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EFFECT OF DRIVING SPEED ON REACTION TIME DURING MOTORWAY DRIVING

JAN TÖRNROS

Swedish Road and Transport Research Institute (VTI), S-581 95 Linköping, Sweden

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Abstract—Effects of driving speed (70, 90 and 110 km/h) on subsidiary auditory reaction time were studied during car driving on a motorway with a speed limit of 110 km/h. Driving distance was held constant at about 200 km. Twenty-four subjects participated in a repeated-measurement design. Reaction time was found to be slower at 70 km/h than at 110 km/h. Before and after the driving session, the subjects' simple reaction time, mood, and alertness were measured in the laboratory. No significant differential after-effects of driving speed were found on any of these measures, although subjects rated themselves as less energetic towards the end of their journey when driving at the former compared to the latter speed.

Keywords—Speed, Driving, Performance, Fatigue

INTRODUCTION

For many years the effects of driving speed on traffic safety have been debated, with an unresolved assumption that drivers will find it more difficult to stay alert at slower speeds.

Two Japanese studies have been identified in which effects on physiological measures were studied during motorway driving. It was found that heart rate increased and critical flicker fusion performance (a measure of visual, temporal discrimination sensitivity) improved at higher speeds. This result was valid for the two situations studied, (a) when comparing different speed limits, 80 km/h and 100 km/h (Hashimoto et al. 1967), and (b) when comparing a driving speed of 70 km/h and free speed on a motorway with no speed restrictions (Hashimoto 1970). These results are not easily interpreted, however, since the relations between these physiological measures and performance variables are not clear. Regarding driving performance, no studies have been identified in which effects from different speed levels have been investigated. What have been studied are (a) a comparison between a speed limit and a recommended speed of 130 km/h (Tränkle 1978), (b) a comparison between an instructed average speed and an instructed constant speed of 70 mph (Safford and Rockwell 1967), and (c) automatically and manually controlled speed in a driving simulator (Sussman and Morris 1970), and in car driving (Sugerman and Cozad 1972). In these studies no

differences were found for the performance variables or for the phenomenological measures under study. The lack of effect in these studies might be at least partly a consequence of the speed levels being too similar in the different conditions.

The aim of the present study was to study effects of different speed levels on performance and phenomenological variables when the variations in speeds were greater than was the case in the studies mentioned above.

Many years ago Lisper and his coworkers developed a subsidiary auditory reaction time task to be presented during car driving on a motorway (Lisper et al. 1971). The validity of this task as an index of driver performance was studied in a series of investigations. In one such study, Laurell and Lisper (1978) investigated the correlation between performance of this task and detection distance to an obstacle as a function of time on task during a three-hour driving session at night. The correlation between the group averages of these two measures was significant ($r = -.78$). The average within-subjects correlation was $-.47$, also a significant value. These results were interpreted by the authors as supporting the validity of the reaction time task as an index of driver performance.

A very similar subsidiary reaction time task was used in the present study. Mood and arousal were also studied. Finally, after-effects of driving at the different speeds were examined in a laboratory study of simple reaction time.

METHOD

Subjects

Subjects in this study were 24 healthy volunteers, who were paid for their participation: 18 men and 6 women, aged twenty to forty-three years of age; they had owned a driving licence for one to fifteen years, had driven a total distance of 6,000 to 350,000 km, and in the previous driving year had driven a distance of 1,000 to 90,000 km.

Design

The speed factor had three levels: 70 km/h, 90 km/h, and 110 km/h. The design was repeated measurements; all subjects participated in all three conditions. The order of presentation was randomly allocated among subjects.

Car driving tasks

The experimental vehicle was a passenger car (Volvo 240 DL, 1982) equipped with redundant controls (accelerator, foot brake, clutch). It was further equipped with an apparatus for auditory reaction-time measurements.

The reaction-time measurement was controlled by an IBM-compatible portable computer (AT286) with a CO processor and EGA graphics (BT sys-COMP/16). The sound signal was created by an adjustable electromagnetic summer (Mallory), mounted to the neck support of the driver's seat. The sound frequency was $2.8 \pm .4$ kHz. Sound pressure at the locus of the subject's head was approximately 50 dBA at 8 V.

For interruption of the sound signal an extra pedal mounted to the floor to the left of the clutch pedal, had to be pressed.

The subjects were instructed to keep the requested constant speed and, when required, overtake the vehicle in front, and to react as quickly as possible to the sound signal by pressing the extra pedal on the floor (with the left foot resting on the pedal). The average interstimulus interval was 2.5 min (range 1–4 min). Measurement of auditory reaction time was initiated when the required speed had been reached on the motorway. Before data analysis, all measurements from the first 5 minutes of the journey were excluded.

The driving distance was around 200 km. The driving test was performed on the motorway connecting the urban areas of Mjölby, Linköping, and Norrköping. The driving time varied greatly as a function of driving speed, from about 2 hours at the fastest speed to about 3 hours at the slowest speed.

Laboratory tests

All laboratory tests were computerized. The computer was a LEO Personal Computer 386/25 equipped with a color screen (EIZO Flexscan 9060S).

The subjects were requested to fill in two questionnaires, one of which is part of the SPES test battery (Swedish Performance Evaluation System; Gamberale, Iregren, and Kjellberg 1989) regarding mood states (two scales, Energy and Stress) developed by Kjellberg and Iwanowski (1989), the other is a computerized version of an arousal scale, included in Kjellberg's and Bohlin's (1974) translated version of Thayer's (1967) Activation-Deactivation Checklist. These questionnaires were filled in before and after the car driving sessions. At the postdriving session they were filled in once more, but subjects were instructed to rate only the last 40 km of the motorway drive. At their final postdriving session they were also requested to rank the three speed conditions with respect to experienced sleepiness/tiredness during the test drive.

At the predriving and postdriving sessions subjects were further tested on a simple reaction time test that is part of the SPES test battery. Test duration was 5 min (actually it was 6 min, but the reaction times from the first 60 sec were excluded before analysis). The average inter stimulus interval was 3.75 sec (range 2.5–5 sec).

Procedure

Two days before their first test session subjects received instructions and practice on the tests. The car-driving task was practised on 40 km of motorway.

For the test sessions subjects appeared at the research institute at 8:30 a.m. After a short introduction they performed the rating-scale tasks and the 5 min reaction-time task before being instructed as to what speed condition had been selected for the day. Then followed the car-driving session, during which subjects were accompanied by the experimenter who avoided conversation. After the subjects returned to the research institute, the laboratory tests were presented in the same order as before. The session ended with another presentation of the rating scales questioning only the last 40 km of the motorway drive.

Beforehand, subjects were instructed to be in good shape for the test sessions (no alcohol the night before, having slept a normal number of hours, feeling perfectly healthy). They were also asked to have a similar breakfast before each of the three test sessions.

Fig. 1. Reaction time before car driving.

RESULTS

Reaction time before and after car driving (5 min RT test)

Analysis of the reaction-time data was based on mean values for each of the 5 minutes of the task. Figures 1 and 2 illustrate how reaction time performance changed over time in the three speed conditions, before and after car driving, respectively. An analysis of variance revealed that although average reaction time was slightly slower after the drive than before, this difference was not significant, $F(1,23) = 2.28$; $p > .10$. Performance tended to deteriorate most after driving at the slowest speed and least after driving at the highest speed; the interaction between speed and test occasion was far from significant, $F(2,46) < 1$. There was an effect of time on task, $F(4,92) = 11.57$; $p < .001$, and an

interaction between time on task and test occasion $F(4,92) = 2.74$; $p < .05$. The triple interaction between speed, test occasion, and time on task was not significant, $F(8,184) < 1$.

These analyses thus show that no overall after-effect of the speed factor was found for the 5 min reaction-time task. The only after-effect that appeared could be described as follows: subjects' average reaction time when tested after car driving was worse at the beginning of the test compared to the situation before car driving. This difference grew smaller as a function of time on task, and at the end of the test it had practically vanished.

Reaction time during car driving

Before analysing the reaction time data, all reaction times gathered during a test session were subdivided into five blocks of equal size, each block thus

Fig. 2. Reaction time after car driving.

Fig. 3. Reaction time during car driving as a function of driving distance.

representing about 40 km of car driving. All data collected while the subjects were overtaking were excluded. For each of the five blocks the arithmetic mean was calculated. This value was used in the analyses.

Figure 3 illustrates how reaction time changed during car driving as a function of driving distance. Subjects reacted fastest when driving at 110 km/h and slowest when driving at 70 km/h. An analysis of variance proved the difference in reaction times between speed conditions to be significant, $F(2,46) = 3.88$, $p < .05$. The effect of driving distance was clear, $F(4,92) = 14.60$, $p < .001$, whereas no significant interaction between speed and driving distance appeared, $F(8,184) < 1$.

The demonstrated effect of driving speed needed to be explored further. To this end post hoc analyses of found differences (Tukey; Kirk 1968) were performed. These showed that it was only the difference between the fastest and the slowest speed (362 ms and 347 ms) that was significant, $q = 3.85$ ($p < .05$). The comparison between 70 km/h and 90 km/h gave the result: $q = 2.60$ ($p > .05$), and the comparison between 90 km/h and 110 km/h gave: $q = 1.25$ ($p > .05$).

It was also of interest to study reaction-time performance as a function of driving time, instead of driving distance. Figure 4 shows the outcome after 2 hours of driving, which was the average driving time at the fastest speed. The difference in reaction times between speed conditions in this case was small and nonsignificant, $F(2,46) = 1.38$, $p > .20$. No interaction with driving time appeared, either, $F(8,184) < 1$.

Subjective ratings of mood and arousal

Figures 5–7 show the subjective ratings for the three factors studied (Energy, Stress, Arousal; all with maximum value 5.0 and minimal value 0.0).

For each factor the difference between the rated value before the drive (A) and the rated value after the drive (C) was calculated. Analogously the difference between the rated value before the drive (A) and the rated value for the last 40 km of the journey (B) was calculated. These data were subjected to analyses of variance. Two such analyses were performed for each factor, one regarding the difference between A and B, the other regarding the difference between A and C. Only one such difference was found to be significant, namely the difference A–B for the energy factor, $F(2,46) = 4.52$, $p < .05$. Pairwise comparisons (Tukey) showed that it is only the difference between 70 km/h and 110 km/h that was significant, $q = 4.39$, ($p < .01$). For the comparison between 70 km/h and 90 km/h the result was $q = 1.92$ ($p > .05$), whereas the comparison between 90 km/h and 110 km/h gave the result $q = 2.44$ ($p > .05$).

Consequently, the subjective ratings showed that the subjects on the average rated themselves as more "energetic" towards the end of the journey when driving at 110 km/h compared to driving at 70 km/h. Figure 5 shows the outcome for the energy factor. Figures 6 and 7 show the results for the other two factors.

Rankings of experienced sleepiness/tiredness

The rankings regarding experienced sleepiness/tiredness during car driving were performed by 20 subjects. A significance test on these data (Friedman two-way analysis of variance by ranks) showed an effect of speed, $F_r = 13.98$ ($p < .01$) (Siegel and Castellan, Jr 1988). Pairwise comparisons showed that it was only the difference between 70 km/h and 110 km/h that was significant—the subjects on the average ranked themselves as more sleepy/tired at 70 km/h compared with 110 km/h.

Fig. 4. Reaction time during car driving as a function of driving time.

Fig. 5. Subjective ratings: Energy.

Fig. 6. Subjective ratings: Stress.

Fig. 7. Subjective ratings: Arousal.

DISCUSSION

The results of the present study can be summarised as follows.

Subsidiary reaction time during car driving was significantly slower at 70 km/h than at 110 km/h.

The result for the short reaction-time test presented before and after the car driving session shows no after-effect of the speed factor. There was only a very weak tendency for degradation of performance at the slowest, compared with the fastest speed.

A similar lack of an after-effect of the speed factor was demonstrated by the subjective ratings. For the arousal and energy factors the tendencies were, however, the same as for the short reaction-time test. A difference between speed conditions was demonstrated only for one of the ratings, namely for those regarding the energy factor towards the end of the journey; the subjects rated themselves as having felt more "energetic" when driving at the fastest speed compared with the slowest speed. For the arousal factor the tendency was similar, but no significant effects were demonstrated. For the stress factor no clear tendency in any direction appeared.

The rankings after the last test sessions indicate that the subjects on the average had felt sleepier or more tired when driving at 70 km/h compared with 110 km/h.

So it is evident that the effects of the speed factor appeared only during car driving, with no after-effects being demonstrated.

In a discussion of possible mechanisms behind the demonstrated effects, it should first be pointed out that the driving times were very different for the different speed conditions, an inevitable consequence of the choice to keep driving distance con-

stant (200 km). The interesting issue, that of separating the effects of speed and driving time, cannot be resolved in the present study. In fact, it is not even logically possible, since these two factors are deterministically related with driving distance held constant. An attempt was, however, made to extract some data bearing upon this issue. To this end, reaction time was studied as a function of driving time, instead of driving distance (Figure 4). No effect from speed appeared in this case where the reaction times from 2 hours of motorway driving in each speed condition were analysed. Based upon this finding, a reasonable hypothesis would be that, provided driving time is held constant, no or only very small effects of driving speed would be found in motorway driving.

Differences in the driving situation may also have had some effect on the outcome of the present study. It may be assumed that it was least monotonous at the fastest speed, illustrated by the fact that the subjects on the average made 35 overtakings at the fastest speed, compared to an average of 0.5 overtakings at the slowest speed.

Further studies are required before any reasonably safe conclusions can be drawn regarding these relations.

What relevance the present findings may have in a real traffic situation can be discussed. The first thing to take into consideration is the size of the effect. The difference between reaction time at the fastest speed, compared with the slowest speed, was 15 ms on the average, with a somewhat larger maximum value, 23 ms. This difference should be compared with what has been found in other studies. Lisper, Laurell, and Van Loon (1974) found that the reaction time on a similar task had increased by

approximately 200 ms just before the subjects fell asleep at the wheel. In another study Lisper, Törnros, and Van Loon (1981) found that the reaction time, again on the same task, was seriously impaired by a prescription drug, diazepam 10 mg; the difference compared with a placebo condition exceeded 50 ms, with maximal difference exceeding 80 ms. In comparison with these other studies, the effects in the present study are small.

It is further necessary to relate the present findings to the large differences between driving speeds regarding reaction distances and braking distances. The reaction distance increases linearly as a function of speed, whereas the braking distance increases more or less quadratically as a function of speed. The braking distance will therefore be nearly 2.5 times as large at 110 km/h compared with 70 km/h. A similar relation exists between speed and motion energy. Whatever the consequences of these conditions might be with regard to traffic safety, the present findings indicate that the possibility of counteracting these consequences by being somewhat more alert at higher speeds are not great. With the small degradation of reaction time found here during 200 km of motorway driving it is improbable that reaction distance would be affected to any great extent but would still be larger at the highest speed. The total stopping distance would probably therefore be advantaged to only a small degree of fast driving and would still be much larger at higher speed.

Another factor should be mentioned here, one that was studied by Solomon (1964) and Fildes, Rumbold, and Leening (1991): the deviation between one's own speed and the speed of other vehicles on the road. These authors analysed the connection between this deviation and accident involvement. Solomon, who studied the impact of large speed deviations (from -40 mph to +30 mph), found, when analysing official accident figures for two-lane and four-lane main rural highways, a U-formed relationship; accident involvement was higher at high speeds but also at low speeds. Accident involvement was lowest when one's own speed was similar to the speeds of the other vehicles on the road. Solomon also found that the accidents had more serious consequences at high speeds. Fildes et al., who had access to a less comprehensive data base of self-reported accidents, studied speed deviations of a smaller magnitude (up to ± 20 km/h). They found increased accident rates at high speeds but found no signs for increased accident involvement at low speeds. On the contrary, accident involvement tended to be lower than normal at low speeds. Fildes et al. declined to draw any firm conclusions from

this finding, and expressed the view that accident involvement at low speeds needs to be explored further.

In the present study effects of driving speed were examined when driving on a motorway having the speed limit of 110 km/h in all three conditions. If a similar study were performed on motorways having different speed limits, it is probable that the interaction with other road users would be more similar in the different conditions than was the case in the present study, and hence any possible stimulating effect of the differential between own and others' speed would be minimised. This might cause driving speed to have somewhat smaller effects on the measures studied. This issue of course needs empirical evidence for clarification.

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Address
S-581 95 Linköping
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Telephone
+ 46 13 20 40 00

Fax
+ 46 13 14 14 36