample unreliable).

Effects of Age. Only age differences large enough to be interpreted as psychologically meaningful were submitted to further analysis. The results of applying the Mann-Whitney test (treating hours as independent observations) to the relevant rating variables are presented in Table 14. Older drivers rated themselves as more drowsy overall and were more aware of time passing. Although they also obtained lower scores for boredom and higher scores for physical discomfort, these differences were not significant. The finding for drowsiness confirms a similar observation in the first study.

Irritations and Types of Physical Discomfort. The distributions of irritations and types of physical discomfort experienced by drivers in both studies are presented in Table 15. Eyestrain from headlights and the design of the cab seat were frequently reported as sources of discomfort in both studies. The main difference between the two sets of reports is that headaches and backaches were more common in the first experiment and leg aches were more common in the second.

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[1] This and the following Wilcoxon test of physical discomfort treat days as independent observations.

Table 13

Mean Self-Ratings for Each Day

Rating dimension	Day 1	2	3	4
Driving ability				
Younger group	4.63	4.67	5.00	5.00
Older group	4.43	4.93	4.93	5.00
Observation				
Younger group	5.00	4.97	5.00	5.00
Older group	4.63	4.97	4.97	4.97
Control				
Younger group	4.70	5.00	5.00	5.00
Older group	4.97	5.00	5.00	5.00
Drowsiness				
Younger group	1.03	1.13	1.03	1.07
Older group	1.13	1.13	1.33	1.37
Boredom				
Younger group	1.13	1.37	1.43	1.53
Older group	1.53	1.07	1.03	1.10
How quickly time passed				
Younger group	4.27	4.83	4.73	4.50
Older group	4.57	5.00	5.00	4.67
Irritation				
Younger group	1.67	1.30	1.27	1.33
Older group	1.70	1.70	1.43	1.23
Physical discomfort				
Younger group	1.73	1.13	1.17	1.60
Older group	2.03	1.87	1.30	1.40
Awareness of time passing				
Younger group	1.07	1.17	1.00	1.00
Older group	1.03	1.10	1.67	1.44

Note. 1 = low; 5 = high.

Table 14

Summary of U Values for Mann-Whitney Test of Age Effects

Variable	Younger group	Older group	U	P
Drowsiness	1.07	1.24	20.5	<.05
Awareness of time passing	1.06	1.31	2.0	<.05
Boredom	1.37	1.18	36.0	n.s.
Physical discomfort	1.41	1.65	28.0	n.s.

Table 15

Sources of Irritation and Physical Discomfort During Driving

	Study	
Variable	Original	Present
Nature of irritations		
Noise	10	0
Physical discomfort	44	45
Operating conditions	36	34
Other	10	21
Nature of physical discomfort		
Seat	35	38
Eyestrain	21	17
Backache	15	8
Headache	8	2
Sore neck	6	4
Sore shoulder	2	4
Leg ache	6	17
Earache	2	0
Sore throat	2	0
Perspiring	4	6
Other	0	4

Note. Figures represent percentage of drivers reporting a given irritation or discomfort.

Duration of Driving Task. The number of hours for which drivers were prepared to have driven on or stopped earlier, recorded after each half-session of driving, are presented in Table 16. On 58% of occasions drivers reported each 5.5-hour driving period to be just right, on 17% of occasions they felt like driving longer (1.5 hours on average), and on 25% of occasions they would have liked to stop earlier (1.2 hours on average). These values correspond to 54%, 27%, and 18%, respectively, in the previous experiment. In line with the results of that experiment, a chi-squared analysis showed the distribution of preferences to be independent of session half (X^2 = 5.6, df = 2, p > .05). Thus, perhaps surprisingly, subjects did not indicate that they were less prepared to continue after the full daily driving session than after only the first 5.5 hours. Although cell frequencies were not large enough to carry out a chi-square test on the distribution of preferences by age, it may be noted that the older drivers would have preferred to have stopped earlier more frequently than the younger drivers (n = 8 and 4, respectively).

Table 16

Number of Hours for Which Drivers Felt Like Continuing To Drive

	Age group					
	Younger			Older		
Day	S_1	S_5	S_6	S_2	S_3	S_4
1						
1st half	0	0	0	0	1	-1
2nd half	-1	-1	0	1	0	0
2						
1st half	0	0	0	-1	Q	-1
2nd half	0	-1	0	0	-1	0
3						
1st half	0	0	0	0	1	0
2nd half	1	1	0	1	-1	-1
4						
1st half	0	0	0	0	-1	0
2nd half	1	-2	5	0	-2	0

Endocrine Measures

In the original study the results showed some slight indication of a biological stress response in the older drivers on the late shift, relative to the other groups studied. These drivers failed to show the expected diurnal rise in testosterone levels and their daily decrease in cortisol was never statistically significant, whereas it was for the early shift drivers on 3 of the 4 experimental days. However, these changes occurred in the context of no reliable task-induced changes in adrenaline, noradrenaline, or prolactin, confirming that the prolonged driving task used may be more appropriately characterised as demanding relatively low levels of physiological arousal. This replication confirmed the original findings for cortisol, prolactin, adrenaline, and noradrenaline, but not for testosterone, for which control day changes were unreliable (see Cullen et al., 1979). Thus the response of the endocrine system indicates that the modified task did not constitute a more demanding biological stressor. Indeed, if one recognises that a possible problem for the late shift driver is staying awake, then the more frequent presence of a leading vehicle may in fact have made the task easier.

DISCUSSION

The focal point of interest in this study is the effects of prolonged driving on professional heavy goods vehicle drivers. The effects were measured in three ways: performance (specifically time headway and its variability), self-report, and endocrine changes.

Performance Changes

This study has shown that, although varying to some extent, time headway is generally maintained at a safe level on the early shift. It is reliably lower on the late shift, particularly after Hour 3, and it also decreases over time to a level which for one hourly sample is on average almost .5 seconds less than the recommended safe headway of 2 seconds. Variability of time headway follows the same general pattern, again being lower on the late shift, especially after Hour 3, and decreasing over time. Furthermore, it appears that independent of these time-related changes, time headway and time headway variability are closely associated. Can or should these observed changes be interpreted as constituting an increase in driver riskiness on the late shift, particularly as that shift proceeded in time?

In the earlier study, apparent time-related changes were recorded: Time headway decreased in Hours 2 and 5. A similar pattern of change occurred in this replication, but with a 50% increase in the number of observations made these decreases were no longer statistically significant. However, these lowered levels of time headway in the original study were not interpreted in terms of increased riskiness for the hours in question but in terms of a change in the driving environment for the driver. It was argued that the time headway selected is a function of the perceived probability of sharp velocity decreases in the lead vehicle and that the time headway changes observed reflected a shift from higher to lower levels of probability that a followed vehicle would slow down or stop. This explanation of time headway performance is also preferred for the results of the current study for a number of reasons.

The shift effect was not independent of hours and was reliable only after Hour 3. It is at this point that the project lead vehicle was introduced to provide a larger sample of following. Based on extrapolations from the earlier "natural" sample of following situations, the experimental lead vehicle contributed about 80% of all following situations in the replication. It is suggested that drivers would recognise the performance of the experimental lead vehicle as being more reliable than the performance of any vehicle they might by chance catch up with on the road and that it would have a smaller probability of exhibiting sharp velocity decreases. Hence drivers could safely follow it more closely.

If this explanation is correct, then one would expect the hourly time headway values for the current late shift to be lower than the corresponding values for the original late shift, particularly after Hour 3. A t-test for correlated samples was carried out to compare both sets of data on the hours for which reliable samples were obtained in the early study. It was found that the current late shift mean (2.01, sd = .32) was significantly lower than the original late shift mean (2.70, sd = .20) ($t = 11.49$, $df = 17$, $p < .01$). It should be noted that the smallest differences between the hourly time headway samples for the original and current experiments were for the first 3 hours of driving, when there was no experimental lead vehicle present in the current study. The hourly means for this analysis are presented in Table 17.

Table 17

Late Shift Time Headway Means for Original and Present Studies

Study	Hour 1	2	3	5	6_1	6_2	7	11
Original	2.92	2.53	2.69	2.36	2.93	2.85	2.61	2.73
Present	2.58	1.84	2.16	1.48	2.15	2.08	1.82	1.96

It is argued therefore that drivers adopted shorter headways in the current late shift because they were for the most part following the experimental lead vehicle and this vehicle was less likely than "unknown" vehicles to exhibit sharp velocity decreases. Consistent with this hypothesis is the further observation that the decrease in braking frequency from the first to the second half of each shift was particularly marked on the late shift.

If time headway is a function of the perceived probability of sharp velocity decreases in the lead vehicle, time headway and time headway variability should both decrease as a function of the amount of time spent following the experimental lead vehicle compared with other vehicles. Although this variable was not recorded directly, an estimate of the proportions of natural and experimentally contrived following periods may be obtained from the data of Table 1, which shows the number of time headway samples per hour for the original and current late shifts. Assuming that the amount and hourly distribution of natural following was the same in both studies, then the proportion of following involving the experimental lead vehicle would be as presented in Table 18.

The Pearson correlation coefficient for percentage of time spent in following the experimental vehicle and hours of driving was $r = .84$ ($df = 9$, $p < .01$, two-tailed), and hourly mean time headway was $r = -.55$ ($df = 9$, $p < .05$, one-tailed) and hourly mean time headway variability was $r = -.78$ ($df = 9$, $p < .01$, two-tailed). Thus, the amount of time spent following the experimental vehicle increased over time and shorter time headway and smaller time headway variability were associated with longer periods spent following the experimental lead vehicle. Furthermore, the partial correlation coefficients presented in Table 19 reveal that both time headway and time headway variability were more closely associated with the amount of time spent following the experimental lead vehicle than with hours driven.

Table 18

Estimate of Proportion of Time in Late Shift Spent Following the Experimental Lead Vehicle

Hour										
1	2	3	4	5	6	7	8	9	10	11
0	0	0	79	80	52	95	93	100	90	92

Note. Proportions are expressed as percentages.

Table 19

Partial Correlation Coefficients for Time Headway, Time Headway Variability, Hours of Driving, and Time Following Experimental Lead Vehicle

	Hours of driving	% time following experimental lead vehicle
Time headway	-.13	-.26
Time headway variability	.30	-.69*

*$p < .05$, two-tailed.

In sum, shorter hourly time headways and smaller time headway variability were associated with longer periods of experimental vehicle following. It may be added that these observations also provide an explanation for the decrease in values of both variables over time on the late shift and for the fact that a similar finding did not occur for the early shift. The amount of experimental lead vehicle following increased over time on the late shift and, of course, there was no experimental lead vehicle following whatsoever on the early shift.

The close association between time headway and time headway variability on the late shift, a relationship that was found to be independent of hours, merits further discussion. In one sense such a relationship is to be expected because of a "bottoming" effect. As average time headway over a period decreases toward zero, clearly the amount of variation possible must decrease also, given a normal distribution of values. There are other reasons why the observed relationship might obtain, however, and these have implications for safety in following manoeuvres.

First, Rockwell (1972) has shown that ease of detection of distance headway change is inversely related to distance. This implies that when drivers adopt shorter headways it is easier for them to detect headway changes and adjust their relative position appropriately. Consistent with this is the finding of Gantzer and Rockwell (1968) and Harras and Mourant (1970) that enhancement of feedback of headway information has the effect of decreasing headway variance. Thus, at least one line of evidence suggests that shorter headways, although in an absolute sense more risky, make possible a less variable following performance.

Short time headways also require more rapid detection and response than longer time headways if the following driver is to avoid collision with the leading vehicle. With a relatively long time headway, a driver can avoid changing speed if there are variations in the speed of the leading vehicle and it has been shown elsewhere that under such circumstances drivers do tend to resist duplicating small changes in lead vehicle velocity (Rockwell & Snider, 1965). They have spare headway to play with so to speak. However, with relatively short time headways tolerance for headway variation necessarily decreases and drivers must be more responsive to headway decreases if they are to avoid rear-end collisions. This is another reason why shorter time headways might be associated with decreased headway variability.

This analysis suggests a driving condition that could have considerable significance from the point of view of riskiness: a condition of decreased time headway coupled with increased headway variability. There is no strong evidence that this combination of variables occurred during any hour of the driving task in which headways became relatively short (see Figures 1 and 2). This further supports the view that decreased time headways need not necessarily be interpreted as implying higher risk. Although the driver has less time to react to sudden decreases in lead vehicle velocity under such circumstances, he may well more than compensate for this by operating at a higher level of competence.

A third and final reason why a positive correlation might exist between time headway and time headway variability stems from the hypothesis that drivers select a headway based on their expectations of sharp velocity decreases in the leading vehicle. When sharp velocity decreases are estimated to have a very low probability, the speed of the leading vehicle must be relatively constant. This in turn implies that it would be easier for the driver who is following to maintain a constant headway. Thus, decreased variability becomes associated with lowered time headway.

The expectancy hypothesis discussed here has been examined more directly in a recent study by Colbourn, Brown, and Copeman (1978). In that study, car drivers with occluded instruments and accompanied by an experimenter followed a leading vehicle at speeds of 30, 40, and 50 miles per hour on a landing strip of an unused airfield while distance headway was recorded at regular intervals. Headway was measured by the use of a "yo-yo" device consisting of a reel of wire mounted on the following vehicle with the free end of the wire attached to the leading vehicle and kept under constant tension.

Expectations of lead vehicle deceleration were manipulated in two ways. In one procedure drivers had to imagine driving under conditions in which the lead vehicle would have either a high or a low probability of slowing down or stopping. In the other procedure drivers were told that at some point along the track the lead vehicle would stop rapidly and they would be expected to do the same. (The cars were driven in an "offset" arrangement to avoid the possibility of an actual collision.)

With the first procedure, the different imagined probabilities of lead vehicle deceleration were not found to affect the headways selected by drivers. However, drivers who expected real braking in the lead vehicle often had to be urged to maintain the headway measured previously in the imagined high-probability condition. The authors concluded, "This suggests that expectancy is a particularly potent factor governing choice of headway, where objective probabilities of speed-change requirements are determinable" (p. 9). Thus, some support for the expectancy hypothesis has been obtained in an experimental car driving situation radically different from the conditions of the present study.

Drivers' Subjective Ratings

As in the earlier study there was generally very little change in drivers' ratings of their performance, feelings of fatigue, and motivation to continue driving. However, against this generally invariant background some slight changes were evident and should perhaps be given more attention than their absolute values might otherwise merit.

A preliminary analysis was carried out to determine the relationship between subjective ratings of ability and riskiness and the objective performance measures of time headway and headway variability. As reported in the previous experiment, no relationship was found. There are a number of possible reasons for this. As discussed earlier, shorter time headways need not necessarily be interpreted as being riskier or representing a decline in driving ability--they may indeed represent a temporary condition of enhanced competence on the part of the driver, even though he has less time in which to respond to a sudden velocity decrease on the part of the leading vehicle. Also, and in relation to this, it may be that only very short time headways are perceived as risky by the driver. Since ratings applied to whole hours, any brief period of driving with very short headways could be outweighed by the driver's evaluation of performance over the rest of the period. Finally, aspects of driving other than time headway and its variability could, of course, contribute to the driver's assessment of his ability and riskiness.

If one examines the effects of hours driving, days, and age of driver on ratings, apart from some evidence of increased physical discomfort over hours for the younger drivers and some indication of performance improvement over days, older drivers appear to present a suggestive profile of poorer adjustment to the working conditions. Although both age groups reported some increased drowsiness over time, older drivers were more drowsy overall and reported more drowsiness over days and increases in exhaustion over hours. There is a slight indication that older drivers would have preferred to have stopped earlier. Finally, although one clearly cannot characterise the task as a biological stressor in terms of the endocrine responses recorded, there is some evidence of relative stress on the older drivers, who maintained their cortisol levels over the duration of the experiment, as opposed to exhibiting the decrease observed in the younger group of drivers. Signs of drowsiness were recorded in 10% of regular runs in a recent study completed in the United Kingdom (Thomas, Sandover, Kaye, & Weiner, 1979) and the age effect suggested here is consistent with the finding (Harris, Mackie et al., 1972) that the accident rate in older bus drivers (over 46 years) increases after 7 to 10 hours of driving in darkness.

Finally, with regard to motivation to continue driving, for the majority of driving periods (blocks of 5.5 hours), subjects said that the work period was "just right." This finding, which reflects what was found in the earlier study, again supports the interpretation that drivers in some way ration their effort over the expected demands of the task and thus accommodate to it despite its excessive duration. Consistent with this interpretation is the observation that drivers were not more likely to say they would have preferred to have stopped earlier after completing the full driving day than after completing only half of it (i.e., after the first 5.5-hour block of driving).

Conclusion

Consistent with the earlier study, this extended replication of the late shift found no clear effects of prolonged driving on performance safety. Although the late shift produced lower mean time headways than the early shift and also showed greater decreases as the shift progressed, these changes are interpreted in terms of the hypothesis that drivers select a headway on the basis of expected sharp velocity decreases in the leading vehicle. It is argued that on the late shift subjects would expect such velocity decreases in the experimental lead vehicle to have a very low probability, so shorter time headways (and, as discussed, smaller time headway variability) were associated with the periods of time spent following the experimental lead vehicle.

This performance need not necessarily imply more dangerous driving; what *would* be critical for safety would be a decrease in time headway coupled with an increase in (or stable) time headway variability. It should be noted from drivers' ratings that the older driver might be more at risk than the young driver on a prolonged late shift such as that under study. Furthermore, it should be stressed that the strategy of adopting headways on the basis of expected decreases in lead vehicle velocity is vulnerable to the actual occurrence of the low probability event as well as to all the factors that might lead to incorrect expectations, factors such as inadequate information or inadequate processing of the information due to lack of experience or impaired judgement. Finally, it might be added that for any given probability of a leading vehicle's stopping, drivers may accept as tolerable a shorter time headway than normal, and for a variety of reasons. One reason could be to maintain arousal. It has been suggested elsewhere that drivers may drive at a higher speed to obtain this effect. Perhaps short headways satisfy the same need.

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