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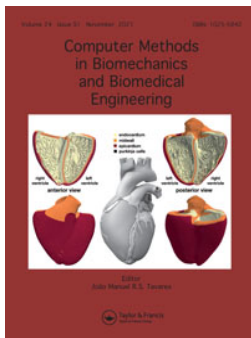
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A preliminary movement analysis to understand the take over control action for an autonomous vehicle

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1. Introduction

With recent advances in vehicle automation, the control system can take partial or total control of the vehicle. From the Level 3 of automation, the driver can engage in a non-driving related task (NDRT) like relaxing, playing, etc. However, because of the limitations of the system, there are situations wherein automated driving is not possible and drivers have to take-over control of vehicle. It is therefore important to understand the take-over process for a safe transition. Many psychological and ergonomic studies investigated the behaviour of drivers and showed that factors such as NDRT distraction (Bueno et al. 2016) or posture (Yang et al. 2018) could affect take-over performance. However, these studies did not consider the biomechanical aspects of the take-over action (e.g. muscle activation). The present work is a pilot study aiming at setting up an experimental protocol for a detailed movement analysis including a temporal and spatial analysis of the end effectors (hands, feet and eyes) and the analysis of muscular activity.

2. Methods

2.1. Participants

Two male volunteers (ages: 24 and 25 years; heights: 178 and 188 cm), participated in this pilot study. Both were experienced drivers. The experimental protocol was approved by Université Gustave Eiffel Committee for research involving human subjects (CRPH).

2.2. Experimental apparatus

The driving simulator (Figure 1) was composed of a steering wheel, three pedals, three mirrors, a control panel as well as 5 screens positioned in a semicircle. The vehicle automation was simulated by the V-HCD software environment (Bellet et al. 2019). Electromyography (EMG) electrodes were placed on the deltoid and brachioradialis muscles of the right arm to detect the onset of steering wheel reaching and the rectus femoris and



Figure 1. Experimental setup.

tibialis anterior of the right leg to detect the onset of emergency braking. An eye-tracking system (Pupil Labs) was used to track participant's gaze behaviour. All driver related measurements (Driving simulator, EMG, Eye-tracking) were synchronized with those from the simulator under the RTMaps software environment. The raw EMG signal was rectified by taking these absolute values, bandpass filtered to remove noise and a low-pass filter was applied to obtain a linear envelope.

2.3. Experimental conditions and procedure

The driving scenario took place on a two-lane highway with a cruising speed of 90 km/h. A critical situation occurred at the end: while the participant's vehicle was in the left lane, a traffic jam occurred; he/she had to avoid a car in front while a car in front on the right prevented from changing lane. The time available to take-over control (Time Budget = 4.3s) was short to simulate an emergency.

Inspired from previous studies (Gold et al. 2013), take-over performance was mainly characterised by temporal parameters in the present study: (1) Take-Over Time (T_{TOT}), duration between the Take-Over Request (TOR) and the participant's reaction on the vehicle commands (e.g. the depression of the brake pedal, or the rotation of the steering wheel), (2) Time of the muscle activation detected by EMG (T_{EMG}) with respect to TOR, (3) Time when the eyes were on the road (T_{EOR}) w.r.t. TOR.

Participants were familiarised with the driving simulator through a trial drive in manual mode and then in automated mode including a Take-Over Request (TOR). Then they performed the driving situation of interest. While in autonomous mode, the participants were instructed to perform a NDRT on a touch-sensitive tablet placed on the dashboard to the right of the steering wheel. They were alerted by an audible alarm that they needed to manage the critical situation.

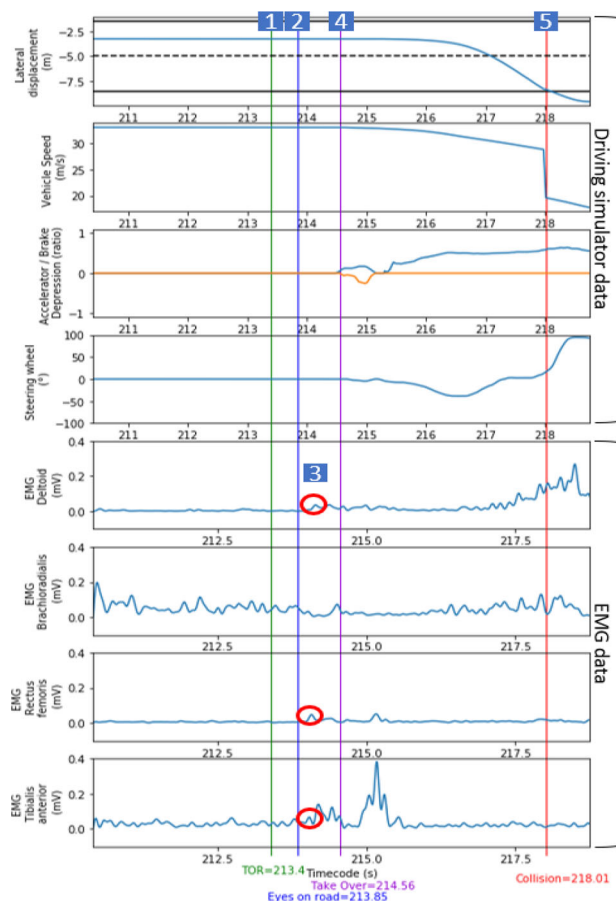


Figure 2. Activity analysis of one trial –3rd signal: Brake Pedal Application Ratio (0 to 1) and Accelerator Pedal Application Ratio (0 to –1) – 4th signal: Steering wheel rotation (–450°: full right turn, +450°: full left turn).

3. Results and discussion

Figure 2 shows signals recorded during a take-over action, 3 seconds before the TOR and 1 second after the collision with five key moments labelled 1 to 5.

At 213.4s (TOR, M1), while the vehicle was automatically driving in the left lane and the participant was distracted by the NDRT, the participant was asked to take control of the vehicle by the alarm. After a duration $T_{EOR}=0.45s$ (M2), his eyes moved out of the NDRT onto the road as detected by the eye-tracking system. Then the participant activated his arm and leg muscles at the same time ($T_{EMG}=0.8s$, M3). The Take-Over Time ($T_{TOT}=1.16s$) was detected simultaneously by the brake and accelerator pedals application (M4). Shortly after, the participant turned the wheel to change lanes and avoid the obstacle. Finally, the participant intended to turn into the emergency lane but collided with a vehicle 4.61 seconds after the TOR (M5).

The EMG on the forearm provided muscle activation when the participant was performing an NDRT

on a touch pad. The activation of the deltoid muscle may indicate arm motion away from the central tablet. The EMG on the tibialis anterior gave an indication of when the foot was lifted to move towards the brake pedal (and accelerator in this case). An EMG electrode would be useful on the gastrocnemius muscle to obtain additional information when depressing the pedal. The motion analysis of the end effectors, associated with gaze behaviour, will allow us to understand the spatial and temporal organisation of driver's actions.

4. Conclusion

This work allowed the development of an experimental protocol for a detailed analysis of the movement during take-over action. Preliminary results showed how a driver behaved in an emergency. Due to a very short Time Budget, the accident could not be avoided. The next step will be to investigate the take-over process under different conditions by varying the level of engagement in driving, NDRT distraction and driver's posture. Furthermore, in the event of an accident, obtaining the driver's posture will allow the analysis of injury risks.

Disclosure statement

No potential conflict of interest was reported by the authors.

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KEYWORDS Automated driving; take-over; reaction times; muscular activity; movement analysis

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