Automotive automation: Investigating the impact on driver mental workload.

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Abstract

Recent advances in technology have meant that an increasing number of vehicle driving tasks are becoming automated. Such automation poses new problems for the ergonomist. Of particular concern in this paper are the twofold effects of automation on mental workload - novel technologies could increase attentional demand and workload, alternatively one could argue that fewer driving tasks will lead to the problem of reduced attentional demand and driver underload. A brief review of previous research is presented, followed by an overview of current research taking place in the Southampton Driving Simulator. Early results suggest that automation does reduce workload, and that underload is indeed a problem, with a significant proportion of drivers unable to effectively reclaim control of the vehicle in an automation failure scenario. Ultimately, this research and a subsequent program of studies will be interpreted within the framework of a recently proposed theory of action, with a view to maximizing both theoretical and applied benefits of this domain.

KEYWORDS: Automation; Active Steering; Adaptive Cruise Control; Mental Workload

Introduction

One hundred years ago, England saw its first horseless carriage take to the roads, in the form of the Daimler Wagonette. This year, Ford Motor Co. released their "Ka", the car for the 1990s. Recently, designers and engineers have combined forces and have come up with "Concept 2096" - the car they envisage we will be driving in 100 years time. Concept 2096 is like no other car we know - it has no wheels, instead a moving rubber base; it has no petrol, rather runs on electrical power beamed to it from a satellite; and it has no windows, due to the most notable distinction that it has no driver, only passengers. An onboard computer receives and processes navigation information, such that the car drives itself.

This may sound like science fiction, however, driverless car technology is already with us. Devices such as Adaptive Cruise Control (ACC) which controls both speed and headway of the user vehicle, and Active Steering (AS) which steers the vehicle automatically, will be available within the decade. It takes no stretch of imagination to see that a car equipped with both ACC and AS will, effectively, be driving itself. Possibly, these could be combined with Global Positioning Systems or other navigational technology, and suddenly Concept 2096 seems a whole lot more plausible.

Novel technologies such as ACC and AS are intended as comfort systems for the driver - they are designed to relieve the driver of workload. Whilst this may be achieved, the introduction of automation into the automobile poses a wealth of cognitive and human factors concerns which are new to the driving domain. This paper presents the problems involved and describes work currently in progress using the Southampton Driving

Simulator to assess the effects of automation primarily on driver attention and mental workload, but ultimately of course the concern is for driver performance. Simultaneously, we hope to explore a recently proposed theory of action, based on a balance between demands and resources of both the task and of the operator. Thus this work is of both applied and theoretical value. Although automation is a well researched topic, the domain of road vehicles is a new one, and thus demands involvement from ergonomists.

Automation and Mental Workload

Designers of complex systems often use the technology at their disposal to attempt to aid operators, and even relieve them of their duties to some extent, in an attempt to eliminate error. This rapidly leads to automation, and automation is accompanied by a plethora of new concerns and problems. Various authors have commented on the dangers of automation.

Reason (1990) discusses the "catch-22" of human supervisory control, in that humans are only present in an automated system to deal with emergencies. They do this by drawing on stored knowledge of such. However, given the limited opportunity to practice procedural responses in an automated system, coupled with the uniqueness of each emergency, the operator's knowledge-base will be sparsely furnished. Thus past experience counts for little. Reason (1990) concludes by stating that supervisory control is a task specifically ill-suited to the limited cognitive capabilities of humans.

An inspirational article by Bainbridge (1983) describes the "ironies of automation". An initial irony lies in the designer's view of the human operator as being unreliable or inefficient. It is, however, the designer's errors which are the major source of problems. Also, in trying to eliminate the operator, they are still left to do the tasks which the designer cannot think how to automate. These tasks typically include monitoring, diagnosis (placing cognitive demands) and takeover (requiring manual skills). The latter two operations both suffer from the skill degradation of an operator starved of rehearsal and feedback, as in supervisory control.

An alternative perspective maintains that it is not the presence of automation per se which is the problem, rather a case of inappropriate design (Norman, 1990). It is stated that the problem with automation is that it is at an intermediate level of intelligence, and Norman (1990) specifically refers to the insufficiency in feedback as a major contributing factor. Norman (1990) suggests making automated systems either more or less intelligent (improvement or removal), but the current level is inappropriate under anything but normal conditions. Thus the culprit is not automation, rather a lack of continual feedback and interaction which keeps the operator "out of the loop". In the event of a failure scenario, operators are left without sufficient knowledge of the situation to be able to deal with it efficiently.

A further consideration of automation is the issue of workload. Reinartz & Gruppe (1993) argue that automated systems present cognitive demands which increase workload. In their view, operators and the automated system are members of the same team. Thus effective control is dependent upon how well that team works and communicates together. The performance of the operator is hindered by the increase in processing load resulting from the additional task of collecting information about the system state (again due to feedback omissions). This is further complicated by the extent of the operator's knowledge about the system. In the event of manual takeover, the operator must either disable interlocks to other systems, or else match his/her actions to those of related process functions.

These issues are generally symptomatic of the transition in the role of the human from operational to supervisory control (Parasuraman, 1987). Such a situation has the paradoxical potential for imposing both overload and underload: reduced attention during normal operations, however difficulties increase when faced with a crisis or system failure (Norman, 1990). In the latter scenario, the human is forced to immediately return to the operator role, gather information about the system state, make a diagnosis and attempt a resolution. Indeed, Gopher & Kimchi (1989) argue that monitoring and decision-making skills in automation already stretch capacity limitations, and there is a need for knowledge and expertise before entering this kind of work.

Thus we see that automation can have bi-directional effects on mental workload (MWL). Concern with what constitutes underload or overload is rife, and has stemmed primarily from the aviation industry (Sanders & McCormick, 1993). Questions about workload become more difficult as technology changes work, resulting in mental load being predominant (Rumar, 1993; Singleton, 1989). Automation is usually intended to reduce workload, although this is not necessarily a good thing - the goal should be to optimize workload, with implementations such as the electronic copilot (Parasuraman, 1987) and human-centered automation (Reichart, 1993; Rumar, 1993). Such optimization will inevitably involve a balancing act between demands and resources of both task and operator. Perhaps this view, which essentially captures the spirit of ergonomics itself, could offer more satisfactory solutions.

Contextual Action Theory (CAT)

In an effort to capture this balance between demands and resources, Stanton (1995) has proposed Contextual Action Theory (CAT). This is essentially a reaction to the fact that much of ergonomics research lacks theoretical development. Indeed, many studies merely eclipse previous efforts with little substantive progression. Rather than assume this trial-and-error approach, CAT attempts to escape from such a cycle and instead offer some predictive power. Couple this with the observation that demand-resource competition is a prevalent concept in the literature, and a general theory of action based on the trade-off between demands and resources seems attractive.

The argument for CAT begins by advocating a consideration of ecological ergonomics - that is, acknowledging the roles of context and environment in predicting behavior. By identifying which aspects of context influence behavior in one situation, parallel aspects can be accounted for in a different environment. That is to say, generalizing from previous research is fundamentally flawed in that specific contextual influences are not considered. Thus only a contextual theory of action is ecologically valid.

These thoughts are congruent with previous writings. Newell (1989) expressed similar opinions about task specificity:

> Although many of the extant attempts at task classification hold face validity by virtue of their intuitive descriptive categorization ... they have had little or no impact on helping to understand the role of task constraints in the more significant goal of fashioning a general theory of action and skill acquisition. (p. 93)

It is also stated that the narrowing of theories to specific experiments or tasks precludes generalization, and that principles of such task constraints are needed for a general theory of action. This is in direct accordance with the proposals of CAT.

Following this, a qualification of the importance of context is made. Stanton highlights the contrast between cognitive psychology (focusing on internal representations) and ecological psychology (concerned with external influences on behavior). However, these views are not mutually exclusive, rather they are considered as existing along a continuum, each extreme missing part of the explanation. Thus context is realized in two forms: internal and external. Indeed, the very knowledge of humans is stored in both areas (Norman, 1988; Schonpflug, 1986). An understanding of the interaction between these two leads Stanton to a contextual theory of human action.

The framework for CAT draws heavily upon the transactional model of stress proposed by Cox & Mackay (1976; cited in Cox, 1978). Thus parallels will be obvious to those familiar with that theory. Here terms such as resources and degradation are substituted for capability and stress. According to the theory, contextual action consists of five phases (see figure 1). The first presents the actual demands of, and appropriates actual resources for, the task. Demands and resources can be both internal and external.

An example of internal demands could be the goals of the driver, whilst internal resources could be represented by training and experience. Road and traffic complexity are examples of external demands, and devices such as navigation aids or other automated devices could be external resources. In the next phase, these demands and resources are appraised such that the actor possesses a perception of each (which may differ from the actual elements). The third phase compares the these elements on three dimensions. Stanton posits that an imbalance could occur between: (a) actual demands and perceived demands, (b) actual resources and perceived resources, or (c) perceived demands and perceived resources. As actual demands and actual resources exist in two dimensions (internal and external), this leads to five possible inequalities:

$Ad_i <> Pd$

$Ad_e <> Pd$

$Ar_i <> Pr$

$Ar_e <> Pr$

$Pd <> Pr$

A/P = actual/perceived

d/r = demands/resources

e/i = external/internal

CAT predicts that these imbalances may lead to degradation. Such degradation can occur via various pathways in the fourth phase, examples of which are emotional (user satisfaction), behavioral (performance), and ultimately abandonment. Therefore an imbalance can lead to either a dissatisfied user, or poor performance, or both. These aspects can change the nature of the task, so finally a feedback phase serves to inform the operator of their performance, and the cycle starts over.

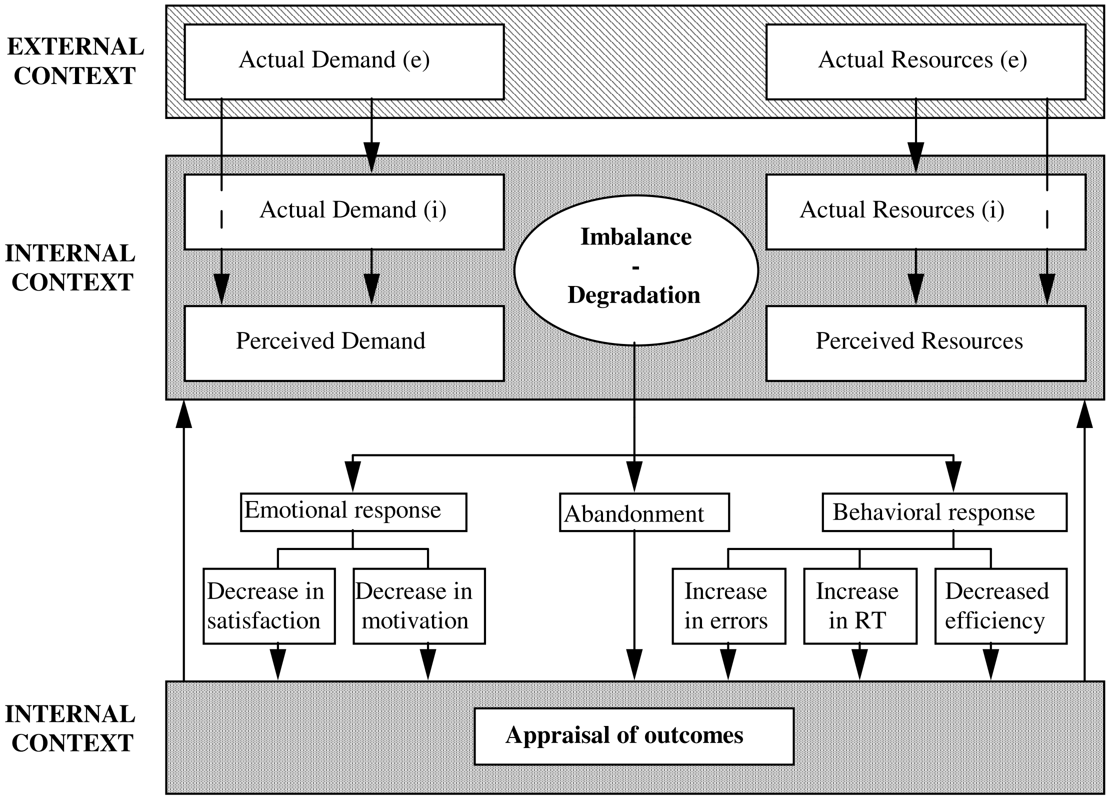

Figure 1: The CAT model

Again, these ideas may be construed as consistent with previous research. Workload has been conceptualized as the interaction of demands, resources and subjective performance criteria (Schlegel, 1993), and also in terms of the balance between automatic and controlled processing (Gopher & Kimchi, 1989). In addition, other authors have commented on the salience of perceived demands and resources:

> Mental load as a concept now serves as an intermediary between imposed and perceived demands. (Jorna, 1992; p. 239)

> ...the basic notion [of mental workload] is related to the difference between the amount of resources available within a person and the amount of resources demanded by the task situation. (Sanders & McCormick, 1993; p. 78)

Undoubtedly, there are many models of demands and resources already in the literature, most notably that of Wickens (1992). Indeed, the plethora of quotes above indicates that the concept of demand-resource trade-off is widely acknowledged, albeit sometimes implicitly. Even the notion of a comparator is not new - risk homeostasis theory (Wilde, 1988) incorporates a comparator for target risk and actual risk. Thus CAT makes no claims about novelty. However, what CAT attempts to offer is an integrated and explicitly theoretical framework for the demands-resources issues involved, which seems to have been lacking so far. It also inevitably provides an intriguing avenue for research into automation and MWL. In the current program of research, it is intended to explore and develop the theory alongside the applied investigations. Indeed, if the adaptive interfaces described earlier are to be realized, the predictive power of a demand-resource theory could prove invaluable.

Previous Research in Vehicle Automation

Thus far, we have seen that road vehicles are becoming increasingly automated, that automation poses potential problems for driver mental workload in terms of the consequences on driver performance, and that Contextual Action Theory offers a theoretical framework for assessing the relationship between demands and resources. Moreover, technology and automation has only become a real concern with road vehicles relatively recently, and research so far has primarily been concerned with driver overload.

Underload is at least as serious an issue as overload (Brookhuis, 1993; Schlegel, 1993), yet has received surprisingly little attention. Our research paradigm therefore involves the effects of automation on driver mental underload, with concerns for driver performance.

The inspiration for this research comes from a couple of sources. One is a paper by Stanton & Marsden (1996), who extrapolated from the aviation field to assess and predict the effects of automation on the driver role. It is anticipated that although there are potential advantages (e.g., reduced stress, enhanced safety) there will be shortfalls in these expected benefits in such areas as equipment reliability, training and skills maintenance, error-inducing designs, and overdependence on the automated system. Stanton & Marsden argue that driver workload is only excessive in exceptional circumstances, implying a dynamic allocation of function approach is likely to be optimal. Otherwise automation could result in increased workload, the risks of which will only be determined through a structured evaluation.

As far as we are aware, there is only one piece of research so far which has attempted such an evaluation. Nilsson (1995) investigated the effects of ACC in critical situations. It was found that ACC did influence behavior, such that for the situation in which collisions occurred (when the car approached a stationary queue), 80 per cent of the collisions occurred when ACC was engaged. Nilsson attributed this to the expectations that drivers have about ACC, rather than to increased workload or decreased alertness.

It is our intention, then, to assess specifically the effects of ACC and Active Steering on driver mental workload, and to explore how this may affect driver performance. Although one might expect automation to increase workload, we anticipate that under normal circumstances, the effects of underload will be more substantial, particularly if a failure situation arises. Imagine a driver who has been traveling for at least 30 minutes with both automated systems engaged, therefore has been out of the loop for long enough that their attention has degraded. Suddenly, one of the automated systems fails. Is it realistic to expect that driver to be able to reclaim control in a safe and timely manner?

Initial studies suggest not. Stanton, Young & McCaulder (1996) used the Southampton Driving Simulator to explore the effects of ACC failure on driver performance. Participants were required to follow a lead vehicle with ACC engaged. At a predetermined point, the ACC system would fail to detect the lead vehicle braking, necessitating participant intervention to avoid a collision. It was found that one-third of all participants collided with the lead vehicle when ACC failed. Although not a majority, this is a substantial proportion of drivers. In addition, the use of a secondary task measure designed to assess spare attentional capacity indicated that under normal circumstances, workload is significantly reduced when ACC is engaged.

Current Research in the Southampton Driving Simulator

Design and Procedure

We are currently using the Southampton Driving Simulator to explore these effects in more detail. The present study (from a series of experiments in progress - Young & Stanton, 1997) intended to reinforce the findings of reduced workload under automation conditions by comparing performance under different combinations of manual and automated driving. Automatic transmission was used throughout the experiment. Participants were given a 30 minute practice session with the simulator under manual driving conditions, to allow acclimatization to the environment. They then drove for 10 minutes in each of four trials: manual driving, using ACC, using Active Steering, and using both ACC and Active Steering (i.e., fully automated vehicle control). The order of these conditions was randomized to make for a completely crossed design.

Instructions to participants were such that a relatively constant speed (and consequently distance traveled) was maintained across all trials. This was achieved by using a “follow-that-car” paradigm - a lead car traveling at 70mph was to be followed for the duration of the trial. Participants were instructed to catch up and then follow the lead car at what they considered to be a safe distance (in the non-ACC conditions; when ACC is engaged headway is controlled automatically). They were asked not to overtake (there were no other leading vehicles on the track, however oncoming vehicles did occupy the opposing lane, making the road single-carriageway), and to drive normally for the remainder of the trial. In the automation conditions, participants engaged the equipment themselves by means of a button on the instrument panel when they had achieved a constant speed (this was not necessarily when they had caught up with the lead vehicle). In the event of a collision, the user car is rendered stationary and conditions are treated as at the start of the run.

Workload was assessed by using a secondary task measure and a subjective mental workload scale - the NASA-TLX (Hart & Staveland, 1988). The TLX was administered immediately after each trial, and participants were instructed to only rate the demand of the primary task (i.e., driving). The secondary task involved participants making similarity judgments about pairs of rotated "matchstick" figures, and was identical to that used by Stanton et al. (1996). This task was user paced, and participants responded via buttons attached to the indicator stalks on the steering column. All primary and secondary task data was recorded automatically by the simulator software. The secondary task drew upon the same attentional resource pools as driving (i.e., visual input, spatial processing and manual response). This was to ensure the secondary task was indeed measuring spare attentional capacity, and not the capacity of a separate attentional pool. To this end, participants were explicitly instructed to respond to the secondary task only when they had time to do so.

30 participants were used in this study, all of whom held a full British driving license for at least 1 year (mean 6.9 years), and who drove for an average 5650 miles per year. 17 of the participants were male, and the average age was 25.3.

The Southampton Driving Simulator

The simulator consists of the front half of a Ford Orion. The steering wheel, accelerator and brake pedal produce analogue voltages. A medium-resolution color monitor displays a view of the road and a simulated instrument panel. An Acorn Archimedes computer fitted with an analogue I/O card reads the controls, runs the simulation software (version 2.12 of Ray Taylor's Aston driving simulator) and generates the display image. The display shows: the road, in solid color with a central broken white line; other traffic in both directions; and simple roadside objects such as speed limit signs.

The resolution of the display limits the visibility range to 200 meters, the distance at which another vehicle is one pixel wide. The driver's field of vision is artificially increased by means of a slight "fish-eye" perspective which can be adjusted.

The vehicle's longitudinal dynamics are accurate, and lateral dynamics are represented by following the steering input exactly. Collisions with other vehicles or the edge of the road are detected and lead to simulated spins. Other vehicles follow a fixed path with scripted speed changes. The re-fresh rate is currently 25 frames per second. The following data are logged: speed, lateral position on the road, distance from the vehicle in front, distance from oncoming vehicle, steering wheel and pedal positions, and collisions.

Results and Discussion

Primary Task Data. The primary task data suggest that the instructions to participants to maintain constant speed and headway were heeded. Mean values for speed and headway were derived across each trial to allow for one-way analyses of variance. Visual inspection of these data revealed a nonparametric distribution, therefore the Friedman Two-Way ANOVA was applied. For headway, significant differences only arose when comparing ACC to non-ACC conditions ($\chi^2(3, N = 30) = 15.6; p < .005$), implying that although participants chose different headways than the automated system, these headways were consistent within participants (mean headways were 177 for manual, 124 for ACC, 125 for AS, 81.6 for ACC+AS). Similarly, the speed data only exhibit significant differences between ACC and non-ACC conditions ($\chi^2(3, N = 30) = 22.7; p < .001$). Indeed, it is apparent that significance was only achieved due to the limited dispersion of these data (the means were 70.0 for manual, 70.2 for ACC, 70.3 for AS, and 70.5 for fully automated control). Thus it can be reasonably assumed that participants adhered to the instructions of following the leading car at a steady headway and speed of 70mph. Furthermore, we can then be confident that any apparent differences in workload from the secondary task or subjective measures are due to actual differences and not artefactual ones (e.g., different driving conditions).

Secondary Task Data. Comparing number of correct responses on the secondary task across the four automation conditions, a Friedman Two-Way ANOVA was highly significant ($\chi^2(3, n = 27) = 68.87; p < .001$). A series of Wilcoxon Matched-Pairs Signed

Ranks tests found all comparisons to be highly significant except when comparing manual driving to ACC supported driving - this was nonsignificant (see figure 2). In all cases, the direction of the difference was as expected - more correct responses (i.e., lower workload) when automation was engaged (means: 106 for manual, 114 for ACC, 179 for Active Steering, 215 for fully automated control). It should be noted that, due to technical problems, secondary task data for three of the trials was lost, therefore these analyses are performed on the data of 27 participants.

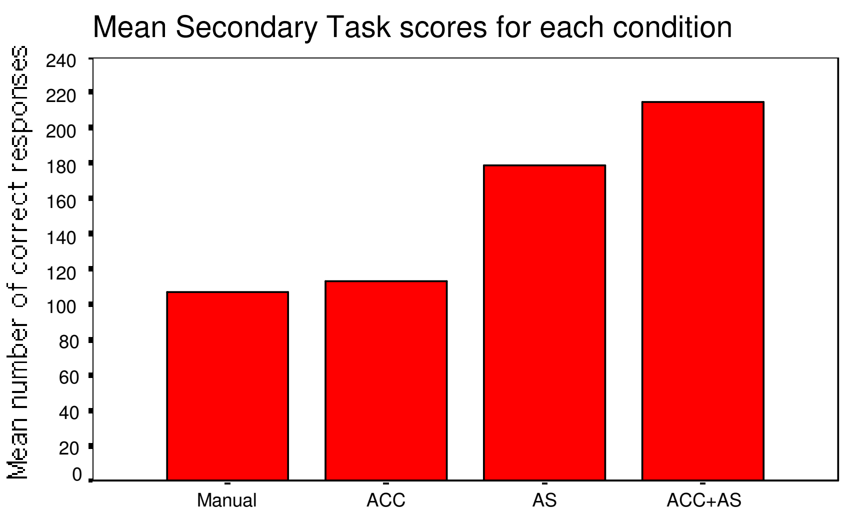

Figure 2: Number of correct responses on the secondary task across automation conditions. Low score indicates high workload. All differences significant at 5% level except Manual vs. ACC.

Subjective Workload Data. Overall Workload (OWL) scores were calculated as means of the raw TLX scale scores. These data presented a very similar picture to the secondary task data. Again, a Friedman Two-Way ANOVA was highly significant ($\chi^2(3, N = 30) = 63.25$; $p < .001$), and the Wilcoxon comparisons were all highly significant except for manual versus ACC, which was again nonsignificant (see figure 3). Once more, the means suggested lower workload (i.e., lower OWL score) correlating with increased automation (63.3 for manual, 61.4 for ACC, 35.4 for Active Steering, 19.6 for fully automated control).

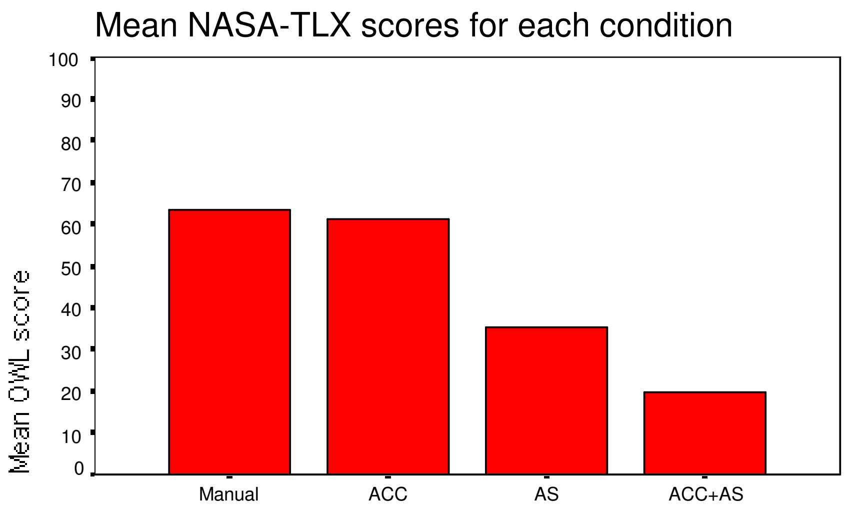

Figure 3: Mean Overall Workload (OWL) score on NASA-TLX across automation conditions. High score indicates high workload. All differences significant at 5% level <u>except</u> Manual vs. ACC.

Thus we see that automation does indeed have a significant effect on driver mental workload, although the specifics of this effect are not quite as expected. The present results are consistent with those of Nilsson (1995), with no effect of ACC on workload, yet conflict with the conclusion of Stanton et al. (1996). Here, a significant reduction in workload was only found when AS is engaged (neither of the previous studies explored AS). This is surprising given that the experimental conditions were essentially equivalent for this study and Stanton et al.

The possibility that these contradictions are due to different measuring techniques (i.e., NASA-TLX in Nilsson's study, secondary task by Stanton et al.) are effectively ruled out when one examines the correlation between the two. As both techniques were used in the present study, it was possible to explore this relationship. A simple visual inspection of the results outlined above suggests that there is an association between the two variables, and a significant correlation confirms this ($r = 0.691$; $p < 0.001$). Thus almost half the variance in either variable is accounted for by the other. From this it may be reasonably assumed that the measures are assessing the same construct (i.e., MWL).

Implications for CAT

Based on the combined results of Nilsson (1995), Stanton et al. (1996) and the current study, there are some firm conclusions and some speculative possibilities we can draw regarding CAT.

It is apparent that, in this situation, AS has a far greater influence on workload than ACC. It has not yet been determined as to why this may be the case, however there are three possible explanations to consider. The first is a practical one. It is probable that lane maintenance constitutes the primary workload element of driving. Removing this task in normal conditions will therefore have a greater effect on workload than relieving the driver of velocity maintenance alone.

Secondly, a related design point is that in the Stanton et al. (1996) study, participants were only required to drive a straight course. Thus, with no lane maintenance to concern them, velocity maintenance may have become the paramount workload issue.

This would imply that any workload effects of ACC in the current study could have been masked by the greater effects of AS, and would account for the further significant reduction in MWL when both systems are engaged. Whilst this would not explain Nilsson's (1995) results, anecdotal evidence suggests all three studies may be correct. Participants reported that when ACC was engaged, they felt they were being forced along, and not able to control their speed at corners as they normally would. It may be the case, then, that the reduction in MWL by ACC on straight paths is negated by increased demand on corners. A Friedman Two-Way ANOVA on the Frustration scores of the TLX supports this to some extent, with this element being significantly lower when AS is engaged ($\chi^2(3, \underline{N} = 30) = 13.9$; $\underline{p} < 0.005$).

Finally, we introduce the concept of malleable resource pools. It may be possible that, in conditions of low demand, an operator's resources shrink to meet that demand, in a converse of the "work expands to fill the time available" tenet. According to the CAT model, this information would be fed back into the original appraisal of demands and resources. A lack of imbalance would mean subjective workload and performance are maintained. Any sudden imbalance (e.g., an ACC failure scenario) would then lead to performance degradation. This is exactly what is evidenced in the Stanton et al. (1996) study. In this manner, reduced workload can lead to performance degradation without invoking models of feedback or vigilance.

Much future research is needed to tease apart these possible effects. The present study suggests that both perceived (as measured by the TLX) and actual demand (as measured by the secondary task) are reduced when AS is engaged. It remains to be seen whether this leads to performance degradation via an imbalance with perceived resources, or via reduced attention as described above. Both explanations are compatible with CAT, and unfortunately previous research is inconclusive on this point. In the former case (a simple imbalance), CAT would predict emotional degradation (i.e., dissatisfaction) with little effect on performance. With malleable resources, the prediction would be reversed - performance degradation without the emotional component.

An ongoing program of research plans to resolve this by investigating further the effects of automation failure on workload and performance. It is likely that if the demands of the situation are outweighed by the resources available, performance will deteriorate in the same way as if the converse were true. This returns us to the argument that workload should be optimized rather than reduced.

Conclusions

It may be demonstrated that the introduction of novel technologies into the automobile has the potential for deteriorating driver performance rather than facilitating it. Automation at some level can lower drivers' mental workload, with the possibility that - should a device fail - the driver faces an explosion of demand to cope with in order to avoid an accident. Research so far suggests that in certain situations, many drivers cannot cope with this eventuality, and a collision is the inevitable result.

Studying these problems may lead to the development of Contextual Action Theory, for they are reducible to imbalances between demands and resources. Early investigations of CAT found a widespread effect of task demands on performance and workload, which may seem somewhat obvious. By exploiting possible underload of the driver, it is hoped that the current studies will yield more revealing and counterintuitive results to further advance the formulation of CAT. If abnormally low demand affects drivers in the same way as abnormally high demand (i.e., if the direction of imbalance is irrelevant), then CAT may prove to be a useful explanatory framework. At present, we believe that ACC reduces workload on straight roads, whilst AS and fully automated vehicle control reliably reduces workload on any road. It is also evident that ACC can lead to performance problems in critical driving situations. Speculatively, we propose that CAT can explain these conclusions by a perceived imbalance between demands and resources, and possibly by the concept of malleable pools of attentional resources.

Ultimately, the series of studies in the Southampton Driving Simulator will use all of these results to propose suggestions for the design of future systems. It is anticipated that such designs will follow the dynamic allocation of function precedent, providing stable levels of demand and therefore hopefully maintaining performance. This would reflect a trend to assist drivers rather than to replace them. Some authors have already advocated the use of adaptive interfaces (Verwey, 1993) or human-centered automation (Reichart, 1993) as a path towards the goal of optimal driver workload. As Parasuraman (1987) asks, given the impact of automation on attention and consequent effects on the human ability to monitor failures, when it comes to technology, it is very often not a case of whether we can, but whether we should. We are adapting this question to ask how we might, given we probably will.

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