

Transitions Between Highly Automated and Longitudinally Assisted Driving: The Role of the Initiator in the Fight for Authority

Davide Maggi¹, Richard Romano, and Oliver Carsten, Institute for Transport Studies, Leeds, UK

Objective: A driving simulator study explored how drivers behaved depending on their initial role during transitions between highly automated driving (HAD) and longitudinally assisted driving (via adaptive cruise control).

Background: During HAD, drivers might issue a take-over request (TOR), initiating a transition of control that was not planned. Understanding how drivers behave in this situation and, ultimately, the implications on road safety is of paramount importance.

Method: Sixteen participants were recruited for this study and performed transitions of control between HAD and longitudinally assisted driving in a driving simulator. While comparing how drivers behaved depending on whether or not they were the initiators, different handover strategies were presented to analyze how drivers adapted to variations in the authority level they were granted at various stages of the transitions.

Results: Whenever they initiated the transition, drivers were more engaged with the driving task and less prone to follow the guidance of the proposed strategies. Moreover, initiating a transition and having the highest authority share during the handover made the drivers more engaged with the driving task and attentive toward the road.

Conclusion: Handover strategies that retained a larger authority share were more effective whenever the automation initiated the transition. Under driver-initiated transitions, reducing drivers' authority was detrimental for both performance and comfort.

Application: As the operational design domain of automated vehicles (Society of Automotive Engineers [SAE] Level 3/4) expands, the drivers might very well fight boredom by taking over spontaneously, introducing safety issues so far not considered but nevertheless very important.

Keywords: driver behavior, vehicle automation, intelligent vehicle systems, human-automation interaction, autonomous driving

Address correspondence to Davide Maggi, Institute for Transport Studies, Leeds LS2 9JT, UK; e-mail: tsdm@leeds.ac.uk

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INTRODUCTION

Although automated driving is a reality, commercially available systems are still not completely autonomous. Those systems are classified as partial automation (Society of Automotive Engineers [SAE] Level 2) and they require drivers' continuous engagement with all the aspects of the driving task. Even higher automation levels, such as conditional automated driving (Level 3) and highly automated driving (HAD Level 4), can implement the driverless motion of the vehicle only within predefined conditions, and they still need human driver intervention (Society of Automotive Engineers, 2018). When not required to continuously monitor the operation of the automated driving system (ADS; SAE Level 3/4), drivers will tend to engage in nondriving-related tasks (Carsten et al., 2012; de Winter et al., 2014), which would have the effect of introducing new issues, uniquely addressed as the out-of-the-loop issue (Endsley & Kiris, 1995; Merat et al., 2019). As obvious and ironic (Bainbridge, 1983) as it can be, if the drivers are no longer involved in the direct control of the vehicle, their capacity to properly control the vehicle will decline. In spite of the inevitable performance decay, the ADS will be forced to request driver intervention whenever it is about to exit its operational design domain, defining the domain over which the automated vehicle can operate safely. This places transition management at the very core of current research studies.

In research, transitions during conditional automated driving and HAD have been mainly addressed in a unidirectional way: the ADS reaches the limit of its operational design domain and, as automated driving is no longer possible, the system issues a take-over request

(TOR) to unprepared drivers, who are supposed to take over within a predefined amount of time (SAE Level 3). Many studies have shown how unprepared drivers are after periods of HAD, but they still retain the same transition process (Strauch, 2018). Drivers' behavior has been analyzed while varying different aspects around the TOR, including drivers' mental load before the TOR (Eriksson & Stanton, 2017a; Louw & Merat, 2017; Lu et al., 2017), demographics (Körber et al., 2016; Wright et al., 2016), TOR modality (Bahram et al., 2015; Forster et al., 2017; Petermeijer et al., 2017), and traffic conditions (Gold et al., 2016; Radlmayr et al., 2014). Eriksson and Stanton (2017b) pointed out that there exists a tremendous variability and, to a certain extent, loss of repeatability between these similar studies, whose main focus was reaction times in transitions. As they successfully underlined, with the increase in ADS reliability, the most common type of transition will likely be noncritical, that is, free of any time-budget restriction; therefore, drivers' reaction time will be of little importance. Indeed, some studies showed that reaction times are not descriptive of drivers' take-over quality (Merat et al., 2014; Vogelpohl et al., 2018; Zeeb et al., 2016); Gold et al. (2016) argued that longer take-over times might be indicative of a better reaction.

Moreover, there is a paucity of knowledge about how drivers would behave whenever they decide to take over by themselves. In this scenario, drivers, as initiators, would not only self-space the take-over, but they would also set the time instant in which the take-over would take place. This concept is not new in literature and it has been classified as "driver initiation—driver in control" by Lu and de Winter (2015), who described it as an "active transition" because the initiator (i.e., the driver) is supposed to be prepared to take over afterwards. "Driver's preference of control" and driver's acknowledgment of an "automation failure" were cited amongst the causes for this type of transition (Lu & de Winter, 2015, p. 2514).

Assuming drivers are ready to intervene only because they have decided to intervene is not consistent with the aforementioned out-of-the-loop issue, which has never been related to the

transition itself but only to the prolonged exposure to automated driving. Recent studies made clear that drivers' readiness to intervene could be insufficient even when they judge themselves ready to take over (Saito et al., 2018; Wada et al., 2016), thereby underlying the importance of easing drivers' reinstatement as the operator.

Flemisch et al. (2008) postulated that a gradual passage from higher to lower automation levels will potentially facilitate the reintegration of the drivers into the driving task. In particular, haptic (i.e., via force feedback) shared control was presented as a viable instrument to provide this gradual control handover, which could be achieved by simply decreasing the amount of guiding torque acting on the steering wheel. Mars et al. (2014) showed that varying the level of haptic authority, while drivers and the ADS are sharing the control, might however induce low acceptance and also conflicts on who is in charge of steering, which, in turn, could affect the induced workload. Indeed, these conflicts lead to an increase in interaction forces, that is, forces applied on the shared interface (Forsyth & MacLean, 2006; Griffiths & Gillespie, 2005; Tsoi et al., 2010). In aviation, to increase the effectiveness of user–system interactions and reduce mental overload, the concept of adaptive automation was introduced (Rouse, 1976). Instead of providing "static" automation modes, an adaptive system could select its own automation level in response to variations in the operating environment and driver performance. This strategy was designed to increase operators' involvement while exploiting the benefits of automation (Morrison et al., 1991).

Within the context of transitions of control, automation adaptation is constrained by the purpose of the transition itself (i.e., transferring control to the user). Nevertheless, the basic concept can be reused and adapted to the handover design problem. Walch et al. (2015) provided a high-level classification of different types of handover strategies (immediate, stepwise, driver-monitored, and system-monitored). Although no evidence on their respective advantages/disadvantages was presented, the "stepwise" handover formulation considered a gradual reintegration of control as a viable solution to reintroduce drivers to the driving

task. However, the lack of evidence on drivers' performance while experiencing any handover other than "immediate" left their design yet to be studied.

Indeed, to provide a gradual authority shift implies imposing a gradual reintegration of drivers' authority. Drivers will be inevitably forced to follow a procedure before being in manual driving and this, in turn, might cause discomfort and even conflict. Past studies proved drivers need up to 15 s to stabilize the vehicle trajectory (Dogan et al., 2019; Merat et al., 2014; Zeeb et al., 2016), meaning that, after the take-over, drivers are far from being adequately in control. Whether a stepwise handover could help drivers to improve their performances after taking over is still to be verified. Moreover, how the gradualness with which these handovers are presented affects drivers warrants further investigation to understand whether the above 15 s could be reduced or not. Therefore, although longer lead times have proven to produce better performance at both operational and tactical levels (Gold et al., 2013), the design of a proper handover process, in which the ADS actively helps drivers, could have beneficial effects not only in terms of performance after the transition, but also in terms of "reintegration" time. Irrespective of intra-individual differences, such a process could potentially ensure that drivers have been properly reinstalled in their original role (i.e., operator) within a predefined amount of time. If this could be achieved, transition planning strategies will be facilitated better and the transitions themselves will likely become more effective and efficient than how they have been addressed to date.

Given the above discussion and in collaboration with Nexteer Automotive, the purpose of this study was to investigate drivers' interaction with the ADS providing different "stepwise" handovers. These handovers were tested both in common take-over scenarios, in which the ADS was issuing a TOR, and with drivers initiating the transition by themselves. The main research questions of this study were:

1. How long does it take for drivers to take over when they initiate the transition themselves?
2. How can the take-over time impact the safety of the transitions?
3. Does the role of drivers as Initiators affect the way they interact with the ADS?

Following the findings of Eriksson and Stanton (2017b) and Walch et al. (2015), drivers' take-over time was expected to be longer whenever drivers were initiating the transition. Nevertheless, drivers were expected to exploit the delayed take-over by preparing themselves for the driving task, thus resembling the effects of a TOR with longer lead time as in Gold et al. (2013), leading to more attentive drivers and, therefore, safer transitions. Given the temporal demand related to automation-initiated transitions (Walch et al., 2015), drivers were expected to request the handover faster but without the necessary engagement with the driving task, preventing them from actively cooperating with the ADS. Therefore, a longer period of shared control would be required in order to promote drivers' full and safe engagement in driving. Nevertheless, the handovers relinquishing back control over a longer time span were thought to ease drivers' reengagement irrespective of the initiation.

METHOD

Participants

An ethics application was made for the project to the University of Leeds Research Ethics Committee and received approval on February 8, 2019. The application number was LTTRAN-099. Following approval, 16 participants (seven males) were recruited, ranging in age from 27 to 45 years ($M = 33.1$, $SD = 5.3$) via the driving simulator database. Participants had a valid driving license for more than 3 years and drove, on average, 8468 miles per year ($SD = 2974$). Participants were paid \$20 each for taking part in a 2-hr study.

Equipment

For this study, the University of Leeds portable simulator was adopted (Figure 1), which was operated on an HP Z400 workstation running Windows 7, using custom-made software. The visual simulation was displayed on a Samsung 40" wide-screen 1920 × 1080 monitor, rendered at 60 Hz. Vehicle control inputs

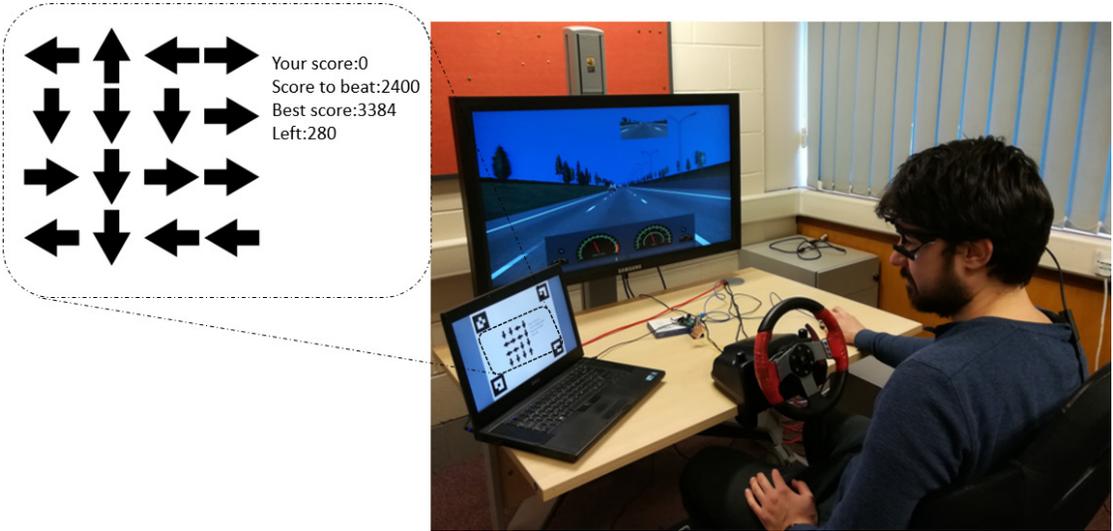


Figure 1. Experimental set-up. While in HAD, the laptop was used to present the arrow task. HAD = highly automated driving.

were via a Logitech G25 dual-motor force feedback steering wheel and pedals. The portable simulator had been upgraded to provide a hands-detection signal, which, with a button depression, was used to trigger the handover. To record eye-tracking data, the Pupil Labs Core head-mounted eye-tracking device was used. Using a head-mounted set-up allowed tracking eyes movements even when the participants were not facing the monitor.

A laptop, placed on the side, was used to display the arrow task, a secondary task consisting on a manual-visual search of a “target” arrow (the one pointing upward) among a cluster of displayed arrows (Hamish Jamson & Merat, 2005). Following the participant’s selection of the target arrow, the successive search request started.

Experimental Design

A within-subject repeated-measures design was used, with all participants completing all conditions. The handover strategies varied the gradualness and authority of the haptic feedback and will be hereafter addressed as immediate, delayed, delayed-assisted, and assisted. Every trial was subdivided into sections, in which only a subset of independent variables

was manipulated (Figure 2): in Section 1, the initiator (driver initiation: DI; automation initiation: AI); in Section 2, the type of feedback (no feedback; strong lane-keeping assist: LKA; lane departure assist: LDA) and the time interval in which drivers experienced the above feedback (2, 7, 15 s); and in Section 3, the presence of the blind-spot assist (Yes/No). In Section 4, we analyzed the aftereffects of the different strategies without any further manipulation. Every section was considered as a nested trial to study different aspects of the handover. A 4×3 counterbalanced design was adopted as the number of handover strategies \times the number of time intervals. Initiators and the blind-spot car were partially counterbalanced.

The experiment took place on a three-lane motorway with low traffic density. Throughout all the experiments, an adaptive cruise control with a default target speed of 70 mph (112.7 km/hr) as the maximum speed allowed on motorways in the UK, with a target headway fixed at 5 s, was in charge of managing the longitudinal dynamics of the vehicle. The lateral controller acted, when active, as an LKA system and it maintained the vehicle in the center of the occupied lane. HAD could be deactivated by requesting a handover. The transitions were

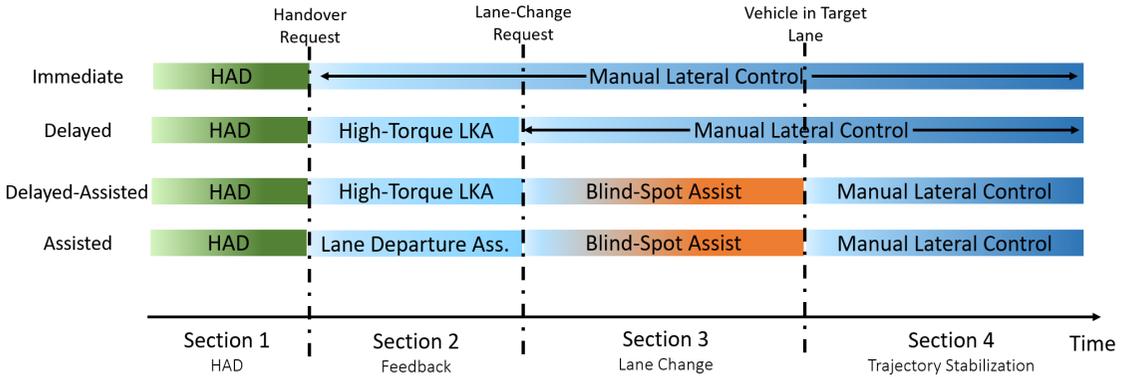


Figure 2. The handover strategies were designed so as to have different authority levels during the handover as well as different supervisory roles afterwards. Every strategy varied the graduality with which the authority was relinquished back to the driver. HAD = highly automated driving; LKA = lane-keeping assist.

not time limited and drivers had to regain control of only the lateral dynamics of the vehicle; the adaptive cruise control remained active. This approach was expected to reduce possible effects due to individual differences in speed selection. The reactivation of the ADS was fully automated: once the drivers removed their hands from the steering wheel, the automation reactivated.

The handover strategies were designed to provide stepwise decreasing levels of assistance throughout the transitions (Figure 2). In Section 2, the lateral assistance was in the form of an LKA with a strong steering authority for the delayed and delayed-assisted strategies and an LDA for the assisted. In Section 3, delayed-assisted and assisted provided an additional steering torque, hindering drivers from steering when a vehicle was in the blind spot.

Procedure

Before the experiment, all participants were briefed regarding the goal of the study; they were given the opportunity to read the Information Sheet and they signed a consent form. They were reminded that none of the transitions would be time limited.

Hence, within the first 10 min, participants were given the opportunity to familiarize themselves with the simulator, the handover procedure, and the arrow task. Following a short break after the familiarization, drivers started

the experimental drive. The experimental drive consisted of 12 trials. Each trial started with 5 min of HAD while drivers were performing the arrow task. In AI cases, drivers were asked to take over via a prerecorded message: “Please, take over.” In DI cases, drivers were instructed during the familiarization that they had to take over by themselves once they completed 280 searches. The number of left arrow tasks was displayed but no take-over messages were prompted.

Once the handover had been requested (hands-on-wheel and button press), drivers experienced different feedback for 2, 7, or 15 s (according to the counterbalanced design). In Section 3, drivers had full lateral control with immediate and delayed handovers or blind-spot assist with delayed-assisted and assisted, and were asked to change the lane through a message displayed on the road. According to the counterbalanced design, while asking drivers to change lane, the simulation introduced a vehicle in the blind spot of the target lane to test the effectiveness/vulnerability of the different strategies. Afterwards, they all had full lateral control and drove for 15 s before being asked to reposition the vehicle in the middle lane via a new visual signal. Once there, drivers were issued with a new acoustic signal informing them of HAD availability. Once drivers removed their hands from the steering wheel, they were asked to rate the experienced trial before reengaging with

the arrow task so that a new trial could begin. Halfway through the experiment, drivers were asked whether they felt any discomfort and offered a short break before carrying on with the study.

The handovers were proposed so that each participant experienced the same strategy for three consecutive times (i.e., trials). This way, it was possible to evaluate the learning trend and, through a postcondition set of questionnaires, investigate perceived workload, trust, and acceptance of the single strategies.

Dependent Variables

The following metrics were collected for each condition per participant.

Reengagement time was defined as the time elapsed between the issuing of TOR (for AI cases) or from the time instant drivers stopped performing the arrow tasks (for DI cases) and the handover request (hands-on-wheel and button press). Grab duration was defined as the elapsed time in which drivers were grabbing the steering wheel before requesting the handover.

Driving performance was measured by steering torque normalized over time, power of high-frequency steering components (HFS), mean lateral position (MLP)—defined as the distance of the ego vehicle center of gravity from the middle of the occupied lane—and the standard deviation of lateral position (SDLP). Increased steering torque is representative of steering conflicts between the driver and the ADS (Mars, Deroo, Charron, 2014). Higher values of HFS (in band 0.3–0.6 Hz) indicate a higher number of steering corrections (McLean & Hoffmann, 1973) and have been associated with an increase in task demand. Percentage toward road center (PRC) was recorded as a measure of drivers' focus and measured as the percent of dwell time spent focusing on the road ahead, as defined in Carsten et al. (2012).

Continuous subjective ratings on a scale from 1 to 10 were collected after every trial to assess workload and comfort fluctuations (1: *Very low* to 10: *Very high*). Every three trials, subjective workload scores were collected via the NASA-TLX subscales (Hart & Staveland, 1988) as well as trust (Jian et al., 2000) and acceptance

(Van Der Laan et al., 1997). Moreover, drivers were asked to rate the perceived level of steering authority they had before the lane change request on a scale from 1 (*Not at all*) to 7 (*Absolutely*).

Analysis

The data were compiled and metrics were calculated using MATLAB 2018a and analyzed using IBM SPSS v24. Kolmogorov–Smirnov tests (Conover, 1999) were used to check for normality and, when necessary, nonparametric tests were adopted (Wilcoxon signed-rank test instead of t tests) and effect sizes were calculated as $r = \text{abs}(Z/\sqrt{N})$ or transformations were made to perform parametric statistical tests (as ANOVA) and a partial eta-squared t^2 was computed as an effect size statistic (Fritz et al., 2012). To check and study possible interactions between independent variables and their relative effects on the dependent ones, a repeated-measures ANOVA was performed. An α value of .05 was used as the criterion for statistical significance. Whenever Mauchly's test of sphericity was violated, degrees of freedom were Greenhouse–Geiser corrected. When relevant effects were found, pairwise comparisons (Bonferroni corrected) were performed as follow-up tests. Descriptive statistics and main results of the ANOVAs can be found in Tables 1 and 2, respectively.

RESULTS

A Wilcoxon signed-rank test revealed (Figure 3) a significant difference in reengagement time between AI and DI cases ($Z = 1.965$, $p = .049$, $r = .49$). In DI cases, drivers took on average 9.51 ± 6.04 s to request the handover, whereas they took 4.98 ± 4.82 s in the AI cases (mean diff. = 4.53 s). In DI cases, on average, drivers spent 1.25 s longer with their hands on the steering wheel before requesting the handover ($t(15) = 2.332$, $p = .034$, Cohen's $d = .82$).

In Section 2, there was a significant interaction between feedback and initiator ($F(1, 31) = 8.721$, $p < .01$, $\eta_p^2 = 0.220$). Drivers significantly reduced their efforts in AI cases (mean diff. = 25.631 Nm/s, $p < .01$). The steering torque was greater whenever drivers were initiators and the

TABLE 1: Descriptive Statistics and Results of the Conducted Pairwise Comparisons

Variable	DI Case		AI Case		<i>t</i> (<i>df</i>)	<i>p</i>	Cohen's <i>d</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>			
Section 2							
Steering torque: Strong LKA (Nm/s)	146.35	65.23	100.33	35.68	3.50 (62)	<.01	2.43
Steering torque: No feed/LDA (Nm/s)	92.39	29.65	87.14	38.87	0.61 (62)	.54	.14
HFS	24.81	8.02	32.96	10.23	5.02 (126)	<.01	.88
PRC: Strong LKA (%)	73.65	20.61	64.83	20.93	1.70 (62)	.09	.40
PRC: No feed/LDA (%)	69.81	17.96	70.24	21.71	0.08 (62)	.90	.02
Section 4							
HFC	24.40	7.33	26.29	6.28	1.57 (126)	.049	.28
MLP (<i>m</i>)	-.12	0.25	-.19	0.23	1.57 (126)	.08	.29
SDLP (<i>m</i>)	0.34	0.09	0.36	0.15	0.74 (126)	.54	.16
Questionnaires							
Continuous subjective ratings workload	4.80	1.84	4.42	1.92	1.15 (126)	.049	.20
Continuous subjective ratings comfort	6.43	1.91	6.66	1.88	0.68 (126)	.21	.12

Note. LKA= lane-keeping assist; LDA = lane departure assist; HFS= high-frequency steering components; PRC = percentage toward road center; MLP = mean lateral position; SDLP =standard deviation of lateral position; AI =automation initiation; DI = driver initiation.

ADS was providing a strong LKA (mean diff. = 46.02 Nm/s, $p < .01$). Significant effects were also found on the HFS, which, overall, was significantly greater in AI cases (mean diff. = 8.15, $p < .01$). Trend-wise, PRC was 9.32% lower whenever the ADS was the initiator and retaining the largest authority share (Figure 4).

Throughout Section 3, the initiator did not significantly affect drivers' behavior. Follow-up tests revealed that, after time intervals of 15 s, the crash rate, compared to the 2 s and 7 s cases, was reduced by 50% ($p < .01$) and 32.5% ($p < .01$), respectively.

In Section 4, the HFS was significantly affected by the initiator but the MLP and the SDLP did not show any significant effect. HFS was lower in DI cases (mean diff. = 1.891, $p = .049$) but drivers were better in keeping the vehicle closer to the lane center. Moreover, SDLP was trend-wise lower, irrespective of the proposed strategy. On the other hand, in AI

cases, 50% of participants showed higher SDLP values with the delayed strategy.

The analysis of the continuous subjective ratings for mental workload revealed the DI case was perceived more demanding (mean diff. = .383, $p = .049$). On the contrary, no significant effect was reported for the subjective comfort ratings. NASA-TLX ratings were not significantly affected by the different strategies and, moreover, none of them was significantly greater than the midscale point. Since the ratings were not statistically different from the midscale point, trust and acceptance questionnaires proved to be inconclusive. While experiencing different feedback, drivers did not perceive any difference in their steering authority. Nevertheless, on average, all drivers reported themselves to be the agents with more authority (mean = 5.1094, $SD = 1.323$), since the reported average score (5.1) was significantly greater than the scale midpoint (mean diff. = 1.1094, $p < .01$).

TABLE 2: Main Results of the Conducted ANOVA Tests

Dependent Variable	$F(df, Error)$	p	η_p^2
Section 2: initiator effects			
Steering torque	18.242 (1, 15)	<.01	0.549
Power of high-frequency steering components	50.096 (1, 15)	<.01	0.770
Section 3: time interval effect			
Crash rate	9.750 (2, 30)	<.01	0.394
Section 4: initiator effects			
Power of high-frequency steering components	4.596 (1, 15)	.049	0.235
Mean lateral position	3.527 (1, 15)	.08	0.190
Standard deviation of lateral position	0.391 (1, 15)	.54	0.025
Continuous subjective ratings: initiator effects			
Perceived workload	4.604 (1, 15)	.049	0.235
Perceived comfort	1.743 (1, 15)	.207	0.104
Questionnaires: handover strategies effect			
Perceived level of control in Section 2	1.030 (3, 45)	.388	0.064

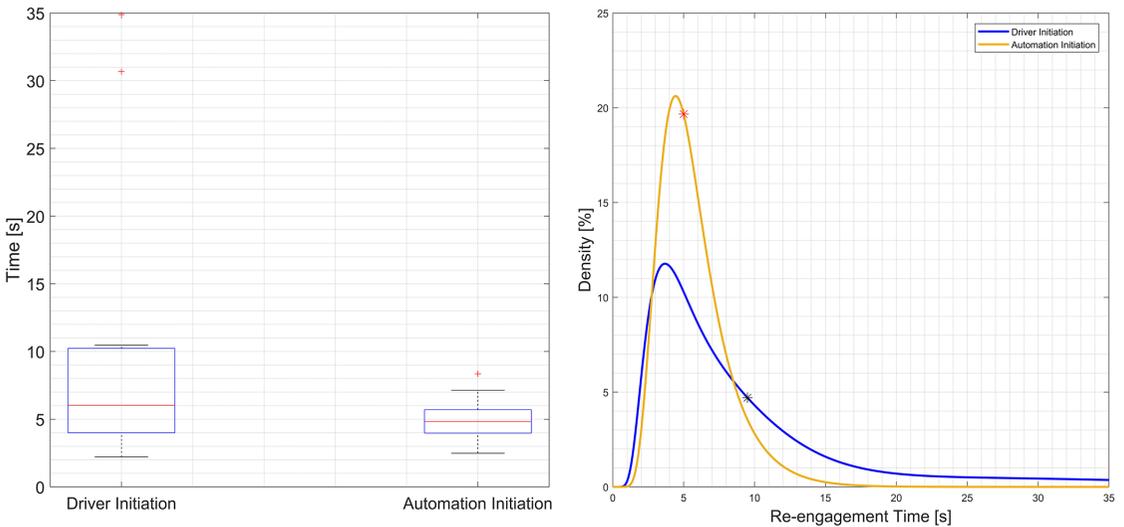


Figure 3. On the left, the reengagement time (median line enclosed) and, on the right, its distribution (mean identified by the asterisks). Both differentiated by the type of initiation (DI and AI). DI = driver initiation; AI = automation initiation.

DISCUSSION

Drivers took between 2.73 s (5th percentile) and 7.99 s (95th percentile; median = 4.98 s) to reengage the driving task after the prompt of a TOR (AI). In DI cases, although the 5th percentile is close to that in AI cases (2.42 s),

the 95th is at 33.62 s and, on average, they took 9.51 s. Forty-three percent drivers took longer than the 95th percentile of the AI case and preferred to grab the steering wheel and wait, on average, 1.91 s before requesting the handover. A possible explanation is that drivers wanted to

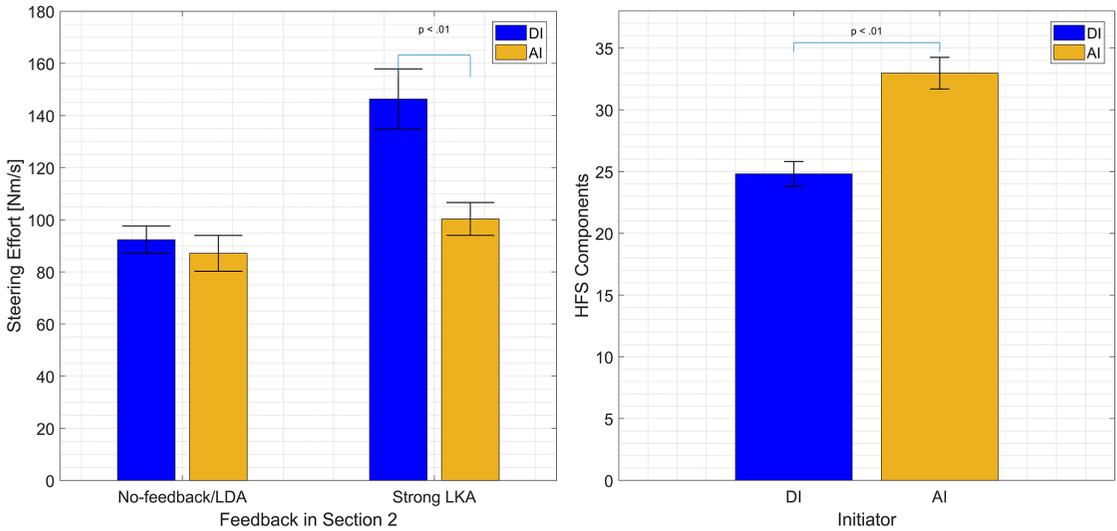


Figure 4. Section 2: on the left, the steering effort and, on the right, the HFS. Both are shown with the respective error bars (mean standard error) and the p value from corresponding t tests. HFS = high-frequency steering components.

ensure they had proper contact with the interface before requesting the control. This suggests that drivers, in DI cases, wanted to take time to make a subjective assessment of their own capabilities, which include their awareness of the surrounding traffic and their capacity to keep the vehicle on a safe trajectory. The higher mental load reported after DI cases might be very well due to their commitment in taking over at the best of their capacities and supports Gold et al.'s (2016) argument. Knowing situation complexity (e.g., traffic condition) affects take-over time (Gold et al., 2016; Radlmayr et al., 2014), these results warrant further evidence: the increased complexity is expected to enhance the observed discrepancies between AI and DI cases, but there is not enough evidence to back this hypothesis. Although artificial, the modality with which the DI transitions were triggered allowed a good level of controllability and, resembling the visual-manual surrogate reference task, was effective in ensuring drivers' disengagement with the driving task (Beller et al., 2013; Gold et al., 2013; Lorenz et al., 2014; Radlmayr et al., 2014).

Throughout Section 2, in AI cases, drivers reduced their steering torque of 46.02 Nm/s

when the ADS was providing a strong LKA compared to DI cases. Under the same conditions, PRC was 8.82% lower, meaning that drivers were actively diverting their attention from the center of the current lane toward other areas, potentially increasing their knowledge of the surroundings and preparing themselves to step into more proactive behavior. In AI cases, the lack of steering engagement led to an increase of the HFS (mean diff. = 8.15), due to the increasing number of correcting actions performed by the ADS while trying to mitigate drivers' poor control. Altogether, this might be indicative of drivers' engagement with the driving task or it might just suggest that drivers thought steering authority lay in the initiator's hands. Accounting for the great capacity drivers have in adapting themselves to changes in haptic feedback (Russell et al., 2016), the discriminant factor for such behavior seemed more likely to be the initiator, hence the second hypothesis. Either way, drivers showed to be more engaged in DI cases and were less prone to be guided by the ADS.

The adopted simulator required drivers to rely on haptic feedback from the blind-spot assist. Although the obtained results might be

affected by the visual impairment, from this study we saw drivers were able to understand the haptic feedback and hence avoid the vehicle while changing lanes only when they had stayed in Section 2 longer. Although, at an operational level, drivers may display performance close to manual driving (Eriksson & Stanton, 2017a; Merat et al., 2014), at a tactical level they were still unprepared. This suggests, while designing handovers, control transition times should always be as long as possible. Of course, in AI transitions, this is a planning issue since the ADS will need to allow the most gradual shift of authority within the given time budget. Due to the intrinsic nature of DI transitions, drivers might reengage in conditions in which the ADS had not considered their interventions, and this, in turn, might raise vulnerabilities on how the transition is handled and how an ADS could, or should, adapt itself to drivers' needs.

When it came to stabilizing the vehicle trajectory after the lane change, drivers' performances were the result of the engagement they showed in Section 2. In particular, in DI cases, the HFS was lower (mean diff. = 1:89), implying that drivers were using less corrective steering actions. Nevertheless, they were better in keeping the vehicle closer to the lane center. Moreover, SDLP was trend-wise lower and not affected by the proposed handovers. In AI cases, the higher SDLP values with delayed handover might be representative of the effects of a misunderstanding: drivers thought the ADS was in charge and, in turn, they let the ADS take care of the driving task; but, once left in manual driving, unsupervised, some of them struggled to properly control the vehicle. Delayed-assisted and assisted handovers helped to mitigate the above, providing further assistance and, in turn, increasing the gradualness of the authority shift. This, in turn, while supporting Flemisch et al. (2008) hypothesis, suggests that, especially in AI cases, handovers should make drivers more responsible for the vehicle motion to mitigate the effects of their reduced engagement. The level of responsibility seemed related to the actual authority allocation during the handover and, although drivers were very poor in assessing their own authority level (from questionnaires they reported they thought

they always had the largest authority share), their behavior showed otherwise. As already recognized (Mars, Deroo, Charron, 2014), at a sensorimotor level, drivers were aware of their authority level and acted accordingly. Hence, as a result of the perceived higher steering authority, the reported mental demand increased.

CONCLUSION

This study found that drivers' behavior throughout the transitions was heavily affected by their role as initiator. Drivers' reengagement time was not normally distributed; therefore, car manufacturers should allow for a more flexible range of control transition times. Moreover, in DI cases, drivers stayed longer with their hands on the steering wheel and focused on the road ahead, which suggests drivers would be more perceptive toward human-machine interfaces, leading their attention towards specific areas to raise their awareness.

Drivers increased their steering effort when they initiated the transition and the ADS was exerting a strong lateral control. Hence, proposing a handover with a strong steering authority should be limited to AI cases only, since imposing it on drivers in DI cases turned out to be detrimental to both performance and driver' comfort. Nevertheless, in AI cases, handover designers should exploit drivers' visual engagement with the driving task, providing human-machine interfaces to drivers who proved to be more prone to gaze wandering.

Results from the third section raised the importance of the supervisory role that the ADS should retain throughout every transition. Results showed that drivers, even after 15 s, were struggling to understand the blind-spot assist. Hence, the ADS should ensure that drivers receive contextual information in advance. Nevertheless, these results might have been heavily affected by the visual impairment due to the adopted simulator.

Results revealed that drivers' performance in stabilizing the vehicle trajectory was still linked to the perception of steering authority they had, and, in turn, to their initial role. Overall, drivers' performance benefitted from more gradual handovers. The sample size did not allow to test the

effects of age and experience on reengagement time and performance.

Since the transition time budget is limited, future studies should investigate how to promote and hasten drivers' engagement with the driving task. Doing so in a handover should reduce the chances for unprepared drivers to be left unsupervised while they are not yet fully engaged.

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KEY POINTS

- Drivers took longer to reengage with the driving task in the driver initiation condition compared to the automation initiation one.
- Drivers increased steering effort when they initiated the takeover and the automated driving system was exerting a strong lateral vehicle control.
- In the AI condition, delayed handover led to more lateral deviation in the form of higher standard deviation of lateral position values, potentially indicating drivers' misunderstanding regarding their responsibility during the transition.

ORCID iD

Davide Maggi  <https://orcid.org/0000-0002-7806-8211>

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Davide Maggi is currently pursuing his PhD with the Institute for Transport Studies, University of Leeds, UK. He received his MSc degree in automation and control engineering from the Politecnico di Milano in 2017.

Richard Romano is currently affiliated with the University of Leeds as Chair in Driving Simulation. He received his PhD from University of Iowa, Industrial Engineering, in 1999.

Oliver Carsten is currently affiliated with the University of Leeds as professor of transport safety in the Institute for Transport Studies (ITS). He received his PhD from the University of Michigan in U.S. Social History in 1981.

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