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Driving a partially automated car with the hands on or off the steering wheel: users' subjective experiences

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Abstract. Which are the subjective feelings and objective risks of driving in an automatic mode when holding the steering wheel or not holding it? Two conditions of simulated driving of a partially automated car have been tested (hands-on and hands-off), in two situations of driving on highways including critical events forcing the driver to take over. The user subjective experiences were compared: the situation awareness, feelings of safety, control, attention, on-board activities, psychological and physical comfort were analyzed on the basis of in-depth interviews right after the activity. For the critical situations designed, the performance results indicate a negative impact of the hands-off condition on the takeover. The hands-off condition is appreciated for its comfort and the multi-activity it allows, but the hands-on condition is objectively and subjectively safer in critical situations.

Keywords: automated driving, take-over, subjective user experience, risk, hands-on/off, awareness, comfort

1 PROBLEM STATEMENT

Driving a partially automated car of level 2 (automatic control of trajectory and speed) can be risky in critical situations when the driver needs to take over (Morales-Alvarez & al, 2020, Zhang & al, 2019). A level 2 automation was defined by the Society of Automotive Engineers as a partial automation, i.e. a driver assistance system of both steering and acceleration/deceleration, using information about the driving environment, and expecting that the driver completes the event detection responses. Level 2 assumes an attentive driver supervising the driving adequacy. The difficulty for the driver is to maintain vigilance with a low level of stimulation and action (Molloy & Parasuraman, 1996) and this is a major issue for partially automated cars, when the driver must take over in situations that the system cannot manage.

The issue is here to know if, when driving without holding the steering wheel (Hands-off), a driver is less attentive and less reactive than a driver who is holding it (Hands-on). The Hand-off system at level 2 is currently allowed on the market in the USA and in Japan, whereas it is not allowed presently in Europe, but it could be in the future.

The objective of this study is to bring empirical results and to answer some of these questions in terms of ergonomic safety and comfort. Our research questions are:

- Which are the impacts of the hands-on versus hands-off driving on the drivers' attention?
- Is it safer when the drivers keep the hand(s) on the wheel or not? How do they react, cognitively and bodily, in a critical situation when they must take over?
- Do the drivers feel more comfortable when holding the steering wheel or not?

2 METHODOLOGY

Fifty eight persons drove a car with a level 2 of autonomy in the dynamic simulator ULTIMATE of Renault.

2.1 Population

The population (58) is on average 40 years old (from 20 to 59) and 20% are women. They are Renault employees but their jobs are varied (part of them are administrative staff) and some are not especially interested in assistance systems. They were not recruited as participants if they had a current professional activity related to the tested systems. They live in Paris or its suburb.

2.2 Conditions and critical events

Two *conditions* were tested:

(COND.1) hands-on, the drivers were asked to drive with at least one hand always on the steering wheel,

(COND.2) hands-off, the drivers were asked to drive with no hand on the steering wheel, except to take over control. A variant of this condition was added for a group with monitoring of the eyes¹.

Two *critical events* occurred during the drive, with take-over need:

(EVENT.1) There is a loss of assistance in a high-speed right turn on the highway, a silent failure. The deactivation was indicated by change on the dashboard (a symbol disappears), by a slight deceleration and a slight change in the steering wheel (less hard). The drivers must take over not to deviate their trajectory on the left.

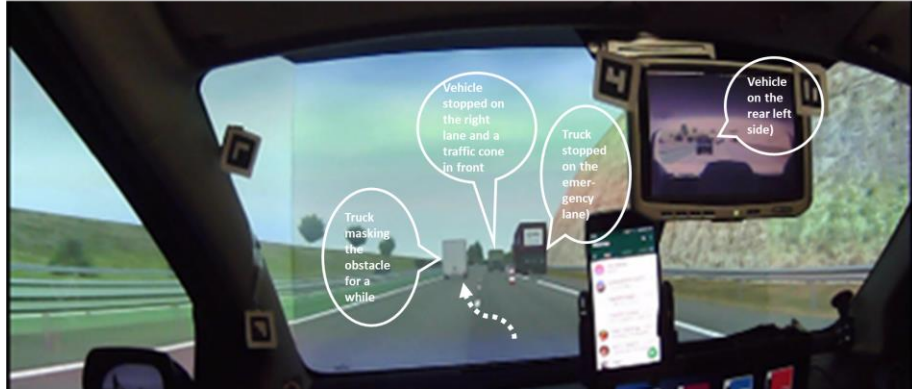
¹ The driver's gaze was monitored by an eyes tracker; if the deviation of the gaze from the driving scene exceeded 5 seconds, an audible alert was emitted to encourage the participant to look back at the road.

Fig. 1. Event 1 (EV1) Incidental loss of assistance in a high-speed turn (130 km/h)



(EVENT.2) The car is on the right lane of the highway, at 110 km/h. A truck is stopped on the low side, and a vehicle is stopped beside, on the right lane of the highway, indicated by a traffic cone; but this obstacle is hidden for a while by a truck which is driving in front of the driver, when this truck is changing lane and makes the obstacle visible, the driver has 8 seconds to react and take control. Another car is driving behind on the left lane, far enough for the driver to move to the right lane. The system cannot handle the situation and the loss of assistance (deactivation) is indicated by a change on the dashboard and an alarm.

Fig 2: Event 2 (EV2) sudden breakdown of assistance followed by an obstacle on the roadway



2.3 Experimental protocol

The temporal development of the experimentation was the following:

- Presentation of the system. It is specified that the driver is responsible of the vehicle behavior and must remain vigilant ; if any problem he/she must take over.
- Appropriation: 10mn driving on the highway and testing the automated system.
- First drive : The participants were driving during 20mn on the highway with condition 1 or 2 ; then incident-1 or 2 occurred ; right after, they stopped the drive, were getting out of the car and were interviewed about what happened during the event, and then during the whole drive. The interview lasted 20 to 45mn.
- Second drive : The participants were driving during 20mn on the highway with the other condition ; then the other incident occurred ; they stopped the drive and were interviewed about what happened during the event, and then during the whole drive. The interview lasted 20 to 45mn.

The order of the incidents and of the conditions varied.

2.4 Interviews

The interviews were based on Vermersch's Explication (or elicitation) Interview technic² to gather the drivers' phenomenological experiences during the drive (Vermersch 1994, Cahour & al 2016). Firstly the driver described what happened at the end of the drive. The Explication Interview is used to help the drivers describe precisely their subjective experience during the events which lasted less than one minute. The instruction was: *"In relation to the incident that has just taken place, can you describe what happened to you, what you perceived, thought, did, felt, during those few seconds just before and after the incident, what comes back to you spontaneously;*

² 25% are in-depth explication interviews lasting 30 to 45minutes, the others are a bit shorter but inspired by the technics of this interview.

then we'll go back chronologically to what happened". Non-inductive questions were used afterwards, following the chronology of the experience, to clarify : actions, awareness of the situation, sensorial perceptions such as gazes, perceived sounds, body movements and gestures, emotions, and thoughts such as hesitations, hypotheses, evaluations. This part of the interview is focused on a very specific moment of a few seconds.

Once the critical event had been described, the more general experience during the driving session was explored, the global impressions, sensations, mental states experienced during the 20mn of drive before the critical event. At the end of the interview, the driver was asked which condition he preferred, Hands-on or Hands-off.

2.5 Analysis of the verbal and behavioral data

The *interviews* were transcribed and analyzed: the verbal protocol of each participant was analyzed in two steps: (1) firstly an analysis of the description of the critical event, its temporal development and the cognitive, emotional and bodily processes during the few seconds of identification of the problem and reaction. (2) Secondly the first and "normal" part of the drive has been analyzed with the following thematic categories: control and security, attention and vigilance, bodily sensations, preferences, others.

The *measures of the observable behaviors* are : (cf Forzy & al, 2021, for more details)

- For Event-1, the lateral offsets trajectories,
- For Event-2, the delay before the lane change and the acceleration.

The conditions were compared using statistical tests (analysis of variance, Chi-squared).

3 RESULTS

During the incidents, the users lived experiences gathered with the interviews indicate several interesting elements about the situation awareness, the reconnection process, the roles representations, the deactivation perceptions and prereflective adjustments, the global feelings and sensations with hands-on or hands-off, and the global preferences.

In a second step, we will develop the main results of the objective measurements comparing the different conditions.

3.1 The users' subjective experience

Situation awareness and bodily/cognitive reconnection. Drivers may be so deeply immersed in their on-board activities (reading, writing,...) that they have no awareness at all of the road situation, and then feel totally surprised when an incident occurs. Hands-on, 23% of the participants said they were not aware of the traffic around at the time of the event. Hands-off, 39% of the participants were not aware of the traffic; the difference does not appear significant ($p=0.15$).

7 EV2 ON (Participant 7, Event 2, ON condition): I had almost forgotten that I was on a two lane road. I didn't know if there were any cars next to me, or on the other side.
 36 EV1 OFF: I had no awareness of the vehicles around me.

When they become aware of the deactivation, they need to reconnect cognitively and bodily for acting. Two drivers describe how they firstly recovered the awareness of their need of action on the steering wheel and in a second step, the awareness of their need of action on the brake pedal.

36 EV1 OFF : It took me a bit of time for my brain to reconnect and say: you're in a car, you have to put your hands back on the steering wheel, your foot on the accelerator.... I had no awareness of the vehicles around me... I wasn't thinking about the pedals at all, just the steering wheel. Which is very strange, one forgets that there were pedals to manage... when I get back to the driving situation, I first get the steering wheel and then the pedals.

Doubts about the roles distribution. Despite the instructions, several drivers have doubts about the roles distribution and feel firstly uncertain and perplex (Boelhrouwer & al, 2019).

30 EV2 Off : is the vehicle going to change by itself or brake by itself? Finally, I hesitated to... I asked myself questions: what should I do? Should I take over or was the vehicle going to do something?

7 EV2 ON : It beeped and in my head I thought everything was automatically managed. So I didn't pay any attention to what was happening in front of me. I told myself that he was warning me that there was certainly a problem, I felt that he was slowing down, that he was doing something. I thought : it's good, he's slowing down because there's an obstacle ahead...

A particularly interesting phenomenon is the link established between the hands on/off position and the distribution of roles between the driver and the vehicle. Many participants tell us that when they were Hands-off, they thought the system would manage alone; whereas when they had their hands on the wheel, they thought they had to manage themselves. So they associate bodily position and role: if I have my hands on the wheel, I am still a driver, otherwise I am like a passenger. The passenger is the one who can do something else while the other controls the driving. Having the steering wheel in one's hands therefore induces a higher responsibility, an actor's position as usual in driving, whereas the hands-off position induces a passive role, one of non-responsible and non-intervening person.

Perceptions of the system deactivation. Once they have perceived cues indicating the system deactivation, they have partially reconnected cognitively. These sensorial cues are:

- *Visual* cues of the screen and road

4 EV2 OFF : I saw that there was the green light for autonomous driving on the dashboard which was no longer displayed ... I thought it's something not normal, it's up to me to avoid the obstacle.

33 EV1 OFF : it was in a bend, and as I always had my eyes on the road a little bit, I could see that at some point I was no longer between my lines
 - *Auditory* alarm, in event 2 (obstacle): 52% did not perceive it, and some misinterpreted it (cf §3.1.2 ex.7.1)

- *Kinesthetic* cues such as deceleration, deviation, and steering wheel movements.

36 EV1 OFF : There's really a different feeling between "the vehicle is managing the exit of the corner" and "the vehicle is not managing the exit of the corner". I felt the difference and that's what alerted me. It's a bit like climbing, you're held by a rope and all of a sudden, for a microsecond, you're in free fall. A sort of free fall effect. First of all, there was a loss of acceleration, because there is a speed maintenance when you are in autonomous driving, and on top of that, the trajectory. So it's a rather brutal double effect, where you have a loss of speed and a trajectory that varies quite rapidly. It's a somewhat brutal movement in relation to driving, which is very smooth in autonomous driving with trajectories that are quite linear. There, it makes a small break.

Holding the steering wheel allows pre-reflected adjustments. For incident-1 (curve), drivers are often unaware of the deactivation at the beginning. In the hands-on condition 38% are not aware of the deactivation but adjust the trajectory in a pre-reflected way, not being reflectively conscious of these adjustments by the hands. Of course these adjustments are not possible when they do not hold the steering wheel. The following participant was clearly not aware of the deactivation but he adjusted the trajectory.

37 EV1 ON : Interviewer : - you have never had to take over at any time?. Participant: - It was imperceptible if it was the case.

On-board activities and vigilance. Drivers' verbalisations often go in the following direction: 'I do more on-board activities Hands-off than Hands-on, or activities that are more absorbing and that I don't usually do while driving'. No verbatim goes the other way (I do more activities Hands-on than Hands-off).

When Hands-off, drivers say they allow themselves activities they do not usually do, such as reading a full article, looking at the landscape in detail (a hot air balloon), looking at the back seat as if there were their grandchildren.

1 EV2 OFF : I was really absorbed in the radio, feeling like I was in passenger mode, being able to do something else.

45 EV2 OFF : I played a bit with my phone in the first test (OFF). I didn't feel I could do it in the second (ON).

Some mistrustful drivers who avoid on-board activities feel more bored or drowsy with Hands-off.

Different feelings hands-on and -off : attention, control, responsibility, risk.

- *Hands-on*, 77% say spontaneously that they feel safer, more in control and more attentive, like a responsible actor, but some talk of an unsatisfying "hybrid solution".

11 ON : I felt more attentive and I felt more in control with hands-on

09 ON : you feel like you're still on the road, more ready to react, whereas in Off mode you don't care about driving.

06 ON : Holding the steering wheel limits what else you want to do, it's not very pleasant, it's not really comfortable; you're not completely at ease with driving and you're not completely at ease with what you're doing; it's a hybrid solution, a bit bastard; you're tempted to do something else but you can't really do it; you react faster but you're not as free.

- *Hands-off* they feel more relaxed, freer and more comfortable, also more passive, less attentive and less responsible, like a passenger. 36% of the participants spontaneously said they felt less in control and less attentive with Hands-off than with Hands-on; some even felt "completely out of control (off the hook ; “décrochés” in French).

04 OFF : More relaxed because you don't have hands. We tell ourselves that a priori we don't have to intervene at all. We are freer to do something else

01 OFF : my attention was a bit lower (in OFF); since I let myself be driven, I feel like I'm in passenger mode so I can do something else

24 OFF : On the negative side, I would tend to be more distracted, which certainly requires, in terms of risk, more reaction time.

To keep control, with hands on or off, drivers remain sensitive to the vehicle's movements (trajectories, decelerations and accelerations), or even, when Hands-on, they try to turn the steering wheel instead of the car.

Physical sensations. Hands-on, the physical sensations of the steering wheel moving in the hands may be unpleasant, with muscular tension in the hands to hold it.

22 ON : Depending on the density with which you hold the steering wheel, you will feel its reactions for lane correction more strongly. One tends to create constraints on the steering wheel without realizing it, so that the system reacts in opposition to possibly correct.. it is not particularly pleasant, this feeling of constraint, in opposition, is a little annoying. Sometimes I've had a lighter hand, barely able to hold the steering wheel, you don't stay there very long. It's true that you tend to get lost in it and to take the wheel in a varied manner.

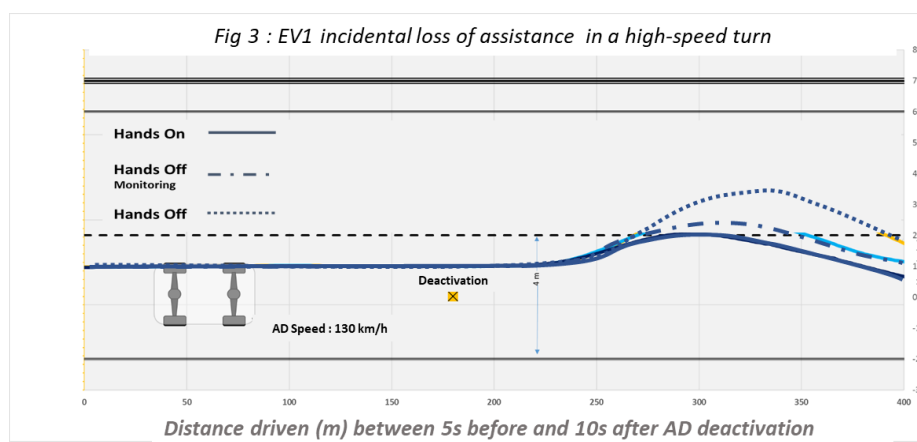
Even if hands-off is more comfortable, some drivers do not know how to position their legs and arms and would like the car to be better designed for this new situation.

Global preferences. In terms of global preferences, 51% of our drivers prefer the hands-off driving, 35% prefer the hands-on driving and 14% neither. It should be pointed out that this evaluation is given after 2x20 minutes of drive in a simulator, maybe it would change over time and in a real driving environment.

3.2 Observable measures: the objective risk

In this article we focused on the subjective experience results obtained with the interviews, but we also obtained results from observable measures. We summarize the results of the observable conducts, and refer to Forzy & al (2021) for a more complete description.

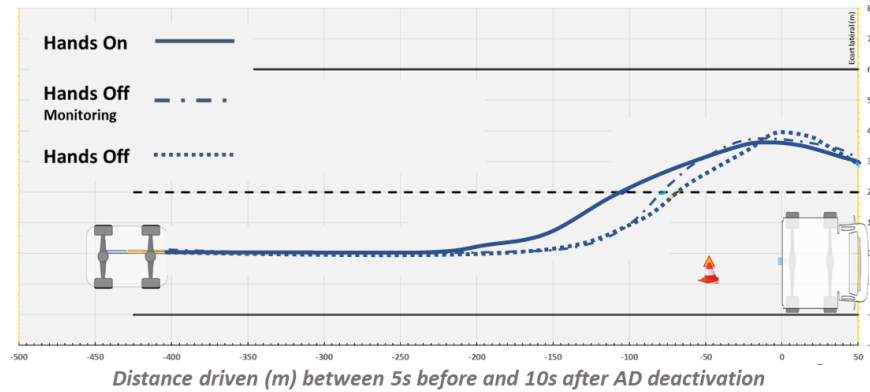
For Event-1 (loss of assistance in a curve) we found a significantly negative impact of the Hands-off condition on the trajectories deviations, compared to hands-on. The drivers produce a significantly larger deviation on the left lane when they do not hold the steering wheel than when they hold it. A gaze monitoring system³, with an alarm when the driver in hands-off condition does not look at the road during more than 5 seconds, does not compensate totally this negative effect but it limits the more distractive behaviors (cf means fig.3).



For incident-2 (obstacle) we observe a significantly longer delay of reaction to avoid the obstacle in the Hands-off condition and significantly more accidents or near accident (cf means fig.4).

³ cf Forzy & al 2021.

Fig 4 : EV2 sudden breakdown of assistance followed by an obstacle on the roadway



We can then conclude that the objective risk is higher when the drivers do not hold the steering wheel than when they hold it and that the eyes monitoring compensates slightly this effect.

4 DISCUSSION

This study shows the richness of the complementarity of objective measures and of the users' verbalizations about their subjective experience of the driving situations (Gustavson & al 2018), to understand how they interpret, feel, and perceive the environment. Beyond the differences in take-over performance, the Elicitation Interviews indicate the gains from holding the steering wheel (Hands-on), mainly: (a) Hands-on driving allows the perception of kinesthetic feedback on the state of the system. This feedback enables the deactivation situation to be interpreted more rapidly. (b) It can enable adjustments to be made to the trajectory in a prereflective manner (EV1). (c) It also encourages the subject to stay attentive and to feel responsible.

The Hands-off condition may be preferred for its comfort, feeling of relaxation and the multi-activity it allows "as if they are a passenger", but the objective and subjective risk in the Hands-on condition is lower in the critical situations of automation deactivation that we studied.

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