Review of Relationships Between Steering Wheel Reversal Rate and Driving Task Demand

WENDY A. MACDONALD and ERROL R. HOFFMANN, Department of Mechanical Engineering, University of Melbourne, Melbourne, Australia

Previous literature and some new data on the relationship between steering wheel reversal rate (SRR) and driving task demand are discussed in terms of a set of theoretical assumptions proposed by Macdonald and Hoffmann (1978). SRR is generally expected to increase with increasing task demand; however, several recent studies found a significant decrease in SRR. It is argued that whether the relationship is positive or negative depends on the level of task difficulty relative to the driver's capacity to cope with it.

INTRODUCTION

A wide variety of experimental measures have been used in investigations of the task demands experienced by drivers. These measures include: subjective estimates of driving task difficulty; calculation of the complexity of attentional demands of the road-traffic environment based on observations of a variety of "events"; indices of the driver's physiological arousal; performance by the driver of various secondary tasks; and performance of the driving task itself.

One of the most commonly used driving performance measures is steering wheel reversal rate (SRR), which is a measure of the number of times per minute that the direction of steering wheel movement is reversed through a small, finite angle, or gap. Reported gap size varies from \( \frac{1}{2} \) to 10 deg, although many authors have not stated its

\(^1\) Requests for reprints should be sent to Dr. W.A. Macdonald, Department of Mechanical Engineering, University of Melbourne, Parkville 3052, Australia.

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the current purpose that SRR is closely correlated with HFA, and the results are discussed in terms of SRR.

A POSITIVE RELATIONSHIP BETWEEN SRR AND TASK DEMAND?

An association between increases in driving task difficulty and increases in SRR has often been reported. For example, Greenshields (1963) found that SRR increased with an index of traffic events density; Rockwell and Lindsay (1968) observed increases in SRR during encounters with oncoming vehicles; McLean and Hoffmann (1972; 1973) found that SRR was higher with decreasing lane width, increasing speed, and reduced preview; Hicks and Wierwille (1979) found higher values of SRR when simulator steering task workload was increased by varying the location of simulated wind gusts. Armour (1978) found that SRR decreased when double center lines were painted on a previously unmarked, winding rural road. This latter change in SRR suggests that the addition of center lines served to define the driver’s safe path more clearly, making his task easier. However, it might have been argued that the center lines decreased effective lane width, making the task more difficult; the result is, therefore, rather ambiguous in terms of the present discussion.

When task difficulty remains constant, it has been found that lower levels of driver capability are often associated with higher SRR. Thus, inexperienced drivers have been found to have higher rates than experienced drivers (Greenshields, 1963; Greenshields and Platt, 1967; Kimball, Ellingstad, and Hagen, 1971). A similar pattern has been shown for high-accident drivers (Greenshields, 1963) and fatigued drivers (Platt, 1963; Safford and Rockwell, 1967).

The general conclusion from these findings appears to be that SRR is directly related to level of driving task demand, whether this is varied by changes in the task or by the driver’s ability to cope with it. Indeed, Curry, Hieatt, and Wilde (1975) state that SRR may provide “a measure of task load,” citing Platt (personal communication, 1970) in support of this view. Recently, however, results have been reported which suggest that this conclusion requires qualification.

PROPOSAL OF A MORE COMPLEX RELATIONSHIP

In a test track experiment, Macdonald and Hoffmann (1977) found that when increased driving task demand was due to extremely narrow lanes, SRR increased as expected. However, SRR decreased when total demand was increased by requiring drivers to perform a secondary task in addition to the steering task (with velocity maintained at a constant level by the co-driver). In an experiment on suburban roads under normal traffic conditions, Macdonald and Hoffmann (1978) found that addition of the same secondary task as in the previous study led to an increase in SRR, while the road section with the most events had the lowest mean value of SRR. It was suggested that these apparently contradictory sets of data could be reconciled if the following assumptions were made:

(a) When demands of the driving task are well within a subject’s performance capacity, he copes with an additional task by increasing total effort.
(b) Increasing effort induces higher values of SRR.
(c) When task demands match or exceed performance capacity, subjects cope with an additional task by changes in attention allocation in such a way that less attention may be available for the steering task, while effort remains constant.
(d) Decreased attention to the steering task results in low values of SRR.

These assumptions imply a relationship between task demand and SRR which may be either positive or negative, depending on the
level of total task difficulty relative to the driver’s capacity to cope with it. It is argued that if task difficulty is increased from a point well below performance capacity, assumptions (a) and (b) apply, so that SRR increases with task demand. However, if difficulty is increased when the driver is already performing at a level close to capacity, assumptions (c) and (d) apply, resulting in lower values of SRR as demand becomes higher.

Assumptions (a) and (c) are consistent with the capacity model of attention proposed by Kahneman (1973) and with the findings of Long (1976), who used signal detection theory to investigate the manner in which attention is shared between two nonverbal tasks. Long concluded that “a shared model of divided attention with a limit to processing capacity seems to have the widest application,” with the “all-or-none” model of divided attention being applicable under conditions of extreme information overload. He pointed out that such a result was “consistent with the notion proposed by Easterbrook (1959) and supported by Kahneman (1973) that attention can be shared only at medium and low levels of information load. At very high levels, attention may be unitary.” In terms of the above assumptions, it may be that at subcapacity levels of total task demand, attention is shared between steering and other subtasks. However, when capacity output of effort or attention is reached, attention can no longer be shared concurrently, so attention is withdrawn, at times, from some or all subtasks, depending on the particular strategy adopted by the subject. Thus, “selectively attending less to a subset of the signals might be the only way of permitting the adequate acquisition of information concerning the remainder” (Long, 1976).

Assumption (b), that increasing effort induces higher values of SRR, is consistent with the analysis of Kelley (1969), supported by McLean and Hoffmann (1975), who pointed out that control frequency measures such as SRR represent control effort rather than an absolute measure of tracking performance. The lack of correlation between SRR and steering performance has often been demonstrated (e.g., McLean and Hoffmann, 1975; Blaauw et al., 1977; Macdonald and Hoffmann, 1977; and Riemersma et al., 1977). It may be that the assumed relationship between effort and SRR is mediated by an increase in physiological arousal level. There is a considerable amount of evidence supporting the argument of Kahneman (1973) that the increasing mental effort evoked by increasing task demands induces a corresponding increase in physiological arousal; SRR has been shown to increase markedly with a drug-induced high arousal level (Safford and Rockwell, 1967) and to decrease under the influence of a depressant drug, e.g., alcohol (Mortimer and Sturgis, 1975).

However, effort or arousal level cannot be the only determinant of SRR, as neither could account for the observed decreases in SRR under very high task demand (presumed to be overload) conditions. Assumption (a) explains such decreases in terms of a decrease in attention to the steering task. Some support for this assumption may be deduced from the results of Wickens and Gopher (1977), who investigated the effects on laboratory task tracking performance of a concurrent serial reaction time task with varying relative priorities between the tasks. Total output power was higher for the dual-task conditions than for the tracking task alone, over all regions of the tracking output power spectra; this result presumably reflects the greater effort evoked by the increased task demands. The dual-task conditions consisted of the same tracking and response time tasks, but in one case the subject gave greater priority to tracking; in another case, priority was given to the response time task. Comparison of the tracking control output power spectra for the
two conditions shows that decreased attention to the tracking task resulted in a proportionate decrease in high-frequency control output, with total output remaining about the same.

It must be acknowledged that this was a laboratory task, not steering a vehicle; nevertheless, comparable results for a driving task would mean that a decrease in attention to the steering task would result in a decrease in SRR. Other aspects of their data led Wickens and Gopher to argue that when tracking was the low-priority task, an "internal attention switch" operated to increase the number of occasions on which the response time task was attended. During these times there was no tracking response at all, as evidenced by "holds" in tracking output. Such a situation is clearly one of all-or-none attention, in which case assumption (d) should apply; the evidence suggests that it did.

IMPLICATIONS OF THE PROPOSED RELATIONSHIP

If it is accepted that the four assumptions are broadly correct, the results of Macdonald and Hoffmann may be interpreted as follows. In the test track study (1977), assumptions (c) and (d) are applicable because the steering task alone demanded close to capacity attention; therefore, in order to perform the secondary task to some personally acceptable standard, subjects allotted less attention to steering. The possibility of this response to imposition of a secondary task with a very demanding primary task has also been suggested by Sullivan (1976). The adoption of such a strategy does not necessarily mean that subjects disobeyed instructions to use only "spare" capacity for secondary task performance; extra capacity might legitimately have been termed spare and, therefore, available for secondary task performance if the steering task was being performed to subjectively acceptable criteria. A decrease in SRR does not necessarily imply a degradation in driving performance, and in this case there was no significant effect of the secondary task on the number of lane marker sticks knocked out of position.

Since publication of the 1977 report, further investigation of the data has shown that the reduction in SRR associated with secondary task performance was least for the narrowest lane and greatest for the widest lane. The interaction was significant, $F(6,36) = 3.45, p < 0.01$. Figure 1 shows the interaction in the form of relationships between SRR and $H$, an information processing index of the steering task difficulty associated with each lane width (Macdonald and Hoffmann, 1977). $H$ is defined as

$$H = \log_2 \left( \frac{W}{W - C} + 1 \right)$$

where $W$ is the lane width and $C$ is the width of the car.

Figure 1. Relationship between SRR and $H$, an index of steering task difficulty for each of the four driving task conditions. Data are from the study reported by Macdonald and Hoffmann (1977). Suffix "L" indicates performance when simulated traffic events are included in the task.
The result is consistent with assumptions (c) and (d). When steering was at its most difficult, drivers evidently allotted less attention to the secondary task. Newman-Keuls tests showed no significant difference in SRR for the narrowest lane between driving with and without a secondary task; and differences in SRR between lanes were significant only for the driving plus secondary task condition, not for driving alone. From another viewpoint, the secondary task can be seen to have acted as a loading task, increasing the sensitivity of SRR as a measure of steering task difficulty. (It was also an effective secondary task, since its performance was significantly related to lane width.)

Effects of Traffic Events and Vehicle Velocity

The second study reported by Macdonald and Hoffmann (1978) was conducted in normal traffic, so that in addition to the continuous subtasks of steering the vehicle and performing the secondary task, drivers had to cope with a variety of relatively brief traffic events. SRR was higher in the presence of the secondary task, which implies that on average the driving task alone did not demand full capacity attention—assumptions (a) and (b). SRR was lowest for the road section with most events, suggesting that an event often overloaded the driver and caused a reallocation of attention such that not only was secondary task performance temporarily suspended (as shown in secondary task performance data), but less attention was available for the steering subtask—assumptions (c) and (d). However, there was a positive linear relationship between number of events and mean velocity \( r = 0.97 \). Since a positive correlation between velocity and SRR has been reported (McLean and Hoffmann, 1975; Curry et al., 1975), it is possible that the low SRR value may have been mediated by lower velocity rather than directly by an increase in number of events.

A study by Riemersma et al. (1977) suggests that the result is not necessarily dependent on velocity effects. Subjects performed a secondary task quite similar to that used by Macdonald and Hoffmann, but with an additional subtask of maintaining a constant standard speed, so this factor was controlled. SRR was found to be lower for a section of motorway having “a higher traffic density and ... a more chaotic appearance because it was situated near a point where two traffic streams merge,” compared with a second section of motorway. It was higher in the presence of the secondary task. These results are similar to those of the Macdonald and Hoffmann (1978) field study and seem explicable in similar terms.

Results of Curry et al. (1975) are also consistent with the present assumptions. They found, in a detailed analysis of data from one subject, that velocity and SRR were directly correlated, while velocity and an “attentional demand” rating of traffic complexity were negatively correlated. They argued that drivers typically decrease velocity as traffic complexity increases in an attempt to maintain constant task demands. Whether SRR decreased as a direct result of the change in velocity or of the change in traffic complexity remains uncertain. Analysis of variance results (using data from all subjects) showed that SRR, when calculated on a time base as in all other studies, was negatively related to number of traffic events in terms of mean values for different sections of road; SRR was lowest in the city, followed by the suburbs, and then two highway sections, while in terms of rate of event occurrence per mile, the highway sections were lowest, and the city highest.

On the other hand, Greenshields (1963) reported that SRR was higher with increased traffic events. The present assumptions would explain this as being due to a lower level of total task demand, such that Green-
shields' subjects could generally cope with events by increasing effort—assumptions (a) and (b)—rather than by reallocating attention at the expense of steering performance—assumptions (c) and (d). It may be that the presence of a secondary task in the experiments of Macdonald and Hoffmann (1978), Riemersma et al. (1977), and Curry et al. (1975) was responsible for the difference between their results and Greenshields'.

Effects of Driving Experience

Capacity to cope with a given task is affected by individual driver factors such as amount of driving experience. A study by Blaauw et al. (1977) investigated how different types of task demand interact, particularly in combination with different levels of driving experience. Task demands were manipulated by means of different instructions to the driver; there were two forms of instruction concerning lateral vehicle control and two forms concerning longitudinal control.

Results showed that the combination of an easy steering task with a commentary loading task resulted in higher SRR values than a strict criterion steering task alone. This finding illustrates clearly that there is not a simple, direct relationship between SRR and steering subtask difficulty because SRR was lower when steering was more difficult.

For the strict criterion steering condition (without loading task) there was a significant interaction between driving experience and longitudinal instructions: SRR of experienced drivers was higher for the two forced velocity conditions than for the free velocity condition, while SRR of inexperienced drivers was lower with forced than with free velocity. To explain these results in terms of the present hypotheses, it must be assumed that addition of the loading task in the lenient criterion steering condition increased task demands to full capacity. The loading task was of an open-ended, self-paced nature, so this is quite likely. The additional demands of the forced velocity instructions were probably then coped with by degrading loading task performance (which was not recorded), since total effort could not be increased beyond its existing capacity level. In other words, increased task demand was coped with not by an increase in effort but by a reallocation of attention at the expense of the loading task; that is, when a loading task was added to an easy steering task, assumptions (c) and (d) applied.

In the difficult steering condition, the inexperienced drivers were overloaded by the imposition of strict performance criteria on longitudinal control, as well as lateral control, and coped with this by decreasing attention to the steering task, with a consequent decrease in SRR. Experienced drivers, on the other hand, were not overloaded, so were able to cope by increasing effort expenditure, with consequent higher values of SRR. Blaauw et al. comment that their findings are consistent with the expectation that "inexperienced drivers do not as easily co-ordinate lateral and velocity control at the same time as experienced drivers." They refer to work showing that the integration of steering and speed control skills requires a substantial amount of driving experience (Kimball et al., 1971). Safren, Cohen, and Schlesinger (1970) observed that there was a positive correlation between SRR and speed change rate for experienced drivers, but a negative correlation for inexperienced drivers. This suggests that inexperienced drivers were switching attention between the two subtasks, rather than concurrently sharing as the experienced drivers appeared to do. In terms of the present interpretation, this attention-switching and associated lack of coordination is at least partly due to inexperienced drivers becoming overloaded at a much lower level of task difficulty than experienced drivers. In some circumstances, then, assumptions (a) and (b)
may be operative for experienced drivers, while assumptions (c) and (d) operate for inexperienced drivers.

CONCLUSION

To summarize the main arguments, high values of SRR are indicative of high driving task demand, whether associated with difficulty of the steering subtask or of some other aspect of the total task. This relationship is probably mediated by a high level of effort or arousal. A low SRR might indicate either low or very high total task demand. Low SRR when task demands are small is simply due to low level of effort. When task demands are high, low SRR indicates a decrease in attention to the steering subtask. No decrease would be expected if the task were completely unitary, consisting only of steering, no matter how difficult. When nonunitary tasks are undertaken, the driver's strategy of attention allocation would be expected to affect the extent of any decrease in SRR.

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