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Tailgating

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Tailgating

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ABSTRACT

Among the causes of rear end crashes is tailgating (following too closely). (In this report, tailgating does not refer only to deliberately aggressive close following, the driver may consider the close distance to be appropriate.) Calculations about how tailgating can lead to rear end crashes are presented. A distinction is made between conditions in which improved braking performance will and those in which it will not reduce the likelihood of a rear end crash. Short gaps between one vehicle and the next are very common in ordinary driving. Because of the possibility of a disturbance in flow being amplified as it passes from one vehicle to another, drivers bear a collective responsibility to vehicles behind them to try to dampen rather than amplify disturbances. Evidence from rear end crashes that were investigated in depth by staff at CASR (Centre for Automotive Safety Research, University of Adelaide) is that inattention in various forms is a more frequent cause than tailgating. (It is noted that methods of classification of rear end crashes are surprisingly coarse and not very helpful for devising remedial measures.) Potential measures to counter tailgating are discussed: advisory signs, markings on the road surface, enforcement by the police, a futuristic proposal for enforcement by the public, and improvements to the vehicle. There is reason to think that each of these would meet with some success.

KEYWORDS

Headway, Vehicle spacing, Driver behaviour

Summary

One obvious cause of rear end crashes is following too closely --- “tailgating”, as it is sometimes called. (In this report, tailgating does not refer only to deliberately aggressive close following, the driver may consider the close distance to be safe and appropriate.) Calculations about how tailgating can lead to rear end crashes are presented. A distinction is made between conditions in which improved braking performance will and those in which it will not reduce the likelihood of a rear end crash.

Short gaps between one vehicle and the next are very common in ordinary driving: on busy motorways, for example, a driver will typically choose to follow only 0.5 to 1.0 seconds behind the vehicle ahead. Because of the possibility of a disturbance in steady vehicle following being amplified as it passes from one vehicle to another, drivers bear a collective responsibility to vehicles behind them to try to dampen rather than amplify disturbances.

Evidence from rear end crashes that were investigated in depth by staff at CASR (Centre for Automotive Safety Research, University of Adelaide) is that inattention in various forms is a more frequent cause than tailgating. It is noted that methods of classification of rear end crashes are surprisingly coarse and not very helpful for devising remedial measures.

Potential measures to counter tailgating are discussed: advisory signs, markings on the road surface, enforcement by the police, a futuristic proposal for enforcement by the public, and improvements to the vehicle. There is reason to think that each of these would meet with some success. But as regards the effect on rear end crashes, there are two limitations. The first is that, as already mentioned, inattention is probably a more frequent cause than tailgating. The second is that close following is common, and if a minimum gap or stricter enforcement were proposed, great care would be needed in choosing the minimum or managing the stricter enforcement.

Advisory signs or increased enforcement would need to pay close attention to safety. For example, a trial in the U.K. some years ago commenced with a setting of 0.7 seconds as the trigger point, which was raised in stages to 1.6 seconds as the trial progressed. If police chose to heavily enforce a minimum of 2 or 3 seconds, there may be some adverse impact on traffic flow. This would be unlikely with a lower choice of minimum, or enforcement carefully tailored to the conditions.

Several ways in which datasets at CASR could be used to throw more light on rear end crashes are discussed.

Contents

1 Introduction

One obvious cause of rear end crashes is following too closely --- "tailgating", as it is sometimes called. In this report, tailgating does not refer only to deliberately aggressive close following. The driver may consider the close distance to be safe and appropriate.

The present report is arranged as follows.

- Section 2 is an introduction to rear end crashes. It summarises the recent report by Baldock et al. (2005).
- Section 3 presents basic calculations about how tailgating can lead to rear end crashes, and distinguishes between conditions in which improved braking performance will or will not reduce the likelihood of a rear end crash. It goes on to discusses the gaps between vehicles that occur in normally-flowing traffic. Because of the possibility of a disturbance in steady vehicle following being amplified as it passes from one vehicle to another, drivers bear a collective responsibility to vehicles behind them to try to dampen rather than amplify disturbances. Also discussed in Section 3 are some psychological issues: aggression, perception and anticipation, and interference between tasks.
- Section 4 returns to discussion of crashes, and a close examination is made of what Baldock et al. (2005) say about rear end crashes that were investigated in depth by staff at CASR. Of the 27 rear end crashes discussed there, the present report describes 2 as partially tailgating and a further 4 as minimally tailgating. Inattention in various forms seems a more frequent cause than tailgating. Also discussed in Section 4 is the classification of rear end crashes.
- Section 5 discusses some possible countermeasures to tailgating: advisory signs, markings on the road surface, enforcement by the police, a futuristic proposal for enforcement by the public, and improvements to the vehicle. Because close following is so common, implementation of any measure that affects the flow of traffic (such as stricter enforcement) would need to be carefully managed.
- Section 6 firstly discusses what effect adoption of a gap of, say, 2 or 3 seconds by all vehicles might have on traffic flow in Adelaide conditions, and secondly identifies several ways in which datasets at CASR could be used to throw more light on rear end crashes.

TERMINOLOGY AND ABBREVIATIONS

Most authors use the terms *headway* and *gap* interchangeably. However, some make a distinction, using headway to refer to the time (or, sometimes, the distance) between the front of one vehicle and the front of the next (or, sometimes, between the first axle of one vehicle and the first axle of the next), and gap to refer to the time or distance between the back of one vehicle and the front of the next. The present report does not discuss methods of measuring distances between vehicles, and thus this distinction is usually not necessary and the terms can be used interchangeably. At some points, one or other term has been deliberately chosen, but usually the usage is that which is most common in a particular context or is that of the author whose work is being discussed.

CASR — Centre for Automotive Safety Research, University of Adelaide.

CTP — Compulsory Third-Party (insurance).

DTEI — Department of Transport, Energy and Infrastructure (South Australia).

MAC — Motor Accident Commission (South Australia).

TARS — The Traffic Accident Reporting System (TARS) database, maintained by DTEI and based on crashes reported to the police.

2 Overview of rear end crashes

An appropriate departure point is the recent report by Baldock et al. (2005), covering the rather broader topic of rear end crashes. But before summarising that report, it should be noted that rear end crashes figure very differently in different datasets.

- According to the Motor Accident Commission (South Australia), approximately 40 per cent of CTP (Compulsory Third Party) claims result from rear end crashes (see http://www.mac.sa.gov.au/road_safety/the_issues/inattention).
- In the dataset of crashes reported to the police that was analysed by Baldock et al. (2005, Section 2), rear end crashes constituted 30 per cent.
- Among fatal and serious crashes in South Australia, rear end crashes were 9 per cent of those in metropolitan Adelaide and 3 per cent of those in rural areas (see Road Crash Facts for South Australia 2005, at http://www.transport.sa.gov.au/pdfs/safety/road_crash/Crash_Facts.pdf).

Another way of looking at this is to ask what proportion of crashes reported to insurance companies can be found in the official (police) statistics --- this proportion can vary considerably between different types of crash. Working in Sydney, Searles (1980) found that it was 36 per cent for right-angle crashes and 20 per cent for rear end crashes, for example. The contrast was not so great for casualty crashes, 64 per cent and 52 per cent. (The figures are given in Table 4.7 of Hutchinson, 1987.)

There are three parts to the report by Baldock et al.: analysis of routinely-reported rear end crashes in South Australia (in the TARS database), discussion of rear end crashes investigated in-depth by the Centre for Automotive Safety Research, University of Adelaide, and a literature review that concentrated on road and vehicle factors.

- From the routinely-reported data for 1998-2002, Baldock et al. found that rear end crashes (relative to other types) are more likely to occur at or near crossroads, during peak traffic times, in daylight, on level roads, and on straight roads. They are less likely to occur in country areas, at night, on weekends, and on undivided roads, and are less likely to result in fatal or serious injury. These characteristics largely reflect traffic density. The driver of the striking, as contrasted with the struck vehicle, was more likely to be young, male, and hold only a provisional driving licence.
- From the cases investigated in-depth, Baldock et al. highlighted inadequate division of attention by the driver of the striking vehicle. That is, the driver may have been not sufficiently focused on the driving task, distracted by something inside the vehicle, distracted by something outside the vehicle, unable to adequately divide attention between two or more driving-related tasks, or unable to direct attention appropriately when changing lanes. In 11 of the 38 cases investigated, a vehicle waiting to turn right was involved: greater provision of right turn lanes is an obvious countermeasure. Other factors included health problems of drivers, unexpected events, congestion due to parked vehicles, and obstructed vision. For more on this, see Section 4.1 below.
- The literature review covered four topics: road design, skid resistance, vehicle conspicuity, and collision avoidance systems. *Road design*: the two issues that have received most attention are stationary vehicles waiting to turn at intersections, and drivers some distance before the intersection not expecting to meet stationary queued traffic (perhaps due to restricted visibility). *Skid resistance*: resurfacing with skid resistant material can substantially reduce wet weather crashes. *Vehicle conspicuity*: measures such as retroreflective tape and centre high mounted stop lamps have probably had a degree of success. *Collision avoidance systems*: a variety of different systems are currently being developed and evaluated.

Discussion of rear end crashes will be continued in Section 4.

3 Tailgating

3.1 Calculations about tailgating

Conventional calculations about tailgating are as below.

Suppose vehicle 2 is following vehicle 1 at constant speed v, the front of vehicle 2 being t_1 seconds behind the back of vehicle 1. Further suppose that vehicle 1 commences emergency braking, and then, after some reaction time t_2, vehicle 2 also commences emergency braking. Then vehicle 2 will or will not normally strike vehicle 1 depending upon whether t_1 is smaller or greater than t_2.

To see that this is the case, let distance be measured from where the back of vehicle 1 is when it commences braking, and let its stopping distance be s. Unless it strikes vehicle 1, the front of vehicle 2 when it comes to rest will be at $-t_1v + t_2v + s$, assuming its stopping distance is the same as that of vehicle 1. Whether this is greater or smaller than s depends upon whether t_1 is greater or smaller than t_2.

If, luckily, the braking performance of vehicle 2 is superior to that of vehicle 1, collision may be avoided even if t_1 is smaller than t_2. If, unluckily, the braking performance of vehicle 2 is worse than that of vehicle 1, collision may occur even if t_1 is greater than t_2.

3.2 Braking performance

Better braking performance might be achieved through improved vehicle or road surface technology. Would rear end crashes thereby be prevented?

- Not necessarily, the reasoning above tells us. A shorter braking distance is likely to apply to both vehicles, and will not affect the key factor, the difference between t_1 and t_2.
- Other types of rear end crashes might indeed be reduced by shortened braking distances. If vehicle 1 is stationary or moving slowly and vehicle 2 is moving, and the driver of vehicle 2 is inattentive but then notices vehicle 1, then a reduced braking distance will indeed improve the chance of avoiding collision.

The distinction between these is that in the tailgating case, the leading vehicle was assumed to brake as hard as it could, whereas in the second case that is not so. The calculation based on emergency braking is a useful one to make because sometimes a leading vehicle does brake sharply, whether for important or unimportant reasons. But it does only represent one type of rear end crash, and conclusions may not apply to others.

There has been much work done, over a long period of time, on reducing braking distances through improving the road surface. An appreciable proportion of rear end crashes can be prevented (Kinnear et al., 1984). As has been noted above, however, crashes initiated by emergency braking are unlikely to be prevented — there is not much point in improving the braking performance of the following vehicle, if that of the leading vehicle is also improved.

3.3 Gaps in normally-flowing traffic

In busy traffic, gaps of less than 1 second are common. Decision reaction times of 2 or 3 seconds are common. Thus we see the importance of being able to react not only to the vehicle ahead, but also to the vehicles ahead of that: their brake lights being in working order is important, and not being visually blocked by the vehicle immediately ahead is important, too.

For reviews of reaction time, see Taoka (1982), Sohn and Stepleman, 1998, Green (2000), and Summala (2000). Simple reaction times are often less than 1 second, but decision reaction times are often much longer. Thus in AASHO (1973, p. 277) we find the following:

"Driver's perception time varies from about 0.5 sec for simple situations to as much as 3 or 4 sec for more complex situations.... For determining minimum stopping sight distances, it is assumed that the perception time value is 1.5 seconds, and that the combined perception-reaction time in braking is 2.5 seconds". What reaction time is most relevant to driving tasks? Noone quite seems to know the answer. Taoka (1982) and Levy et al. (2006) draw attention to differences between driving and typical psychological experiments on reaction time. (See also Section 3.5 below.) For present purposes, it is sufficient to make the point that reaction time can be appreciably greater than the gap chosen.

Evidence that short gaps are common in some circumstances includes the following. Brackstone et al. (2002, p. 339) reported the median gap on a U.K. motorway to be about 1 second. For references to earlier studies in the U.K., see the first paragraph of Postans and Wilson (1983). Marsden et al. (2003, p. 12) reported the most likely gap at about 95 km/h on a French motorway to be 0.5 seconds. Moore and Rumar (1999, pp. 58-59) referred to several studies, including one that reported the most likely gap on U.S. freeways to be 0.8 seconds. An experiment conducted on a divided highway in Israel by Taieb-Maimon and Shinar (2001) asked drivers to choose first a "minimum safe" gap and then a "comfortable" one. The median choices, which did not vary with speed over the range 50 km/h to 100 km/h, were 0.7 and 1.0 seconds. And according to Treiterer and Nemeth (1970), "The term 'following too closely' sounds more like an excuse than a determination of the cause since it is almost impossible, in high density traffic flow, to keep an absolutely safe distance from the car ahead all the time when lane changes occur frequently."

It might expected that if the leading vehicle is large, the gap chosen will be larger, as no longer is it possible to see vehicles further ahead. But Sayer et al. (2003) reported the reverse of this: gaps when following what they called light trucks (sport utility vehicles, minivans, vans, pickup trucks, but not commercial vehicles) tended to be smaller than when following cars. Observations on a U.K. motorway by Postans and Wilson (1983) showed that trucks tended to tailgate trucks, and cars tended to tailgate cars. Presumably the major reason was preference for driving speed.

3.4 Collective responsibility

As discussed in Section 3.1, if the vehicle ahead begins emergency braking, the following vehicle will only be able to avoid collision if the time gap exceeds the driver's reaction time (assuming the vehicles' braking performances are the same). Davis and Swenson (2006) make an interesting point about the collective responsibility of a stream of vehicles for their mutual safety: not only do all drivers have a responsibility for not striking the vehicle ahead, but they also have a responsibility to dampen, rather than amplify, any deceleration disturbance that starts ahead of them. Davis and Swenson analysed video recordings of three freeway rear-end collisions. For each of the collisions, they concluded that a vehicle ahead of the vehicles that collided was a causal factor through following too closely relative to their reaction time. In making such a statement, the meaning of causation needs to be dealt with, and Davis and Swenson do so. Also, the statement does not imply the colliding vehicles were blameless — and, indeed, they were not blameless.

3.5 Some psychological considerations

Aggression. The literature on road rage refers to deliberate, intimidatory, tailgating as one form of aggression on the road. Tailgating was among the main problem areas identified by focus groups in Dallas, Texas (Walters et al., 2000, Section 3.3). Persistent risky drivers were defined by Begg and Langley (2004) to be those saying they often or fairly often performed a specific risky activity at both age 21 and age 26, in a cohort study. In the case of following closely behind slow drivers, 4 per cent of males and 1 per cent of females were classified as persistently risky, in a New Zealand sample. Personality may be correlated with following distance (Brackstone, 2003). This literature generally does not distinguish between reasons for deliberate tailgating. Sometimes, tailgating is an expression of anger. But it is likely that deliberate tailgating is sometimes not anger or aggression in the usual sense, but an intentional signal of haste and a desire to pass the vehicle ahead (Rajalin et al., 1997). Communication between one driver and another is very limited --- a way of courteously expressing haste might eliminate some instances of this form of tailgating.

Perception and anticipation. A major reason that more crashes do not occur is (presumably) that drivers look further ahead than the vehicle immediately in front of them. A driver who is second in a platoon of traffic can often see the road ahead, and anticipate whether there is any reason the first vehicle may need to slow; a driver who is further back in a platoon can often see the brake lights of several vehicles ahead and thus judge whether any are slowing. It is likely that centre high-mounted brake lights reduce rear end crashes (Rausch et al., 1982; Kahane, 1989), and this may be one of the mechanisms by which they are effective.

Interference between tasks. A recent paper by Levy et al. (2006) demonstrated interference between tasks: the reaction time before braking becomes slower when the stimulus is coincident with another task than when there is a gap of 350 milliseconds. Levy et al. used a medium-fidelity driving simulator. They noted that the interference occurred even though they considered the interfering task to be a trivial one and the braking task itself to be simple.

The usefulness of psychology. Beyond the results it reports, there is a further reason for referring to the paper by Levy et al. (2006). Over many decades, psychological experiments of some apparent relevance to tailgating have been carried out --- perception, attention, decision, reaction are mainstream topics in psychology, their importance when driving in a traffic stream is obvious, and they have been extensively studied both from theoretical and applied viewpoints. Yet in preparing this report, the present writer came across very little that compelled attention. It is this dearth of obviously relevant studies that the paper of Levy et al. throws light on. Despite it being, in a sense, a straightforward demonstration of interference between tasks, Levy et al. claim novelty for their experiment. The reason lies in several criticisms they make of psychological experimentation, particularly in regards to realism. (a) The overall experimental set-up was more similar to real-world driving than typical experiments on reaction are. (b) Driving is a highly-practised task, unlike those in most experiments. (c) In some previous experiments, the subject may have been able to use the interfering stimulus as a cue to brake. (d) The braking task, in real life and in their simulator, is neither quite a simple reaction task nor a choice reaction task.

4 Rear end crashes

4.1 Evidence from in-depth crash investigations at CASR

The report by Baldock et al. (2005) was introduced in Section 2 above. This report does not explicitly dismiss the importance of tailgating, but there are three ways in which it suggests that tailgating is not responsible for a high proportion of rear end crashes.

- The report gives no attention to tailgating.
- In the routinely-reported data, "inattention" was reported more than three times as often as "follow too closely" as the driver error in rear end crashes. In very many cases, it is difficult for the police to arrive at one view or the other as to the nature of the error, and it could be that "inattention" is a used as a vague catch-all category. Nevertheless, this data is some indication that tailgating is a cause in only a minority of cases. (Many things can cause rear end crashes — poor visibility, high speed, inattention, following too closely, and so on. In their Table 2.11, Baldock et al. give a long list of the proportions of different driver errors, according to the police, in rear end crashes as compared with other types.)
- Evidence about tailgating from the cases investigated in-depth by CASR staff; this will now be given some further attention.

Section 3 of the report by Baldock et al. discussed the 38 rear end crashes that were included in the sample of 286 crashes (in metropolitan Adelaide) that were the subject of in-depth investigation between April 2002 and February 2005. There are brief accounts of 27 rear end crashes that are relevant. Some classification of these is needed in respect of tailgating. In assessing whether tailgating is a contributory factor to a rear end crash, there are alternatives beyond yes and no.

- Yes. There was evidence that the following vehicle was being driven aggressively and the gap was absurdly short.
- Yes. There was evidence that the gap was short.
- Partially. There was sudden strong braking by the leading vehicle. Though there was no evidence that the next vehicle was following more closely than is common, nevertheless collision occurred.
- Minimally. There was a steady stream of traffic and no evidence that the next vehicle was following more closely than is common. A rear end collision would, no doubt, have been less likely had the gap been longer, but some other factor (such as failure of attention) was more prominent in the crash causation.
- No. For example, there was evidence that the struck vehicle had been stationary for several seconds.

In terms of the above classification, none of those in Baldock et al. (2005) were unambiguously tailgating crashes; 2 were the result of an unexpected event on the road and consequent sudden braking, and so would fall into the partially tailgating category; in the case of a further 4 crashes, the vehicle was in a steady stream of traffic but other factors were so prominent in the crash causation that it seems misleading to describe the crash as tailgating to more than a minimal extent. Table 4.1 lists the 6 crashes and notes the relevant features.

Table 4.1
Six crashes discussed in Baldock et al. (2005) that could be classed as tailgating

Crash	Page in Baldock et al. (2005)	Tailgating	Comments
M019	29	partially	reversing vehicle ahead
M129	30	partially	dog on road
M256	21, 30, 31	minimally	blind bend; driver distraction
M132	23	minimally	paying attention to mirror
M166	23, 28	minimally	paying attention to mirror
M174	23	minimally	paying attention to mirror

Looking back to an earlier study, McLean et al. (1979) reported on 304 crashes investigated in-depth. There seem to have been 24 rear end crashes among these, and following too closely was identified as a factor in 3 of these (cases 176, 184, and 277, at pages 57, 61, and 61). There were some other cases in which the striking vehicle had been following, but not closely, the struck vehicle. Alcohol, excessive speed, inattention, and distraction were commonly-noted contributory factors.

4.2 Classification of rear end crashes

The above discussion leads naturally to consideration of the classification of rear end crashes. Baldock et al. organised their discussion of cases as below.

- Inadequate allocation of attention, subclassified as: inattention; distraction; inadequate division of attention; unsafe lane changes.
- No designated right turn lanes, subclassified as: arterial roads; non-arterial single lane roads.
- Health issues of drivers of striking vehicles.
- Parking on arterial roads.
- Unexpected events on the road.
- Miscellaneous infrastructure issues.

Classification of rear end crashes in other sources is coarser than this. Chapter 6 of Hutchinson (1987) discusses the recording of crash circumstances in many jurisdictions. Reference to this shows that driver errors such as driving too close to the vehicle ahead may be recorded, rear end crashes may be classified according to whether the leading vehicle was stationary or decelerating or moving steadily, and cases in which there was a change of lane by one vehicle may be identifiable. But that is all.

There is no mention of tailgating or following too closely in Figure 2 of Knipling et al. (1992), which was based on the Indiana Tri-Level Study. The major groups of causes there are recognition errors (recognition that the vehicle ahead is stationary or slow moving) and decision errors. (According to Jones et al. (1981), the Indiana study estimated that between 0.2 per cent and 2.0 per cent of all crashes investigated by in-depth or on-site teams were caused by following too closely.) In Table 2 of Knipling et al. (1992), the principal causal factors in 74 rear end crashes randomly selected from the (U.S.) 1991 National Accident Sampling System were as follows. Driver inattentive, 48 crashes. Driver inattentive and following too closely, 8. Following too closely, 6. Alcohol, 6. Miscellaneous other, 6.

In routinely-collected crash data from Victoria, rear end crashes are classified according to whether the leading vehicle was travelling straight ahead, turning left, or turning right. Data for 1989 and 1990 was analysed by Andreassen et al. (1996a, Section 3; 1996b, Appendix B). They found the proportions of the three types were 68 per cent, 12 per cent, and 21 per cent.

Navin et al. (2000) listed seven reasons why rear end collisions occur: defective vehicle braking systems, inadequate vehicle tyre conditions, late braking due to driver inattention, excessive vehicle speed or erratic manoeuvres due to aggressive driving behaviour, defective pavement conditions, unfavourable road geometric characteristics, and insufficient and inconsistent road information. Whilst the list is not intended to be comprehensive, the fact that simple following too closely is not included surely suggests it was not considered a leading factor.

Thus it seems that, though rear end crashes seem simple, they are typically not classified in ways that are helpful for devising remedial measures.

5 Countermeasures to tailgating

It is possible that advisory signs at the roadside might persuade drivers to leave longer gaps, and that markings on the road might help them judge what is an appropriate length of gap, and these measures are discussed in Sections 5.1 and 5.2. Tailgating is largely a voluntary behaviour, and it is natural to direct countermeasures at the driver rather than the vehicle or the road. Furthermore, part of the background to the present report was the possibility of increased enforcement, with the aid of technology, of traffic laws requiring drivers to keep a safe distance, with a two second gap possibly defining what is safe. Thus Section 5.3 is directed to enforcement. Section 5.4 summarises a proposal whereby any member of the public could penalise or reward the driving of others. Section 5.5 discusses vehicle improvements.

5.1 Advisory signs: Direct evidence from experimental interventions

Signs warning of short headways have been used for some decades. After installation of an automatic warning sign at Ascot, Berkshire, there was an improvement of about one third in the proportion of drivers following at less than a 1.0 second gap (Helliar-Symons, 1983). Similar improvements were later obtained at four further sites (Helliar-Symons and Ray, 1986). At the beginning of the Ascot experiment, the sign was triggered only by gaps less than 0.7 seconds. This trigger level was successively raised to 1.0 second, 1.3 seconds, 1.6 seconds, and 2.0 seconds, before settling on 1.6 seconds for most of the experiment at Ascot and for the further four sites.

Two more recent studies of signs have also attempted to provide direct evidence for or against their effectiveness. Writing from Memphis, Tennessee, Michael et al. (2000, p. 57) claimed their study was "unique in that it implemented an intervention to decrease tailgating during normal traffic flow". The intervention was a hand-held sign urging drivers to avoid crashes by not tailgating. The proportion of drivers complying with the two second rule increased from 49 per cent to 57 per cent. In Finland, Rämä and Kulmala (2000) found that at one site a variable message sign decreased the proportion of short headways. These experiments were small-scale, and either were unable to detect crash reductions or did not study this.

5.2 Dots or chevrons on the road surface

Regularly-spaced markings (dots or chevrons have been used) can help drivers judge the distance between the vehicle ahead and themselves. Suppose the dots are 80 feet apart and a driver maintains a headway such that two dots are in sight at all times. Then when the driver reaches dot number 1, dot number 3 must be visible, 160 feet ahead. If the speed limit is 60 miles per hour (88 feet per second), and traffic is travelling at that speed, the gap is approximately 1.8 seconds. A trial on a U.K. motorway (Helliar-Symons et al., 1995) used chevrons spaced 40 metres apart. At 70 miles per hour, this implies a gap of about 2.5 seconds. (However, the signs that instruct drivers what to do are typically not clear in meaning: they are ambiguous as to whether dot number 3 must be visible at the moment dot number 1 disappears, or whether the distance between two markings plus a little more before and after is sufficient. Consequently, it is not altogether clear what time gap is implied by a particular speed.)

There is some recent evidence that average headways are increased (Minnesota Department of Transportation, 2006), but it seems that the latest generation of treatments have been small in scale and there is as yet no evidence about effects on crashes. Such road markings are inflexible in that when they are appropriate for traffic travelling at the speed limit, they will be too distantly spaced for lower speed traffic (Huddart and Lafont, 1990). Indeed, markings on a highway section in Washington state were removed because they added to congestion when speeds were slow (Washington State Department of Transportation, 2006). For a summary of French uses of chevron markings in the 1980's, see Huddart and Lafont (1990). (Incidentally, the intent in France was to teach drivers an appropriate headway, that would also be adopted elsewhere.) For a British trial on a motorway, see Helliar-Symons et al. (1995) and Helliar-Symons and Butler (1995). The report by Turnbull Fenner (1998) cites a personal communication from G Junnor of Ontario to the effect that the markings (chevrons) used there were considered distracting and disorienting.

Helliar-Symons and Butler (1995) concluded that chevron markings on motorways had a pronounced effect on crashes (a 56 per cent reduction), and should be encouraged. Single-vehicle crashes, as well as multi-vehicle crashes, were substantially reduced, perhaps because of an alerting effect of the markings.

5.3 Enforcement

A following distance of (at least) 2 or 3 seconds is widely recommended. In South Australia, the Driver's Handbook describes 2 seconds as reasonably safe, noting that this represents the time to apply the brakes only. The Driver Qualification Handbook in NSW recommends 3 seconds. According to ETSC (1999, p. 30): "In most countries time-headways less than 1 second are regarded as illegal. However, 3 seconds outside urban areas and 2 seconds in urban areas are generally recommended as safe driving distances." The U.S.A. seems to have changed, a few years ago, from emphasising 2 seconds to 3 seconds. It might be noted that it is questionable whether drivers are capable of judging their time gap behind the preceding vehicle, and hence whether it is wise to phrase advice in these terms. It was noted in Section 3.3 that in an experiment reported by Taieb-Maimon and Shinar (2001), the median choice of a "minimum safe" headway was 0.7 seconds; however, when drivers were asked to estimate their time headways, responses tended to be much greater, with medians between 1.9 seconds (at 50 km/h) and 2.6 seconds (at 100 km/h).

However, careful consideration would need to be given to the management of increased enforcement. The issue is an obvious contradiction between calculations that show that a gap of 1 second (say) is dangerous, and the experience of drivers every day that a gap of 1 second passes off without incident.

- One important way of managing enforcement is through extra information beyond the gap between vehicles. If a police officer observes road conditions and traffic flow and driver behaviour, that information will help anyone judge whether following at a gap of only 1 second is dangerous or not. It is likely, depending upon exactly what the law is, that it will be relevant to whether a traffic offence has been committed.
- On the other hand, the issue would come to the fore if some automatic means of enforcement were envisaged, without information other than the gap itself and the speed.

Rule 126 of the Australian Road Rules is titled Keeping a safe distance behind vehicles. It is worded as follows: "A driver must drive a sufficient distance behind a vehicle travelling in front of the driver so the driver can, if necessary, stop safely to avoid a collision with the vehicle." Thus what gap is appropriate is left quite open, and is up to the driver's judgment. It might be thought possible to introduce some limit, in an attempt to dispense with the need for supplementary information from the police officer and make penalisation easier. That is, a driver could be penalised for following at a gap less than t seconds, and not penalised for following at a gap greater than t seconds. On the issue of difficulty in penalising the offence, Michael et al. (2000, p. 62) (writing from Tennessee) note that "Unfortunately, officers do not at present have an objective method for identifying 'following too close' that can be used to provide convincing evidence in a court of law. Officers will routinely cite violations only when following too close can be identified as readily as speeding or driving under the influence". (Michael et al. seem to be calling for both a specific limit and a technology to implement it.)

If this option --- that is, of defining an offence in terms of a gap, without supplementary evidence being needed about the danger of the gap in the specific conditions --- were pursued, a decision about the appropriate gap limit t would be needed. It seems unwise to follow through with this option until a strategy has been developed to justify the choice of t. As noted above, even 2 seconds can be shown to be unsafe on the basis of certain reasonable assumptions. It might also be noted that according to Taieb-Maimon and Shinar (2001), the Israeli police enforce a headway of 1.0 seconds. A speed of 10 miles per hour is 14.7 feet per second, or 4.5 metres per second, so the old guideline of 1 car length per 10 miles per hour corresponds to roughly 1 second also. According to Lierkamp (2003), a video-based enforcement system in the Netherlands uses 0.5 seconds as the trigger. Experiments with in-vehicle warning systems by two different groups of researchers both presented results in terms of the proportion of gaps less than 0.8 seconds (Shinar and Schechtman, 2002; Regan, Young, et al., 2005). Going back to the 1980's, monitoring equipment in the U.S.A. was set to display the message *VIOLATION* when the gap was less than 0.7 seconds, and *DANGER* when the gap was between 0.7 and 1.25 seconds (Helliar-Symons, 1983). When used in the U.K., on a single-carriageway two-way road, only a single message was displayed, triggered at 1.6 seconds (after trialling various settings between 0.7 seconds and 2.0 seconds) (Helliar-Symons, 1983). Helliar-Symons (1983, p. 7) uses the descriptions "dangerously closely" and "imprudently closely" for less than 0.7 seconds and less than 1 second, respectively. Writing from Japan, Ohta (1993) refers to gaps of between 1.1 and 1.7 seconds as "comfortable", with less than 0.6 seconds as the "danger" zone. These practices could be taken as hints that increased enforcement is likely to concentrate on gaps of less than a second.

The reasoning below draws attention to different difficulties for different choices of t: 2 seconds, 1.3 seconds, and 0.6 seconds.

- Suppose t is about 2 seconds. The justification for this would be the well-known two second rule. The objection is that such gaps are extremely common and almost every driver in a stream of traffic could be penalised.
- Suppose t is about 1.3 seconds. The justification would be that it is appreciably more generous to the motorist than the strict application of the two second rule, and so fewer would be penalised. There are two objections. First, while there are fewer gaps less than 1.3 sec than there are less than 2 sec, they are still very commonly encountered. Second, in not penalising a gap of 1.4 sec, the impression may be given that a gap of 1.4 sec is acceptable and safe, which contradicts the two second rule and even more the three second rule.
- Suppose t is about 0.6 seconds. The justification for this would be via an analogy with the tradition in traffic engineering of using the 85th percentile speed as a guide for setting the speed limit, i.e., 15 per cent of vehicles are travelling faster. Figures reported in Brackstone et al. (2002, p. 339) indicate that on a U.K. motorway, about 15 per cent of drivers were adopting gaps of less than 0.6 sec. The objection is that it might give the impression that 0.7 sec is acceptable and safe. (For a vehicle travelling at 80 km/h, for example, 0.7 sec corresponds to about 16 metres.)

There is a trade-off between the two types of objection. If t is as long as 2 seconds, normal driving will be penalised, and there may be little public support. If t is shorter, there will still be many drivers penalised in relatively normal circumstances, and yet there will be failure to penalise gaps that calculations easily demonstrate are unsafe. If t is very short, everyone penalised will undoubtedly deserve to be, but very unsafe gaps will not be penalised. It is not necessarily impossible to overcome this problem — rigid criteria for an offence are familiar in the form of speed limits and blood alcohol limits — but the issue would need careful management.

None of this, of course, is an objection to enforcement by police sensitive to both what the driver is doing and the surrounding traffic environment. Nor is it an objection to publicity that urges drivers to avoid tailgating and stay well behind the vehicle in front.

5.4 Enforcement --- By other drivers and the public

Concern with aggressive driving seems to be a rather bigger issue in the United States than Australia, and innovative proposals sometimes emerge. In a 67-page article in the *New York University Law Review*, Strahilevitz (2006) proposes a system in which everyone (drivers, pedestrians, etc.) should be able to penalise or reward the driving of others. The system would involve each vehicle prominently displaying a unique identifier, and a central phone number that anyone can call to award negative or positive points for bad or good driving of that vehicle, with penalties (fines, increased insurance premiums) and rewards resulting. The idea assumes that many accidents occur because of obviously bad driving, and that this happens in part because drivers are for practical purposes anonymous. Its inspiration is twofold: on the one hand, the signs on trucks that say "How's my driving?" (or "My conduct as a professional driver is on display") along with a phone number, and on the other hand, the reputation-tracking systems developed by eBay and others.

There are obvious objections to such a radical proposal. But Strahilevitz does address them seriously. He is neutral concerning a number of detailed matters, and notes the possibility of high-tech variations on the proposal. The big issue that Strahilevitz does not tackle is whether and to what extent driving behaviour is correlated with crashes. That is, suppose all drivers were given accurate feedback about how their driving was perceived by others, and suppose further that they accordingly modified their driving; would an appreciable number of crashes be prevented?

5.5 The vehicle: Advanced warning systems, and brake lights

The review by Baldock et al. (2005) covered both vehicle conspicuity and advanced collision avoidance systems. They concluded (p. 41), "Alerting drivers to the risk of collision.... can be accomplished with increased conspicuity of the rear of vehicles, and with the introduction of intelligent transport systems such as adaptive cruise control and advanced collision warning systems.... It is necessary to examine the way drivers interact with [these systems] in real-world settings before being certain that they can provide cost-effective reductions in levels of crash involvement." The concern in that last sentence (and also expressed by other authors) is that drivers may rely too much on the technology, and become less attentive. For example, Advanced Cruise Control (ACC) may lead to increased speed and decreased gap (Dragutinovic et al., 2005).

A lot of work is being done by vehicle and electronics companies. It is conceivable that some form of high-tech safety system might be introduced in the near future and be found to be highly effective, but it seems unlikely. The tone of the remarks in ETSC (1999, p. 30) was that it will take a long time before the technology becomes effective. Regan, Young, et al. (2005) report a real-world trial of a Following Distance Warning system by 15 drivers. Results were promising, but inconclusive: the proportion of driving time spent at headways below 0.8 sec was reduced from 6 per cent to 1 per cent, but this was not statistically significant. Drivers disliked the many warnings received either when driving in a manner they considered safe and normal, or when another vehicle cut in front of them (Regan, Stephan, et al., 2005). Some other studies have had positive results: Shinar and Schechtman (2002) reported that the time spent in gaps of 0.8 sec or less was reduced by about 25 per cent when a warning system was in use, and McGehee et al. (1993) found that for subjects having an initial gap of 2.4 seconds or less, the average gap increased from 1.4 seconds to 2.7 seconds when there was a colour-coded display of the time gap.

In many cases of tailgating, the driver is relying on visual cues from several vehicles further ahead. At such distances, perception of rate of deceleration is certainly very poor. Present-day brake lights do not distinguish between mild and strong braking. Improvements have considerable potential to reduce the risk of tailgating crashes. In their review of rear lights, Moore and Rumar (1999, p. 62) are pessimistic about systems that indicate strength of deceleration. In support of their pessimism, Moore and Rumar cited the work of R G

Mortimer (see Mortimer, 1981), Rockwell and Treiterer (1968), and Rutley and Mace (1969). However, it is worth examining this evidence further.

- In the real-world experiment by Mortimer (1981), some taxis were equipped with a flashing supplementary brake lamp (system 1), others were equipped with a flashing supplementary brake lamp that flashed at different rates according to the level of deceleration (system 2). Those with system 2 had a rather *higher* rate of being struck from behind while stopping than those with system 1. Several objections should stop us drawing too firm a conclusion. (a) With an experimental system like this, other vehicle drivers may not have known the meaning of different rates of flashing. (b) The numbers of crashes (5 in one group and 9 in the other) are so small that the difference is estimated only imprecisely and is not significantly different from zero. (This was so even though the taxis drove some 18 million miles in the course of the experiment.) (c) It is possible that information on rate of deceleration will chiefly benefit not the vehicle that is equipped, but vehicles behind it.
- The other reports (Rockwell and Treiterer, 1968, and Rutley and Mace, 1969) are of car-following experiments, not crash occurrence. And both found improvements in the reaction by following drivers when lights operated by taking the foot off the accelerator signalled what the leading vehicle was doing. Lack of further benefit from a more complex system could be due to the drivers being attentive and not caught by surprise.

Thus it seems premature to dismiss the potential of improved rear lighting for reducing the risk of tailgating crashes. A paper by Kuge et al. (2002) serves as an example of a description of an improved brake light system. It includes earlier illumination (via the detection of quick release of the accelerator), flashing, and appropriate location and shape.

If it could not be seen that a vehicle was not equipped with an improved brake light system, there would be a danger of drivers drawing incorrect negative inferences: when there is no signal of sharp deceleration, this might be because there is no sharp deceleration, or it might be because the vehicle is not equipped with such a light.

6 Discussion

6.1 Likely effects on traffic flow

Gaps appreciably shorter than 2 seconds are common in busy traffic. Consideration needs to be given to the possibility that if all vehicles adopted a gap of, say, 2 or 3 seconds behind the one in front, this would interfere with the smooth flow of traffic and cause congestion --- if there were doubt, it might be good reason not to define an offence in terms of a gap, or use automatic equipment to enforce long gaps. It is difficult to be sure about this. On the one hand, measures are sometimes taken against tailgating, and there is no breakdown of the traffic flow. On the other hand, there have been problems when using markings on the road surface to encourage longer gaps than usual (see Section 5.2).

An attempt at theoretical investigation of this issue by Huddart and Lafont (1990) is not of direct use: whilst it is correct in arguing that a distance-based criterion (road markings, see Section 5.2) may have an adverse effect on flow at low speeds, it does not address the questions of what effect a time-based criterion of 2 seconds would really have in practice, or whether some other gap would be better. Also, it uses 2400-2800 vehicles per hour as the maximum flow of a motorway lane, an extraordinarily high figure. In any case, theory is unlikely to be convincing: there is known to be conflict between theory (gaps of a fraction of a second are obviously dangerous) and experience (that most drivers most of the time do not crash when the gap is a fraction of a second).

In the traffic engineering literature, a flow of 1800 vehicles per hour (i.e., one vehicle per 2 seconds) is prominently mentioned in two contexts: as the discharge rate per lane when a traffic signal turns green, and as the maximum flow per lane on motorways. This suggests (a) that a minimum of 2 seconds between vehicles would not prevent a given volume of traffic from passing along a road, and (b) that a minimum of 2.1 seconds might indeed do that. Unfortunately, neither of these suggestions can be considered as firmly established. As to the first, drivers are constantly adjusting the speeds and positions of their vehicles relative to others; forcing them to always remain at least 2 seconds behind the vehicle in front would restrict their freedom of manoeuvre and could conceivably interfere with traffic flow. And as to the second, this is nearly irrelevant, as flows of 1800 vehicles per hour per lane are very rare in Adelaide, and thus there is no need for gaps to be as short as 2 seconds.

It seems unlikely that automatically penalising gaps shorter than 0.5 seconds would interfere with traffic flow. It seems likely that automatically penalising gaps shorter than 3 seconds would not have public support, and would have the potential to interfere with traffic flow. If a regime of increased or automatic enforcement of appropriate or safe gaps between vehicles were under consideration, the decision as to what is appropriate or safe would need to be thought through carefully, as discussed earlier (Section 5.3). It is obvious that increased penalising of short gaps would need to be done with care --- for safety, as well as traffic flow, reasons. Given this, it seems unlikely that in Adelaide conditions increased police activity or use of advisory signs would ever be enough to be a problem. Conceivably, it might be possible to find some wording of a law that would make it easier to penalise drivers adopting short gaps, as Michael et al. (2000) urge, without obliging the police to enforce long gaps at sites where short gaps are common and normal and almost safe. Consideration of the wording of law is beyond the scope of the present report.

6.2 Looking to the future

Rear end crashes are, on the face of it, a very simple type of crash. They have been studied for many decades. Yet it seems that many varieties of rear end crash are surprisingly poorly understood. Baldock et al. (2005) appear to be saying, though they do not spell out their conclusions in quite these terms, that failure of attention (in one form or another) is the chief factor --- not tailgating. Obviously, greater gaps give a greater margin of safety, and countermeasures against tailgating would be expected to have some benefit, but it seems unlikely that this would be substantial.

Tailgating is widely recognised as dangerous. However, it also seems to be widely believed that only a small proportion of rear end crashes can reasonably be attributed to tailgating. Could it be that countermeasures directed at tailgating might nevertheless have substantial success? An extra margin of safety, even a fraction of a second, from an increased gap would be expected to be beneficial, like reduced speed is. This possibility cannot be ruled out, and there is the advantage that tailgating is a simple behaviour that might be responsive to education and enforcement. Nevertheless, it is questionable whether it would be wise to devote much effort to this when it seems that the bigger problem is failure of attention (in various forms).

There are several ways that CASR could build on the foundation laid by Baldock et al.:

- Extend their study to further rear end crashes that were investigated in depth, that is, ones investigated prior to April 2002.
- Review the textual field of a sample of rear end crashes in the database of routinely-reported crashes.
- To attempt to throw more light on tailgating, crashes said to involve following too closely in the police-reported dataset should be compared with other rear end crashes. (As noted earlier, such judgments are error-prone, and thus this might or might not be fruitful.)
- More broadly, both the in-depth and the routine data tend to repay repeated examination. In the case of routinely-collected data, the chief immediate product of the analysis is a set of descriptive statistics. In the case of in-depth investigations, the chief immediate product is a series of stories. Both types of study can be taken further via an active process of generating hypotheses about the findings, deducing consequences of those hypotheses, and then returning to the dataset to compare it with the deductions.
- Routine video surveillance of traffic, especially at junctions, might have useful information both about crashes and about traffic conditions that did not lead to crashes.

Despite the scepticism about psychology that was expressed in Section 3.5, it would also seem worthwhile to review whether the extensive experimental and theoretical literature on attention can contribute to understanding rear end crashes. For example, an experienced driver commonly does not think consciously about the road and traffic ahead, yet is able to react when needed. But are there some drivers who, in some sense, get lost in their thoughts and are unable to react? And the complexity of the road situation or the driving task is sometimes a factor in crash causation. In a general way, assisting the driver by making the task easier should be an aim of both the vehicle designer and the traffic engineer, but is common sense the only guide to this, or is some more systematic approach possible?

It was noted in Section 3.3 that Treiterer and Nemeth (1970) were dissatisfied with the term "following too closely". And according to McLean et al. (1979, p. 57), "Inattention is often an unsatisfactory category in any listing of causal factors since it can conceal other more basic characteristics of the accident sequence". Since the time that was written, CASR has investigated many more crashes in depth, has access to more than 20 years routinely-collected crash data from South Australia (TARS), and there has been substantial experimental research on the nature of attention published. Perhaps the time has come to attempt to go beyond the clichés of *following too closely* and *inattention*.

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