Conditionally and highly automated vehicle handover:

A study exploring vocal communication between two drivers

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Abstract

Automated Vehicles with levels 3 and 4 capability involve the handover of control and responsibility between driver and automation. The handover task represents a vulnerability in a given system due to the reduction of situation awareness and possible breakdowns in communication. Handover assistants are a design approach proposed to counteract these vulnerabilities. This study investigated the concept of a vocal handover assistant by exploring information transferred, and the methods for doing so, in naturalistic vocal handover between two drivers. Additionally, it was hypothesised that scripted vocal methods would differ in measures of workload, usability, acceptance and the effect on longitudinal/lateral driving behaviour. In each trial, two drivers took part in a driving simulation exchanging control from one-another. Drivers took part in six conditions: four pre-set conditions related to a different interaction style and two 'free-form' conditions before and after pre-set conditions. Our results show a change in information-types transferred and methods adopted for communication from before to after taking part in pre-set conditions. Other findings highlight considerations to be made such as training, personalization, the transmission of priority as well as contextual information, and how handover methods may affect the control of the vehicle following handover. Grice's Maxims were applied to handover methods to facilitate discussion. We present four considerations for future design: efficiency, personalization, and presentation of prioritised and context-related information.

Keywords: handover, takeover, high automation, vocal communication, automobile

1. Introduction

Driverless vehicles promise to remove the human operator in favour of safer driving, as well as freeing up the passenger to take part in non-driving related tasks during their journey (Waldrop, 2015). With Audi having released its ‘traffic jam assist’ capable A8 in early 2018, a new era of automated vehicle technology has been made available to the public (Audi, 2018). However, this represents the first steps on the path to ‘full automation’ (Level 5 automation; SAE J3016, 2016), that is, where no human operator required at any point in the journey. Some manufacturers such as Google, are in the process of developing full automation, whereas others are preparing to release vehicles that can function in automated mode for a proportion of a journey (Level 3 & 4 automation; SAE J3016, 2016), similar to that of the Audi A8.

1.1 Handover of control in level three and four automation

Level three and four (Conditionally/Highly Automated Vehicles; C/HAVs) differ in their capability safely respond to emergency situations. Level three requires the driver to be ‘on-hand’ in case they need to intervene in response to a design/system violation, whereas level four vehicles may request for driver intervention, but are able to safely operate even if the driver does not respond (SAE J3016, 2016). However, level three and level four automation may share the request for human intervention due to the vehicle leaving a pre-specified ‘operational design domain’, such as a geographical boundary (Banks, & Stanton, 2016; Eriksson, & Stanton, 2017a; SAE J3016, 2016; Stanton, & Marsden, 1996). The handover task is not a novel concept; in shift-work domains where errors can lead to disastrous consequences, these handovers must be carefully considered, as they represent a vulnerability in a system (e.g. Molesworth, & Estival, 2015; Thomas, Schultz, Hannaford, & Runciman, 2013). This vulnerability is largely due to a reduction in ‘situation awareness’ (SA) as a result of being ‘out-of-the-loop’ for an extended period of time (de Carvalho, Benchekroun, &

Gomes, 2012; Endsley, 1995; Endsley, & Kiris, 1995; Louw, Merat, & Jamson, 2015; de Winter, Happee, Martens, & Stanton, 2014). In turn, this can lead to an increase in errors, and consequently, an increase in incidents (Stanton, Young, & McCaulder, 1997).

In the driving task, the reduction of SA has been found to increase risk when the driver receives control from an automated system (Brandenburg, & Skottke, 2014; Merat, & Jamson, 2009). Dependent on level, handover could be initiated for two reasons: when automation requires driver intervention because of an emergency (level 3), or when automation hands over to the driver due to leaving an 'operational design domain' (applicable to both level 3 and 4 automation; SAE J3016, 2016). It has been proposed that the latter reason should take place over a "comfortable transition time" to ensure adequate time for SA to be raised, as well as being adaptable to the driving context and driver awareness (NHTSA, 2013). There is still much debate over what constitutes as "comfortable transition time" (Merat et al., 2014) although a recent study by Eriksson and Stanton (2017a) showed that this ranged between 1.97s and 25.75s (Mdn = 4.56) when simply asked to takeover with no time-restriction. Willemsen, Stuiver, and Hogema (2014) propose that take-over time should be modified based on driver awareness prior to handover.

To ensure that level three/four capable vehicles are safe, researchers and designers must carefully consider the handover and the range of factors that the handover task influences. These include lateral stability, driver attention and decision-making (Brandenburg, & Skottke, 2014; Merat, & Jamson, 2009; Eriksson, & Stanton, 2017b). Another area to be considered is how automation and the human-driver will share responsibility of the driving task, as outlined by the SAE standard (Kyriakidis, et al., 2017; SAE J3016, 2016), as these policies will dictate requirements for handover protocols. From a legal perspective, it may also be important for a vehicle to ensure that SA is raised prior to handover, and that the driver is physically and mentally prepared to take control of the vehicle. This verification is already in place in domains such as Nuclear Power Plants (de Carvalho, Benchekroun, & Gomes, 2012). This study addresses the ways of utilising vocal communication as a strategy to raise SA and better coordinate C/HAVs handover process. In particular, this study explores communication structures and information types being transmitted during handover.

1.2 Handover Design

As the handover requires a high level of coordination from both driver and automation, it has been proposed that there should be a form of handover assist to raise SA prior to handover (e.g. Eriksson, & Stanton, 2017c; Walch, Lange, Baumann, & Weber, 2015). Saffarian, de Winter and Happee (2012) suggest that feedback and interaction should occur between the driver and automation, and that handover designs should carefully consider warnings and displays with particular attention to driver preferences. Further, Martens and van den Beukel (2013) show that there are considerations that should be made such as driver attention, non-driving tasks, and mode confusion, so that handover interactions can be improved.

Many other areas related to C/HAV handover have been addressed, such as SA (Merat & Jamson, 2009; Stanton, Young, & McCaulder, 1997), notifications (Bazilinkskyy, & de Winter, 2015), time to takeover (Eriksson, & Stanton, 2017a; Gold, Happee, & Bengler, 2017; Young, & Stanton, 2007; Zeeb, Buchner, & Schrauf, 2015), effect of demographics (Körber et al., 2016), effect of traffic density (Gold, Körber, Lechner, & Bengler, 2016), effect on driver behaviour (Merat et al., 2014; Naujoks, Mai, & Nekum, 2014), distractions (Mok et al., 2015), temporal/complexity constraints (Eriksson, Marcos, Kircher, Västfjäll, & Stanton, 2015), and handover assistants (Eriksson, et al., 2017; Walch et al., 2015).

A handover design must adhere to human factors design principles such as the calibration of driver workload (Stanton, Young, & McCaulder, 1997; Young, & Stanton, 2004), the usability of the system (Harvey, & Stanton, 2013), and be capable of building appropriate levels of trust with the driver (Kazi, Stanton, Walker, & Young, 2007); these factors can affect the functionality of the system. Considering the end-user and the context in which the handover occurs is important, as there are a range of influences on handover performance such as, roadway laws, traffic density, weather, driver experience, age, gender (Saffarian, de Winter, & Happee, 2012).

1.3 Applying human communication theory to human-machine handover

There has been much debate over how applicable human-human communication (HHC)/computer-mediated communication (CMC) is to applications to human-computer interaction (HCI). Several communication researchers suggest that the nature of communication for joint-activity is similar, regardless of the agents present (e.g. coordination, shared goals, resolve breakdowns in communication; Klein, Feltovich, & Woods, 2005). This line of thinking has also been discussed in the field of automation (Klein, Woods, Bradshaw, Hoffman, & Feltovich, 2004). Bradshaw et al. (2003) second this stand-point by showing that joint activity via HHC or HCI involve what they call 'collaborative autonomy', that is, the process of understanding, problem solving, and executing certain tasks.

Perhaps the largest body of work regarding similarities between HHC and HCI comes from Reeves and Nass (1996), who outline their 'Media Equation' that illustrates how humans interact with technology as if they are real people. For example, it has been shown that factors such as cooperation, aggression, courtesy, and trust could play a role in these interactions. Some of these factors have been applied to vehicle automation (e.g. Bickmore,

& Cassell, 2001; Eriksson, & Stanton, 2017c). Inter-personal communication theories such as Common Ground (Clark, 1996) and the cooperative principle (Grice, 1975) have given researchers ways of approaching interface design considering how operators give and receive information during coordinated processes (e.g. Eriksson, & Stanton, 2017c).

Clark and Brennan (1991) outline the concept of 'common ground' (CG) in which language is a collaborative process where CG is established through 'joint activity' using pre-existing CG. Clark's (1994) theory describes how humans utilise CG as a way of "minimising effort" during collaboration, and that interactions should be made explicit, to ensure that both parties are coordinating sufficiently. Even though this theory originates from HHC research, the concept has been applied to computer mediated communication, and human computer interaction. CG implicates that methods of communication that involve bidirectional interaction and feedback, as well as visual references that better establish CG to be useful in communicative processes.

Similarly, communication is more effective if it aligns with the four maxims outlined by Grice's cooperative principle (1975):

1. The Maxim of Quantity – The degree to which information is informative, but not over-loading
2. The Maxim of Quality – The degree at which information is grounded in truth and how well it is supported by evidence.
3. The Maxim of Relation – The degree at which information is relevant to the task/activity being conducted.
4. The Maxim of Manner – How well information is provided in relation to ambiguity, obscurity and that information is presented briefly and orderly.

These maxims have been applied to automation interaction in cockpits and in automotive design (Eriksson et al., 2017; Eriksson, & Stanton, 2017) and have been proposed as a useful tool in automation design.

To apply the concepts of inter-personal communication to technological systems, ‘natural voice recognition’ has been proposed as an important component in future driver-vehicle coordination (Harvey, & Stanton, 2013; Large, Clark, Quandt, Burnett, & Skrypchuk, 2017). The use of vocal interaction during handover is typical in a range of high-risk domains such as medicine, aviation and energy manufacturing/distribution (Patterson, Roth, Woods, Chow, & Gomes, 2004), and has been proposed as a method of information transfer in C/HAVs (Bazilinskyy, & de Winter, 2015; Eriksson, & Stanton, 2017c). This interaction style is supported by the literature surrounding capacity limits in working memory, which shows that multiple channels exist to process different modalities of information (Baddeley, 1992). Research into the use of multi-media suggests that the presentation of vocal cues better compliments visual information than the use of pictorial cues, as pictorial cues may contend with other visual cues for attentional resources. This suggests that there may be advantages to using audio and vocal communication when compared to visual interfaces alone (Bazilinskyy, Petermeijer, Petrovych, Dodou, & de Winter, 2018; Gyselinck, Jamet, & Dubois, 2008; Large et al., 2017).

In C/HAV handover, knowledge of what information should be relayed to the driver, and how this should be done, is limited. The handover task has been examined in shift-work domains such as healthcare, aviation/air traffic control, and energy manufacturing/distribution. In these domains, failure to transmit information effectively during handover can lead to disastrous consequences (Patterson et al., 2004; Salmon, Walker, & Stanton, 2016). Strategies of communication in these domains could inform C/HAV handover, as they both involve a human taking control and responsibility for a task from another agent; including what information is required, how information is prioritised, and how it is delivered (e.g. Adamson, Lardner, & Miller, 1999; Eurocontrol, 2012; Patterson et al., 2004; Riesenberg, Leitzsch, & Little, 2008). We therefore propose that these pre-existing strategies in these domains should serve as a basis for testing handover protocol in C/HAVs.

Handover in these domains is typically conducted between two human shift-workers due to changing personnel. Vocal communication is the primary method of information transfer in many domains (Patterson et al., 2004). Most notable strategies across the literature are the requirement for a structured checklist (e.g. Riesenberg, Leitzsch, & Little, 2008), vocal bi-directional exchange (e.g. Rayo et al., 2014), good knowledge of the past (e.g. Adamson et al., 1999), training (e.g. Li, Powell, & Horberry, 2012), and technological aids (Cheung et al., 2010). These strategies allow the person taking over to establish their own mental model of the driving environment (Revell & Stanton, 2012, 2017; Stanton, & Young, 2000). All of these methods provide a basis upon which to design handover in C/HAVs.

1.5 Current study, aims and hypotheses

The aim of this study was to create a handover environment analogous to that of shift-handover. In this setting, two drivers can vocally communicate with one another and exchange control of the vehicle. In doing so, preferred handover strategies and the types of information that were transmitted during handovers were measured. The authors apply Grice's (1975) cooperative principle to the experimental handover structures to guide discussion. The aims of this research were:

- To gain a better understanding of drivers' naturalistic (Angrosino, 2016) and preferred information content and method of information transmission during handover.

- To assess workload, usability and acceptance concerning tested handover methods
- To gain a clearer understanding of why drivers prefer or require certain types of information transfer or interaction style
- To explore whether handover methods and information transfer has an effect on driving performance following the handover.

To achieve these aims, the following hypotheses were generated:

1. When able to naturally handover to one-another, with no pre-set structure, information transmission will increase after experiencing a set of pre-defined handovers.
2. When able to naturally handover to another driver with no pre-set structure, information content and methods will more likely represent that of the pre-defined conditions after taking part in them.
3. There will be a difference in driver workload (NASA-Task Load Index – NASA-TLX; Hart, & Staveland, 1988), usability (System Usability Scale - SUS; Brooke, 1996) and acceptance ratings (System Acceptance Scale - SAS, Van der Laan, Heino, & De Waard, 1997) in relation to pre-defined conditions undertaken.
4. Drivers' longitudinal and lateral control will vary following handover, in relation to the handover condition undertaken.
5. There will be individual differences in driver preferences to handover interaction

2. Method

2.1 Participants

Participants were recruited through advertisements on the university website and advertisements on campus. Forty participants were recruited aged 18 to 61 (29M, 11F; mean age = 31.1, SD = 10.07) and took part in the study. Participants held full driving licences, and had no impairments preventing the operation of the driving simulator. As the end-user will be varied in driving experience, no specific driving experience criteria was set. Participants had a mean of 7169 annual miles, ranged between 0 and 20,000 (SD = 5151 miles). As the experiment required two participants, they were paired according to availability and on a first-come-first-serve basis. Adverts stated that participants were not eligible if they were not paired with strangers, and this was ensured prior to the study. Ethical approval was given by the University of Southampton Ethics committee (ERGO number: 26691).

2.2 Experimental Conditions

In line with literature surrounding handover in high-risk domains (Riesenberg, Leitzsch, & Little, 2008), a structured checklist was constructed inspired by two concepts: IPSGA as a driver coaching system (Stanton, Walker, Young, Kazi, & Salmon, 2007) and PRAWNS (Walker, Stanton, Wells, & Gibson, 2010, Wilkinson & Lardner, 2012). The checklist proposed was 'HazLanFueSEA' and represents:

- Controls – Instruction to place hands/feet on wheel
- Hazards – Information such as close vehicles
- Lane – Lateral position on the roadway
- Fuel – Indicated as 'miles remaining'
- Speed – Indicated as 'miles per hour'
- Exit – Information on junction number and distance from junction

- Action – The action the driver is required to take (e.g. enter left lane and exit).

HazLanFueSEA starts with a request for the current driver to place their hands on the wheel and their foot on the accelerator prior to receiving the checklist information.

To explore driver behaviour, attitudes, and the effects on natural handovers, four ‘pre-defined’ handovers were tested, inspired by the literature in shift-handover. These conditions were implemented using a repeated-measures design:

- Out-going driver delivering HazLanFueSEA with read-back responses from the incoming driver (see Boyd et al., 2014). Referred to in this study as ‘Checklist with Read Back’ (CL/RB)
- Delivering HazLanFueSEA in an interactive conversation-style questioning format conducted by the current driver (e.g. Question: what is in the left lane? Answer: an approaching red car; Bickmore, & Cassell, 2001). Referred to in this study as ‘Checklist with Guided Questioning’ (CL/GQ).
- The questioning of the current drivers’ knowledge and intentions, asking whatever the incoming driver feels is necessary. This condition was inspired by common ground theory and the presence of a two-way process that can foster the repair process in communication. Referred to in this study as ‘Open Questioning’ (OQ) (see Clark & Brennan, 1991; Rayo et al., 2014)
- A timed handover involving no information transfer regarding the driving environment (60 seconds countdown) modelled on an existing handover design revealed by Volvo (Volvo Car Group, 2015). Referred to in this study as ‘Timed’ (T)

Before delivering CL/RB, CL/GQ and OQ, the driver in control of the vehicle initiated the handover process by stating to the other driver “I am ready to handover”. The driver in control awaited an acknowledgement prior to delivering the vocal protocol specified in the condition.

To guide our discussion, conditions were rated in relation to Grice's (1975) maxims of effective communication (Table 1). Cohen's κ was run to determine whether there was agreement between two researchers ratings in regards to how well the conditions address Grice's cooperative principles. There was moderate agreement between the two researchers' ratings ($\kappa = .464$, $p = .019$).

Table 1.

Authors' ratings of pre-defined vocal structures in relation to Grice's (1975) Maxims

	CL/RB	CL/GQ	OQ	Timed
Quantity	3(?)	3(?)	4	-
Quality	3	5	3	-
Relation	3	3	5	-
Manner	5	4	3	5

Note. Ratings range from 1 to 5. (?) Indicates an uncertainty, particularly whether there is too much/too little information being delivered due to individual preferences.

- *Quantity* – The checklist conditions provide a lot of information, but still run the risk of over-providing information. Whereas open questions is dependent on whether or not the driver asks for information. But to them, they will get a subjective optimum quantity of information.
- *Quality* – CL/GQ encourages the search for a driver's own evidence. CL/RB and OQ may be in part dependent on faith, but information is still in the environment/on the cluster.

- *Relation* – Checklist items are assumed to be relevant to the task, but this is yet to be confirmed. Whereas open questions meets this maxim by only providing what the driver desires.
- *Manner* – The CL/RB condition is the most structured and orderly, followed by CL/GQ. Open questions may be less prescriptive and result in confusion as to the original question asked.

It is worth noting that the timed condition does not deliver any explicit scenario information, so the authors have not given Timer a rating for the first three maxims. However, the structure is orderly so scores highly on the maxim of Manner.

2.3 Design

These pre-defined conditions were counterbalanced across participants using a balanced Latin square where conditions occurred at different times, and were preceded and followed by a different condition in each combination (see table 2). Ten participants took part in each combination.

Table 2.

A balanced Latin-square showing the counterbalancing of pre-defined conditions

1	A	B	C	D
2	B	D	A	C
3	D	C	B	A
4	C	A	D	B

To test whether naturalistic information content and transmission methods were influenced by the participation in pre-defined handovers, two ‘free-form’ handover conditions were conducted before and after taking part in the four pre-defined conditions. In the ‘free-form’ conditions, participants could engage in the handover however they wished, and were not given any indication as to what information to transmit, or how to transmit it, so that emergent themes from ‘free-form’ handovers can be compared to pre-defined handovers experienced, and gauge whether they had an influence on ‘free-form’ handover interactions. After the experiment, participants filled out a short questionnaire asking them to provide their thoughts on the pre-defined conditions, and give any of their own recommendations for future handover design.

2.4 Apparatus

The study was conducted in the Southampton University Driving Simulator (SUDS). The simulator has a fixed base and 135 degree field of view. The simulator is designed to create a safe environment from which to analyse driving behaviour that does not incur the adverse effects of distraction on the road, yet still aims to create a naturalistic environment. Validity comparisons between simulator and real-world environments show that a simulated environment can produce strong positive correlations in driver behaviour (e.g. Eriksson, Banks, & Stanton, 2017). However, limitations such as reduced risk perception have been demonstrated in such environments (Underwood, Crundall, & Chapman, 2011).The simulator was modified so that the Land Rover Discovery could support two steering wheels, two displays, and 2 sets of control inputs. The steering wheels had the capability of taking control of the vehicle through the click of a button on the device taking control (see figure 1).

Fig 1. Driving simulator set-up to simulate handover between two drivers

STISIM Drive was used to create a freeway environment modelled on the M24, junction 5 to 7, in the United Kingdom. Assuming an average speed of 60mph, the constructed route environment was looped two and a half times during a single scenario. This was to ensure that the condition ran for enough time for six complete handovers to take place with enough time for the driving environment to change prior to the next handover (10-12 minutes). To balance traffic density, traffic speed and headway, traffic was set at 52/57/62 miles per hour in the left, middle and right lane respectively. This allowed cars to be placed closer to one another without their reactive behaviour being triggered (i.e. when there is less than a three second headway to an obstacle) which would result in them braking and causing congestion. Cars were then placed within a minimum of 300 feet in front of one another to clear this headway-time. They were then varied randomly up to 600 feet. Traffic was generated after 1000 feet to ensure the participant could match their speed before its appearance.

2.5 Procedure

After reading the information sheet outlining risks such as motion sickness, the participant provided their informed consent. Following this, participants were given an introduction to the procedure and how to operate the driving simulator. This included an introduction to the visual display and the button they were required to press when taking control. A trial was then conducted consisting of five minutes of motorway driving (2 and a half each) to allow participants to get familiar with controls and the environment. No vocal handovers were conducted and control was switched when the experimenter instructed.

Participants were then shown how to fill out the three questionnaires following each condition, the NASA-TLX, the SUS, and the SAS. When participants were ready, experimental blocks began. The study design was a repeated measures design, with each pair taking part in each handover procedure. There were six handover conditions. The first and last conditions were always natural, where participants were allowed to handover to one another as they wished, with the four pre-defined conditions being conducted in the specific counter-balance order for that pairing.

Participants were given an example script of how the condition would take place, and a cue card was attached to the steering wheel to remind them of the current condition. Participants were asked to simulate a motorway junction exit of junction 7, where the action was to move into the left lane exit. Each condition consisted of six handovers (3 in either the role of automation or driver) and took approximately 10 minutes to complete. Each handover consisted of participants transferring control to one another, initiated by the person currently in control of the vehicle. Each moment a handover was to be performed was dictated by the experimenter tapping the participant's shoulder. Handovers were spaced approximately one minute apart, although variance at the experimenter's discretion was conducted to avoid prediction. 36 handovers were conducted throughout the entire experiment. The entire procedure took between 1.5 and 2 hours to complete depending on speed of questionnaire completion. Participants were given short breaks between conditions whenever they felt they needed them.

Once the experimental blocks had been complete, participants filled out a questionnaire where they were able to provide feedback on the experimental conditions, and provide their suggestions for future handover design. They were then debriefed, paid £10 to cover travel expenses and thanked for their time.

2.6 Method of Analysis

Transcripts were coded according to the information vocally transmitted, and method of delivery during handover. For each participant the percentage of handovers (out of six) involving the transmission of each information type, and each method of transmission, was calculated for each pair. A t-test was conducted to analyse whether information transfer increased from before to after taking part in the pre-defined handover conditions. The same percentage calculation was used for the 'open questioning' condition to measure what information was transmitted during this condition.

As questionnaire results were generated from a repeated-measures design, the analyses undertaken were Friedman tests with Bonferroni-corrected Wilcoxon post-hoc analyses (six comparisons; $\alpha = .0083$). The longitudinal velocity data represented a parabola pattern, therefore this data was analysed using a linear regression with a quadratic term to test intercept, slope and shape. Finally, to give a good indication of the extent at which drivers veered and corrected themselves following handover, lateral velocity data were averaged across five seconds following the handover and analysed using a Friedman test followed with Wilcoxon post-hoc analyses (six comparisons; $\alpha = .0083$).

3. Results

3.1 ’Free-form’ conditions

Figure 2 shows the mean percentage of handovers for all participants that involved information transfer before and after experiencing the four pre-defined conditions. The percentage sharply increases, indicating a higher likelihood of information transfer during the second ‘free-form’ condition. A t-test indicated a significant difference ($t(19) = 5.8$, $p < .001$).

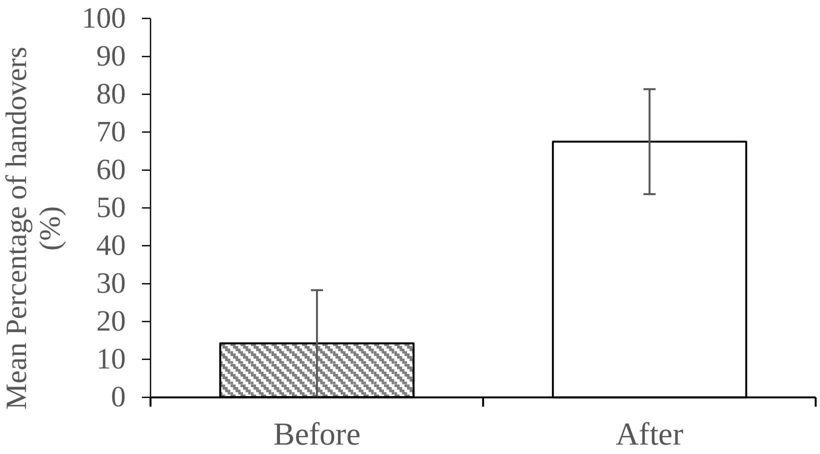


Fig 2. Mean percentage of handovers involving information transmission before and after pre-defined conditions

Information transmitted during handover greatly increased across all categories except for information types: ‘adapt action’, ‘advice giving’ and ‘road layout’, which decreased in usage slightly during the second ‘free-form’ condition (see figure. 3). The most common information themes to appear in the first ‘free-form’ condition were speed, other vehicles and vehicle position. There were also occurrences of instructing one another to change speed/position (adapt action) prior to handing over. Information types with no bar present either before or after pre-defined conditions represent zero instances of the transmission of this information type over all experiments.

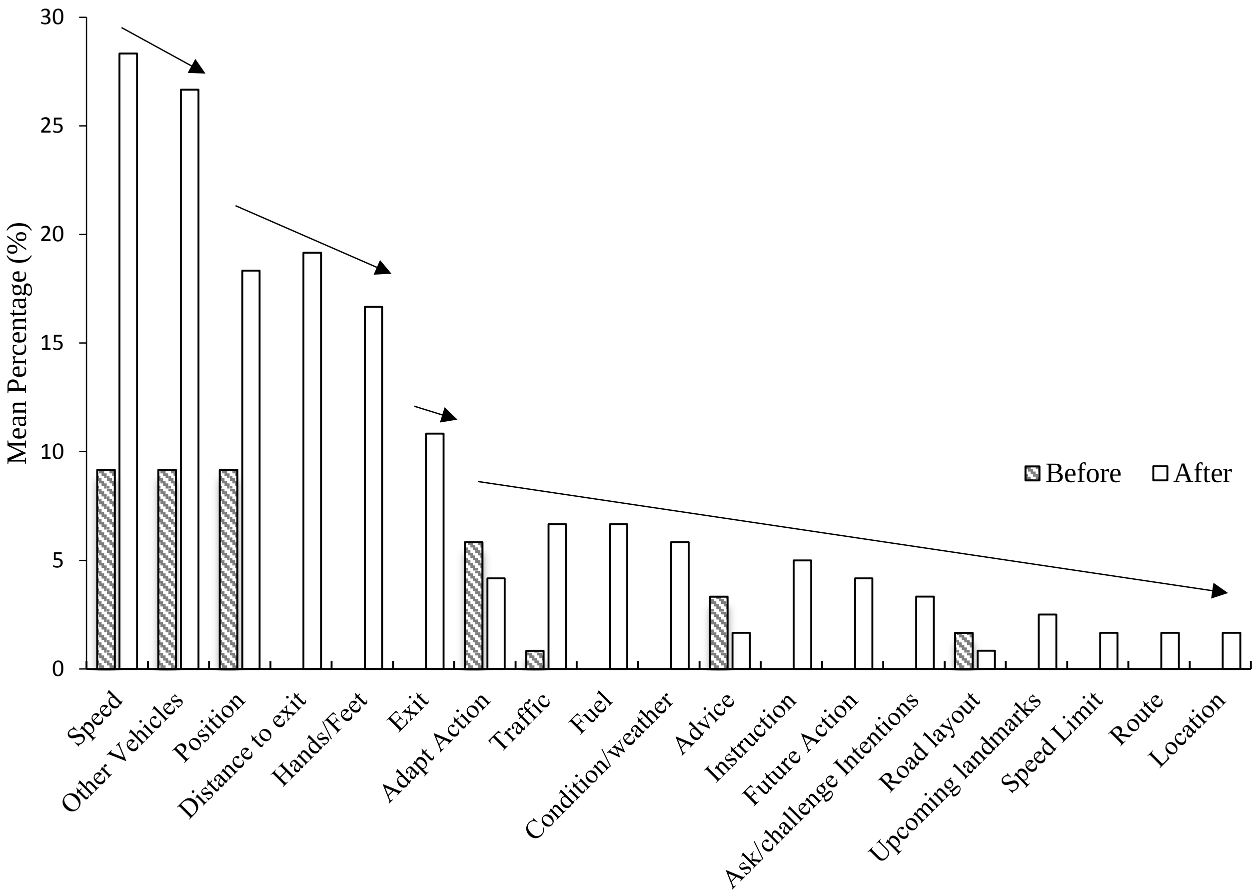


Fig 3. Natural conditions - mean percentage of handovers including information transmission for each information type before and after pre-defined conditions. Arrows indicate emergent frequency groupings.

In the second 'free-form' condition, the most common information types were those transmitted during the pre-defined condition. There were many new information types transmitted that were unrelated to the pre-defined conditions such as weather/road conditions, traffic information, instruction giving, and asking about/challenging intentions. Drivers transmitted a mean of 0.39 (SD = 0.95) information types before pre-defined conditions, increasing to 1.6 (SD = 1.67) after the pre-defined conditions. These information types were grouped based on prevalence, and represent four distinct groupings (figure. 3).

There was a great shift in methods used before and after the pre-defined conditions, these methods are defined in table 3.

Table 3.

Definitions of handover methods conducted during 'free-form' handover conditions

Handover Method	Definition
Hybrid	The use of two or more of the following handover methods combined in a single handover
Simple Exchange	Handovers that consisted only of a notification and a confirmation, with no information transmission.
Monologue	Handovers that consisted of a steam of information being delivered from the current driver, with no response being asked for from the incoming driver, like that of CL/RB or CL/GQ.
Open Questioning	Handovers that involved an interaction on the basis of questioning the current driver about what they know about the driving environment
Timed	The use of a countdown conducted by the current driver to indicate a timeframe for receiving control. Deployed with or without information transfer.
Guided Questions	The use of interactive questioning, where the current driver quizzes the incoming driver regarding the driving environment.
Read Back	Handovers that use a repeat-back method to demonstrate that information is being received.

Before the pre-defined conditions, the majority of handovers consisted of a simple exchange, representing only a handover notification and a confirmation with no information transmission. Following the pre-defined conditions, participants adapted their strategies through either combining methods or staying with a single handover method. Figure 4 shows the mean percentage of handovers using a particular handover method, both before and after pre-defined conditions.

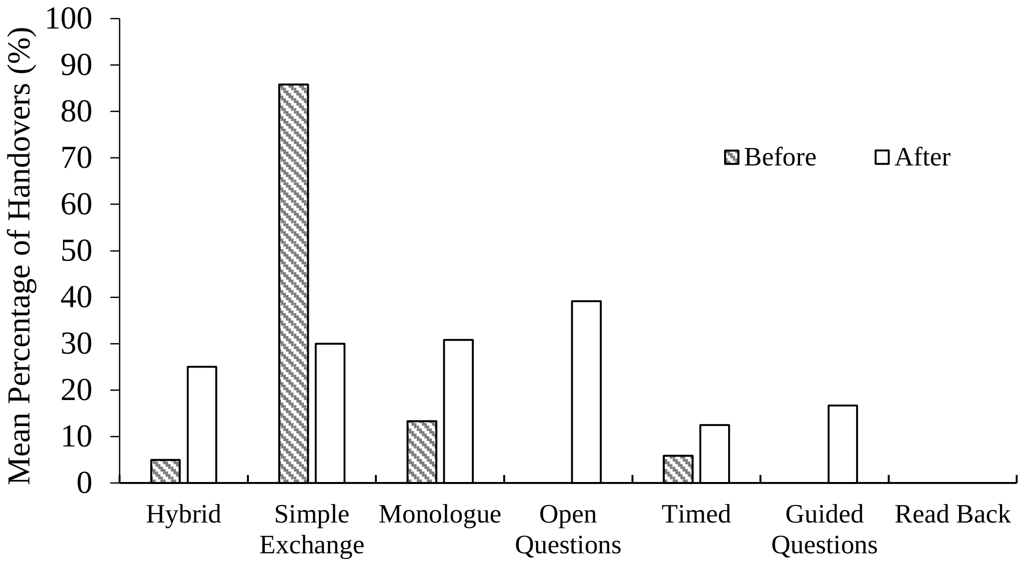


Fig 4. Natural conditions - mean percentage of handovers conducted using handover method before and after pre-defined conditions.

It shows the percentage of handovers that involved method hybridization, increasing from 4% to 25%. Simple exchange decreased from 85% to 30%. All other methods, with the exclusion of read-back, which did not get used in either 'free-form' conditions (represented by the absence of bars in the bar chart), increased in usage. The most common method was open questions, although this method was commonly hybridised with other methods. One method, that was not used in the pre-defined conditions is categorised as 'monologue' and represents the one-way delivery of information in a single packet of speech. Further, when CL/GQ was utilised it typically only included information regarding hands/feet on control inputs. Simple exchange remained one of the most common methods of handover, and also reflects the percentage of handovers that did not involve information transfer (see figure 4).

3.2 Use of open questioning

During the open questioning condition, drivers seemed to interact in a different manner. Questions revolved around immediate threats, speed and future action, with a specific focus on what will come up ahead such as traffic, route information, and whether there any upcoming landmarks such as petrol stations or speed cameras. Participants transmitted a mean of 2.05 (SD = 1.27) information types per handover interaction. Information types transmitted during this condition are displayed in figure 5.

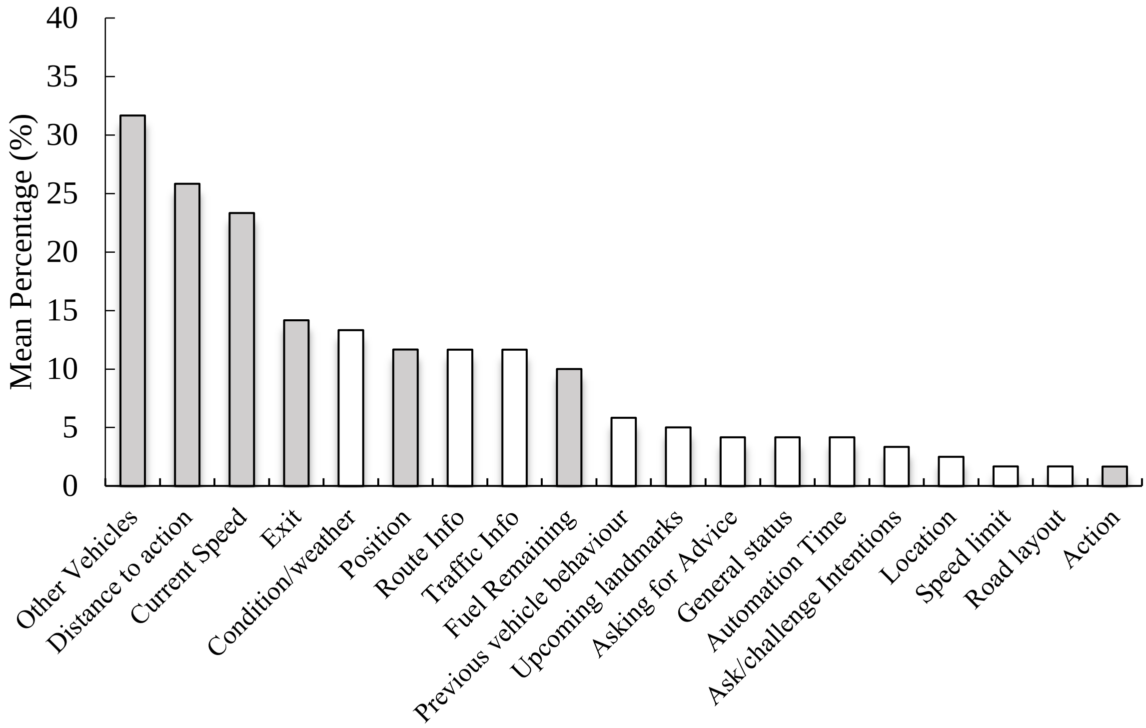


Fig 5. Mean percentage of handovers including information transmission for each information type before and after pre-defined conditions. Greyed bars indicate information transmitted in HazLanFueSEA.

3.3 NASA-TLX, SUS, & SAS

The assumption of normality was violated for multiple combinations of condition/dependent variable, therefore non-parametric tests were conducted. Four values were missing due to participant error. As there were so few missing values it seemed unnecessary to remove cases in full, therefore these values were imputed using the Expectation Maximization method (Borman, 2004). Descriptive statistics are displayed in Figure 6.

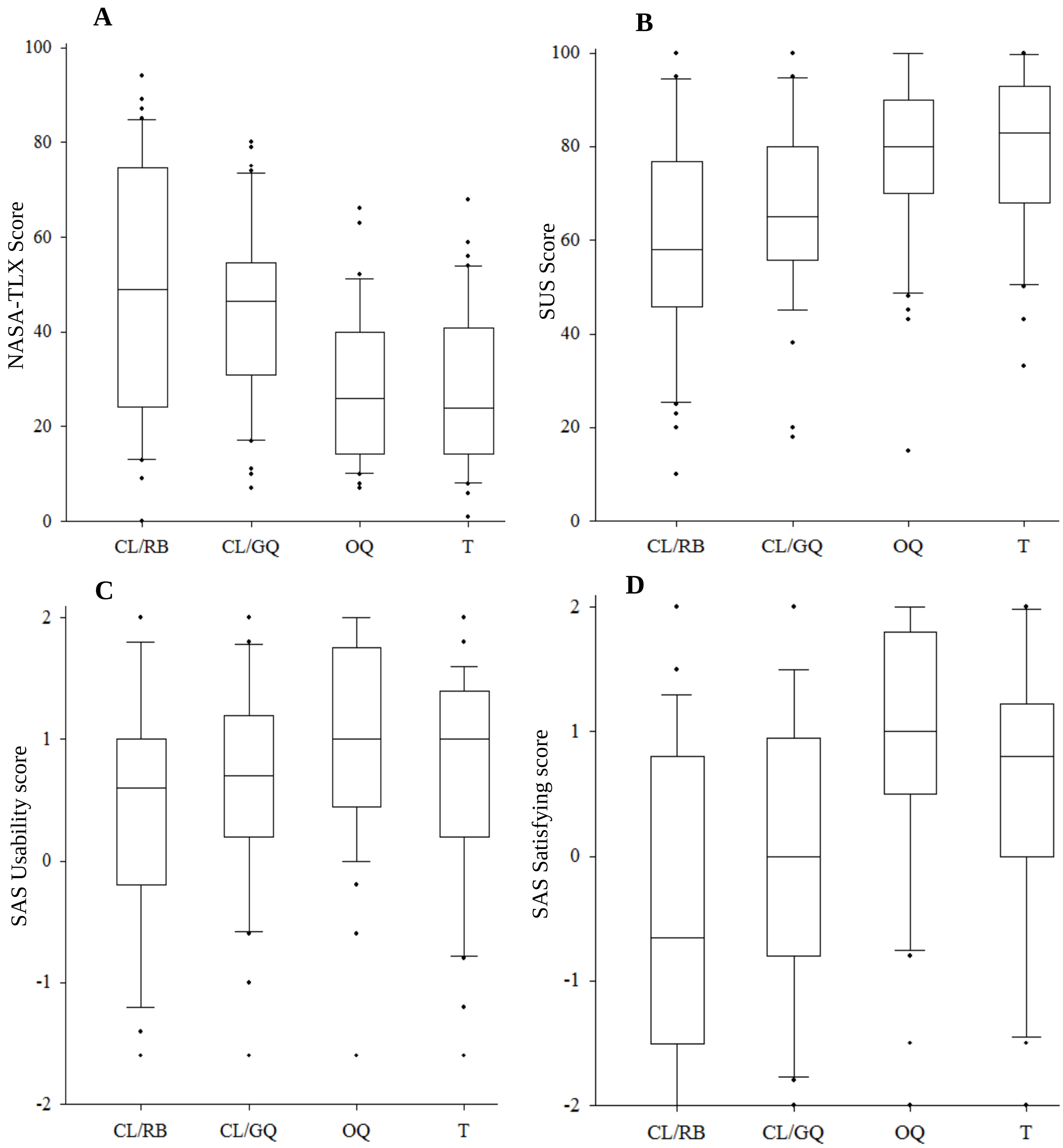


Fig 6. Boxplots to show results from NASA-Task Load Index (panel A), System Usability Scale (panel B), System Acceptance Scale – Usability (panel C) and System Acceptance Scale – Satisfying (panel D) between the four pre-defined handover condition. Whiskers indicate 10^{th} and 90^{th} percentile range.

Four Friedman Tests were conducted for each dependent variable: NASA Task Load Index scores, System Usability Scale scores, and scores from the two sub-scales of the System Acceptance Scale. These were analysed using handover condition as the within-subject variable with four levels: Read back, CL/GQ, Open Questions and Timed. A main effect of handover condition was found for all dependent variables tested ($p < .05$). Results are displayed in table 4.

Table 4.

Results from the four Friedman Tests analysing mean differences in NASA-TLX, SUS, and the AS subscales between handover conditions

Source	df	χ^2	p
NASA-TLX	3	34.64	.001*
SUS	3	26.01	.001*
AS-Usability	3	11.37	.01*
AS-Satisfying	3	24.14	.001*

Note. * = $p < .05$

Table 5 displays post-hoc pairwise comparisons for questionnaire responses. Significant differences vary based on measure, although typically, these comparisons can largely be grouped into Read back and CL/GQ receiving similar mean ratings, as well as Open Questions and Timed. Differences were greater in the NASA-TLX and SUS, whereas the AS Usefulness scale showed few significant differences during post-hoc analyses.

Table 5.

Post hoc analyses - Wilcoxon Signed Rank tests analysing differences in scores for the NASA-TLX, SUS, and the AS subscales between each handover condition.

Pairing	NASA-TLX			SUS			SAS-Use			SAS-Satis		
	Z	Sig.	r	Z	Sig.	r	*Z*	Sig.	r	*Z*	Sig.	r
CL/RB - CL/GQ	-1.08	.28	-0.17	-1.97	.049	-0.31	-1.78	.074	-0.28	-2.21	.027	-0.35
CL/RB - OQ	-3.94	.001*	-0.62	-3.93	.001*	-0.62	-2.97	.003*	-0.47	-4.08	.001*	-0.65
CL/RB - T	-4.03	.001*	-0.64	-4.46	.001*	-0.71	-1.12	.263	-0.18	-3.23	.001*	-0.51
CL/GQ - OQ	-4.41	.001*	-0.70	-2.87	.004*	-0.45	-2.01	.044	-0.32	-3.30	.001*	-0.52
CL/GQ – T	-4.20	.001*	-0.66	-3.28	.001*	-0.52	-.13	.900	-0.02	-2.04	.041	-0.32
OQ - T	-.24	.807	-0.04	-.11	.912	-0.02	-2.28	.023	-0.36	-1.68	.093	-0.27

Note α = .0083, * indicates significance ($p < .0083$)

3.4 Change in speed following handover

Figure 7 displays mean speeds following handover over the first five seconds of taking control. All conditions showed a parabola effect where speed decreased in the first two seconds following handover with speed steadily increasing from between two and four

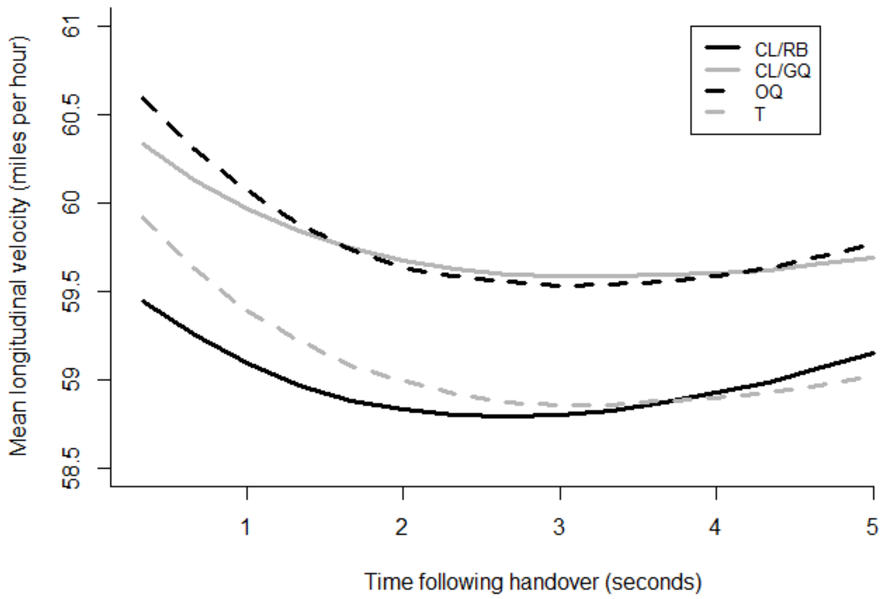


Fig 7. Line graph showing the change in vehicle longitudinal speed post-handover

seconds following handover.

Table 6 shows the output for a linear regression using the stepwise enter method. As the data appear to be non-linear, speed as a function of time did not show an effect. However, adding the condition intercept and the quadratic terms both improved the model ($p < .001$) showing that conditions significantly differ in their overall speeds. The model of best fit as a result of linear regression stepwise analysis was "Speed ~ Time + Cond Intercept + Quadratic Term".

Table 6.

Model	df	*F*	p	SST	Δr^2
Speed ~ Time	1, 2278	-	.077	-	.0009
Speed ~ Time + Cond Intercept	1, 2277	65.87	.001*	9	.0006
Speed ~ Time + Cond Intercept + Quadratic Term	1, 2276	748004	.001*	98070	.997
Speed ~ Time * Cond Intercept + Quadratic Term	1, 2275	1.66	.2	0	.997
Speed ~ Time * Cond Intercept + Quadratic Term * Cond	1, 2274	0.25	.62	0	.997

Note. Cond = Condition

3.5 Lateral velocity following handover

Mean lateral velocity was generated by taking the first five seconds following handover, calculating the square root of squares, and averaging across the time-period, illustrated by the

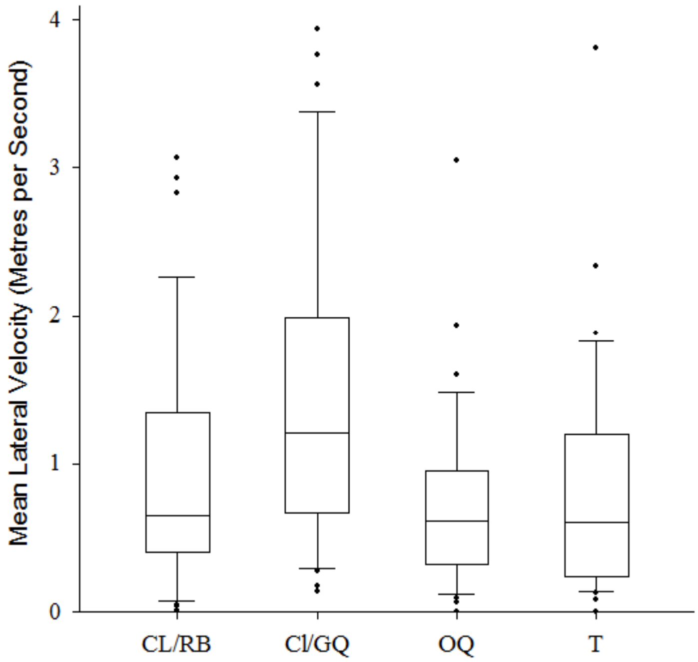
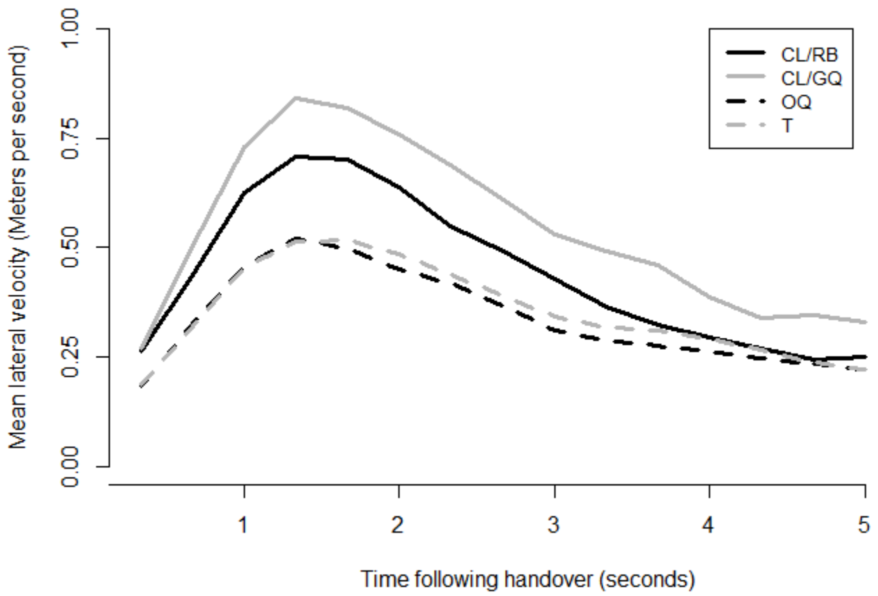


Fig 8. Mean lateral velocity over five seconds following the handover of control.

following equation: $v_{AbsLat} = \sqrt{v_{Lat}{}^2}$. Boxplots for lateral velocity are shown in figure 8.

A Friedman Test was run to explore whether handover condition had an effect on mean lateral velocity five seconds after handing over control. The test indicated that there was a main effect of handover condition on mean lateral velocity [$\chi^2(3)$= 8.2, p = .042]. Post-hoc Wilcoxon Signed-rank tests with Bonferroni corrections (α = .0083) revealed a significant difference between CL/GQ paired with CL/RB [r = -0.59, Z = -3.24, p = .001], and OQ [r = -0.49, Z = -2.71, p = .001]. All other comparisons did not show significant differences (p > .0083). An illustration of how this relates to time is displayed in figure 9.



3.6 Qualitative feedback

To explore why drivers preferred certain strategies to others, qualitative feedback was received regarding the pre-defined conditions. Positive and negative feedback related to the pre-defined conditions are summarised by the themes outlined in table 7.

Fig 9. Line graph showing lateral velocity over five seconds following the handover of control split across handover conditions.

Table 7.

Themes generated from qualitative questionnaire responses with regards to the four pre-defined conditions

		CL/RB	CL/GQ	OQ	T
Positive themes	Safety	9	8	6	-
	Efficiency	3	2	3	6
	Personalization	-	-	10	-
	Self-paced	-	-	-	3
Negative themes	Inefficient	8	8	3	-
	Frustrating	9	5	3	-
	Unsafe	-	-	-	8
	Stressful	-	-	-	7
	Unnecessary	6	-	-	-
	High Workload	-	-	2	-

Participants generally acknowledged that CL/RB, CL/GQ and OQ played a role in safety (e.g. Participant 6 - "Repeating back is useful, as you become aware of the situation"). Some participants felt that the timed condition allowed for efficiency (e.g. Participant 39 – "The timed condition was simple and quick", although some felt the same about the other

Note. CL/RB = Checklist w/ Read Back, CL/GQ = Checklist w/ Guided Questions, OQ = Open Questions, T = Timed

conditions. The highest number of responses in a given condition was the personalization of open questioning, allowing contextual information to be relayed that the driver though to be most useful (e.g. Participant 18 - "Being able to question was good as I found out what I needed to know"). However, a few found benefits in being able to conduct the handover alone using the timed condition without being dictated to (e.g. participant 15 – “Timed made me feel confident that I could assess the situation for myself”).

Negative feedback reflected themes measured in the questionnaires. Most comments related to CL/RB and CL/GQ were concerned with the verification method rather than the information the system was providing. For example, many participants found CL/RB to be frustrating, inefficient and unnecessary (e.g. Participant 7 - “Repeating back was annoying and time consuming”), however many of these comments were also made for CL/GQ and OQ (e.g. participant 4 - “questions took too much mental toll, took a while to learn and get used to, and were most annoying”). The timed condition received no feedback regarding inefficiency or frustration, instead, participants found it stressful and largely unsafe (e.g. participant 19 – “The timed one was easy, but I felt pressure to take over quickly so I don’t always check all the info”).

4.0 Discussion

The aims of this research were to explore how vocal communication during handover can be applied to C/HAVs. Two drivers handed control between one another in a driving simulator equipped with two steering wheels and two sets of control inputs. In particular, this study explored naturalistic and emergent handover vocal communication methods (Angrosino, 2016; Eriksson, & Stanton, 2017c), and the information types transmitted during 'free-form' conditions. This study found that information transmission increased, and vocal communication methods and information transmitted differed greatly from before to after experiencing a set of pre-defined conditions inspired by shift-handover literature. Pre-defined conditions consisted of a checklist with read back (Boyd et al., 2014), a checklist with conversation-style questioning (adapted from: Bickmore, & Cassell, 2001), open questioning of current driver (adapted from: Rayo et al., 2014), and a timed handover with a countdown. Differences in vehicle control between pre-defined conditions were also found, and qualitative feedback provided insights into drivers' preferred handover protocols.

Overall, the percentage of 'free-form' handovers involving information transfer increased dramatically after experiencing the pre-defined conditions. The reasons for this change may include drawing inspiration from the pre-defined conditions, as well as learning effects. Regardless of the contributors to this change, this highlights areas for consideration, such as the use of training programmes, which reflects a current method undertaken in shift-handover (e.g. Li, Powell, & Horberry, 2012).

Grice's (1975) Maxims could provide valuable insight in how to interpret these findings. In this section, each maxim is discussed in relation to the interactions that took place, and the feedback provided by participants regarding each condition.

- Quantity – In the CL/RB and CL/GQ condition, participants found that the communication method was inefficient, thereby violating the maxim of quantity. It appears that participants did not feel as if it was necessary to verify information transfer for each individual piece of information transmitted (not overloading; concise delivery of information). For the OQ condition, participants felt that the level of personalization was a positive aspect, indicating that they prefer to dictate the amount of information provided themselves.
- Quality – It was thought that the requirement to check information visually in the CL/GQ condition would be beneficial to drivers. However, our findings do not provide any insight into whether drivers felt that the truthfulness of either condition was greater than another.
- Relation – In this study, the maxim of relation and quantity appear to be closely linked. Information deemed to exceed the optimum quantity could also be assumed to be unnecessary for the task. The procedure involved in the CL/RB conditions was deemed as unnecessary for several drivers, as well as scoring low on the acceptance/usability scales. Whereas the comments regarding the high degree of personalization offered by OQ, and the ability to ask questions that are contextual indicates that OQ addresses this maxim sufficiently. Open questioning of the current driver was the most common method observed, although this was likely to occur in conjunction with other methods. This shows that, when available, drivers naturally interact with the automated system to provide them information that they feel is necessary. These findings support the usage of a two-way interaction system, much

like that of shift-handover in other domains (e.g. Cheung et al., 2010; Patterson, & Woods, 2001).

- Manner – Subjective questionnaire ratings show that CL/RB and CL/GQ conditions may not be the preferred way of communicating with an automated syetem. Rather, participants would more likely establish whether transmission was successful following the complete delivery of information (the strategy of Monologue; Fig 4, section 3.1), or favour non-verbal exchanges (i.e. Simple Exchange; Fig 4, section 3.1). The timed condition may indeed meet the maxim of manner, as this condition may be viewed as simplistic and concise.

Differences in the information types transmitted in the two ‘free-form’ conditions could also provide insights into what information participants would like to receive from vocal communication with automation. Before taking part in the pre-defined conditions, the most common information types were speed, other road vehicles, position on road, as well as requests being made between both participants to adjust their driving behaviour prior to handover. Firstly, these findings confirm the intuitive nature of our checklist, as speed, other vehicles and lane position are featured in HazLanFueSEA, and the inspirations for its development (Walker, Stanton, Wells, & Gibson, 2010; Stanton, Walker, Young, Kazi, & Salmon, 2007). These information types remained in the top four most transmitted types after the pre-defined conditions were conducted. Drivers’ willingness to interact in this format provides further evidence towards the effectiveness of using checklists in the handover task, at least as a training tool (Riesenburg, Leitzsch, & Little, 2009; Walker, Stanton, Wells, & Gibson, 2010).

All but one information type increased after taking part in the pre-defined conditions, showing an increase in the diversity of information transmitted. Interestingly, information typically revolved around HazLanFueSEA, with additional information types including traffic/route information and weather conditions. These novel information types should be considered for future checklist design (Riesenburg, Leitzsch, & Little, 2009; Walker, Stanton, Wells, & Gibson, 2010). The least common information type from HazLanFueSEA was the action element. One interpretation of this is that moving to the left lane is implicit knowledge, and so in our scenario this would not be an information type necessarily worth transmitting but may be more relevant in other contexts.

Findings related to longitudinal behaviour post-handover show that there is no difference in velocity change as a result of handover method. Conversely, mean lateral velocity over time, following handover, seemed to be a lot higher in the CL/GQ condition. Explanations for this include the requirement for the driver to pay attention to the environment to answer questions, whereas the CL/RB, OQ and T conditions did not require the driver to actively search the driving environment. The effects of handover interactions and visual behaviour could be a consideration during future experiments.

From a design perspective, a balance should be struck between the system being usable, and the system being safe. Participants reported that the HazLanFueSEA conditions were safe due to the wealth of information being transmitted. However, drivers generally prefer open questioning due to its flexibility in providing information the driver wants to know as well as allowing the system to acknowledge that the user is engaged. This supports a handover design inspired by two-way communication (e.g. Cheung et al., 2010; Patterson, & Woods, 2001). This may have its own set-backs, as a potential issue for designers could be that OQ does not deliver need-to-know information unless asked for. Further, as 30% of handovers were that of simple exchange, to increase safety, dynamic interfaces could be used to compensate for the reduced interactions that take place in this condition. In doing so, drivers that prefer not to engage in vocal communication can receive handover assistance through another medium (e.g. Tonnis, Lange, & Klinker, 2007; Walch et al., 2015). Finally, attention should be paid towards how the system confirms the driver's SA. That is, if legal or safety concerns invoke attention in this form of handover design (de Carvalho, Benchekroun, & Gomes, 2012).

One of the key findings of this study is the diverse nature of drivers' preferences. During experiments, drivers either preferred to interact vocally in great depth or handover with limited amount of information transfer. Usage of information types were diverse with many information types being utilised by only a few drivers. To that end, the results from this study point towards the need for personalization and integrate the features that drivers find to be most useful across all conditions (see Small, Finn, & Adams, 2011; Weld et al., 2003).

There have been a number of suggestions for HMI's to provide a platform for information relay during handover, as well as providing information to the driver during automated driving, representing the approach of combined performance of driver and automation (Merat, & Lee, 2012). To our knowledge, how vocal interaction with can be integrated with visual cues in regards to handover is yet to be considered in detail. Many of these streams have been considered in isolation, for example, handover assistants (Walch et al., 2015), vocal feedback (Eriksson, & Stanton, 2017c; Stanton, & Edworthy, 1999), and haptic feedback (Petermeijer, Hornberger, Ganotis, de Winter, & K. J. Bengler, 2017). In line with Malleable Attentional Resource Theory (MART) the attentional resources of a human is finite and variable across certain tasks (Wickens, 1991; Young, & Stanton, 2002; 2004), therefore designs should be tested that combine already tested concepts in handover design so that a single effective handover protocol can be formulated and tested.

4.4 Conclusions

This study explored the use of vocal communication as a tool for handover HMI design in level three and level four vehicles (Large et al., 2017; Stanton, & Edworthy, 1999). How this technology can be applied is currently not known. This study addressed the application of vocal communication in the handover task in the context of level 3 and level 4 vehicles by conducting handovers in a range of 'free-form' and pre-defined conditions in a dual-controlled driving simulation between two human drivers.

Naturalistic and emergent themes from driver communication indicate an openness to information transfer, including the use of a checklist and interactive questioning. Due to the changing handover behaviour from before to after experiencing structured conditions, these results provide evidence for the potential effectiveness of training programmes to encourage effective vocal handover styles. Being able to ask questions of the automation was also the most utilised in free-form conditions and was rated the most usable, accepted and least mentally demanding process. If constraints allow for such designs, this approach may be fruitful in future design.

Qualitative feedback and questionnaire data indicate the requirement for further examination of SA verification methods, as well as the requirement to explore the potential for personalization suited to driver preferences. Results also indicate that HMI designs should have the capacity to provide contextual information that is tailored to the environment. However, if a system must ensure information transfer has occurred, more exploration into driver to vehicle feedback is required as participants in this study demonstrated frustration to conditions such as read-back. Overall, drivers desire an efficient, safe and usable handover assistant. The authors propose that further research should determine whether the methods and information types generated by this experiment do indeed raise SA prior to handover, and how personalization can be applied to handover HMI design.

As a result of this experiment, the following should be considered in future vocal handover assistant designs:

- A usable and efficient way to confirm information transfer so that drivers do not become frustrated with handover interactions
- The delivery of crucial and concise information, so that drivers receive the information they require without unnecessary information being received.
- A degree of personalization to facilitate individual differences/preferences.
- A way for drivers to gain up-to-date contextual information on demand.

5.0 Acknowledgements

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