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Adaptive Cruise Control: A Categorical Imperative to the New World in 21ST Century?

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Abstract

With the new millennium upon us, vehicle automation devices such as Adaptive Cruise Control are being offered by major motor manufactures. Over the last five years, the development of these systems has been reflected by the increasing number of publications in technical journals. However, there does not seem to have been a similar effort in the ergonomics literature devoted to the effects of vehicle automation on driving performance. The current paper investigates whether driving performance with automation changes across levels of driver skill. This issue raises substantial practical concerns. As vehicle automation becomes commonplace, the demographics of the driving population which have access to it will become increasingly variable. Therefore, the results are interpreted with respect to issues of litigation and training for inexperienced drivers with automation.

Keywords: adaptive cruise control, automation, ergonomics, technology, steering.

1 Introduction

As we enter the new millennium, new vehicle automation devices are being offered by major motor manufactures. Adaptive Cruise Control (ACC) has been released in the last year, offering total longitudinal control of the vehicle. Soon, we will see lateral control devices such as Active Steering (AS) talking to the roads. During the development of these devices, a number of papers have been published detailing the technology, control strategies and modeling techniques involved (e.g, Richardson *et al*, 1997). However, it seems that the ergonomics community has not kept pace with their engineering counterparts, with few publications about the effects of vehicle automation on the driver (for exceptions see Bloomfield and Carroll, 1996; Stanton et al, 1997, Young and Stanton, 1997). In particular, none of the research to data has investigated whether driver skill is an important factor in determining the impact of automation in future vehicles.

Driving is a classic example of a skilled activity. The role of experience and skill in driving has led many to the conclusion that at least some elements of the driving task represent automatic behaviour (Stanton and Marsden, 1996).

The advantages of automaticity are realized in areas of driving as vehicle control (Blaauw, 1982), choice of driving strategy (Coyne, 1994), and brake reaction time (Nilsson, 1995), However, automaticity can also lead to certain accidents. Hale et al (1988) found that drivers approaching a familiar crossroads has strong expectations that it would be clear, such that they failed to perceive oncoming traffic.

It will eventually become the case that any driver may step into a vehicle equipped with automated systems, regardless of their experience. Initially, novel technologies are fitted to prestige models only, implying that the drivers who have access to them are highly experienced. However, just as with power assisted steering, anti-lock brakes, and even automatic transmission, these new devices will eventually filter down to become widely available. It is conceivable that a newly-qualified driver with basic training could immediately use a vehicle equipped with ACC, or in the future, as.

The interaction of skill and automation is important for a number of reasons. It is posited here that all operators- novices and experts alike-essentially satisfy the criteria for automaticity when faced with as knowledge, Bainbridge (1978) make the point that increased demand essentially transforms an expert into a novice. It is surely plausible to assume that the reverse would be true in a situation of unusually low demand. However, whereas the expert has an enhanced knowledge base and can anticipate events, the novice is deprived of t his ability. Thus they will not react as experts in critical situations, such as the

overearned braking response (e.g Nilsson 1995).
The present paper presents driving performance data from a large scale experiment conducted in the Southampton Driving Simulator. Although the results are of theoretical significance in terms of skill acquisition, the practical applications are highlighted here. Therefore, the primary task results are analyzed in detail, with respect to issues of litigation and training for inexperienced drivers with automation.

2 Method

A mixed design was used. Level of automation constituted the within-subjects variable, with four levels: manual (i.e., the participant controls speed, headway, and steering), ACC (i.e., longitudinal and lateral control are automated). The latter condition essentially constitutes fully automated vehicle control. Order of presentation of these conditions was randomized to counterbalance practice effects.
Driver skill level was between-subjects factor, again with four levels: novice (i.e., never driven before), leaner (i.e. currently learning but does not hold a full licence), expert (i.e held a full licence for at least one year), and advanced (i.e., member of the institute of Advanced Motorists in the UK). The latter group was chosen as a high level skill group because these drivers have undertaken further training based on police driving skills, and are considered to be 50-70% less likely to be involved in an accident than other drivers without such training. There were 23 novice drivers in this experiment, and 30 participants in each of the leaner, expert, and advanced conditions.
A 15-minutes practice run was followed by the four experimental conditions, each lasting 10 minutes. In each of the experimental trials, participants were instructed to follow a lead vehicle traveling at 70mph for the entire duration. The simulated road was a mixture of straight and curved sections.
Data reduction and analysis
Given the demands of the primary task (i.e maintain a consistent speed and headway), it was felt that a measure of location (i.e. mean) and dispersion (i.e, instability) would suffice as dependent variables speed and headway. Instability refers to the standard deviation of the regression line of speed/headway against time, and was recommended as a driving performance measure by Bloomfield and Carroll (1996).
Dependent variables for lateral position were more simple-time out of lane, and absolute number of land exclusions. It was felt that these would be fairer estimates of performance than means and instability, as ‘good’ driving performance is not necessarily characterized by driving in a perfect straight line in the centre of the lane (see Coyne, 1994, for further details).
All dependent variables were subjected to repeated measures analyses of variance (ANOVAs), with repeated contrasts or post hoc t-tests where appropriate. Only significant results are reported.

3 Results

There were main effects of automation on average headway ($F_{3, 327}$ = 17.4; p<0.001) and average speed ($F_{3, 327}$ = 17.4; p<0.001). For average headway, repeated contrasts showed no difference between manual and ACC conditions, however a significant reduction in the AS condition ($F_{1,109}$ = 11.5; p<0.005) and the ACC+AS condition ($F_{1,109}$ = 39.5; p<0.001) were observed. A similar pattern emerged for average speed, with no difference between manual and ACC conditions, but significant increases in the AS ($F_{1,109}$ = 5.64; p<0.05) and ACC + AS ($F_{1,109}$ = 23.6; p<0.001) conditions.
For headway instability, main effects of automation ($F_{3,327}$= 14.8; p<0.001) and skill ($F_{3,109}$ = 2.83; p<0.05). Repeated contrasts reveal that headway instability does not differ between manual and ACC conditions, however decreases in the AS ($F_{1,109}$ = 13.2; p<0.001) and ACC+AS ($F_{1,109}$ = 5.60; p<0.05)conditions. Post hoc t-tests show that instability in the expert group is lower than in each of ht e novice ($t_{,210}$ = 2.60; p<0.05), learner (t_{238} = -4.05; p< 0.001), and advanced groups (t_{238} = -4.62; p< 0.001).
There was also a significant interaction between skill and automation on headway instability ($F_{9,327}$ = 2.74; p < 0.005). For the purpose of this paper, only interactions in the manual and AS conditions are reported, due to the fact that the remaining two conditions use ACC, which automates headway control. In the manual condition, the expert group exhibited significantly greater headway than the novice (t_{51} = 2.22; p < 0.05). Learner (t_{58}= -3.09; p < 0.005). And advanced groups (t_{58} = 2.56; p < 0.05). In the AS condition, there was more instability in the advanced group than the expert group (t_{58} = 2.08; p < 0.05).
Speed instability showed a main effect of automation ($F_{3,327}$= 48.0; p<0.001) and skill ($F_{3.109}$ = 28.8;

$p<0.05$). Further investigations reveal no difference between the manual and ACC conditions, however speed instability decreases with AS ($F_{1,109} = 27.0$; $p < 0.001$) and again with ACC + AS ($F_{1,109} = 36.3$; $p < 0.001$). In addition, the expert group shows less instability than each of the novice ($t_{210} = -3.01$; $p < 0.005$), leaner ($t_{238} = -3.44$; $p < 0.005$) and advanced group ($t_{238} = -1.98$; $p < 0.05$).

And interaction between skill and automation was also found for speed instability ($F_{9,327}= 3.05$; $p< 0.005$). Again only interactions in the manual condition are reported as speed is automated in each of the AC conditions (there were no significant interactions in the AS condition). Under manual driving, then, instability for expert drivers is lower than novices ($t_{51} = -2.31$; $p < 0.05$) and learners ($t_{58} = -2.63$; $p < 0.05$). Also, the advanced drivers showed less instability than the learners ($t_{58} = 2.05$; $p < 0.05$).

The lateral position measure of time out of lane showed main effects for automation ($F_{3,327} = 303.0$; $p < 0.001$) and skill ($F_{3,109} = 5.43$; $p < 0.005$). Post hoc contrasts revealed that time out of lane is reduced when AS is engaged compared to non-AS conditions ($F_{1,109} = 328.5$; $p < 0.001$). Advanced drivers spend less time out of lane than novices ($t_{210} = 3.24$; $p < 0.005$), learners ($t_{238} = 2.97$; $p< 0.005$) and experts ($t_{238} = 2.25$; $p < 0.05$).

There was an interaction between skill and automation for time out of lane ($F_{9,327} = 5.02$; $p < 0.001$). Only significant results in the manual and ACC conditions are reported, as lateral control is automated in the remaining two conditions. In the manual condition, the advanced group spent less time out of lane than the novice ($t_{51} = 3.29$; $p < 0.005$), leaner ($t_{58} = 3.31$; $p < 0.005$), and expert groups ($t_{58} = 2.66$; $p < 0.05$). In the ACC condition, the advanced group spent less time out of lane than the novices ($t_{51} = 3.59$; $p < 0.005$) and learners ($t_{58} = 3.27$; $p < 0.005$); also, the experts less time out of lane than the novices ($t_{51} = -2.14$; $p< 0.05$).

Finally, the number of lane excursions exhibited main effects for automation ($F_{3,327} = 662.1$; $p < 0.001$) and skill ($F_{3,109} = 7.23$; $p < 0.001$) . Lane excursions are reduced when comparing AS conditions to non-AS conditions ($F_{1,109} = 742.3$; $p < 0.001$). Lane excursions are lower for the advanced group compared to the novice ($t_{210} = 2.81$; $p < 0.01$) and learner groups ($t_{238} = 2.51$; $p < 0.05$).

And interaction was found between automation and skill for number of lane excursions ($F_{9,327} = 6.21$; $p<0.001$). Again, only relevant results in the non-AS conditions are presented. In manual driving, advanced drivers made less lane excursions than novices ($t_{51} = 3.25$; $p < 0.005$) and learners ($t_{58} = 3.12$; $p < 0.005$). When driving with ACC, the advanced group made less lane excursions than the novices ($t_{51} = 4.40$; $p < 0.001$), the learners ($t_{58} = 4.11$; $p < 0.001$), and the experts ($t_{58} = 2.22$; $p < 0.05$), whilst experts made less lane excursions than novices ($t_{51} = -2.30$; $p < 0.05$).

4 Summary/Discussion

The results of this experiment are quite complex, however can be summarized as follows. In general, longitudinal control was at its most stable in the expert driver group, and stability increased with more level of automation. However this was tempered by automation, such that when AS was used, the advantage of experts largely disappeared.

For lateral control, there is a clear difference between AS and non-AS conditions. Now, though, it is the advanced group who are generally better at keeping the vehicle in lane. Automation reveals a further difference between skill groups, to the extent that when ACC is used, the experts are more stable than novice drivers.

There are a number of implications arising from these results. It seems that increasing levels of automation dos indeed attenuate observable differences in performance between skill groups, as suggested above. That is, the performance of inexperienced drivers on longitudinal control resembles that of experts only when lateral control is automated. On the face of it, this is a promising finding- everybody will drive better with more automation. But what happens when the driver has to take over again? Presumably the automatic behaviour of experts will quickly resume, save for a little skill degradation. Those with less experience though may have more trouble recalling stored routines and responding in a controlled manner.

So, would increased driver training solve the problem? It is not possible to train for unique and unexpected events, such as automation failure, so this would be a limited solution. This also raises the issue of litigation-if a system failure results in an accident, who would be held responsible? An investigation into skill difference when coping with automation failure is currently being carried out in the Southampton Driving Simulator. This study will shed more light on the question of whether the knowledge bases of expert's providers an advantage over less experienced drivers in critical stations.

Perhaps one day, when vehicles become fully automated, these questions will not be so important. In the meantime, while the human is still an integral part of the system, it is necessary to consider their capabilities and limitations. The automated utopia or 'autopia' of the future may very well be mired in questions of litigation and acceptance (cf. Hancock et al, 1996). It is up to ergonomics to ensure that our millennium highways do not turn out to be as dystopian as Huxley's (1970) own Brave New World.

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