The impact of Non-Driving Related Tasks on Take-over Performance in Conditionally Automated Driving – A Review of the Empirical Evidence

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***Abstract*—Conditional automated driving (CAD) systems (SAE level 3) will soon be introduced to the public market. This automation level is designed to take care of all aspects of the dynamic driving task in specific application areas and does not require the driver to continuously monitor the system performance. However, in contrast to higher levels of automation the "fallback-ready" user always has to be able to regain control if requested by the system. As CAD allows the driver to engage in non-driving-related tasks (NDRTs) past human factors research has looked at their effects on take-over time and quality especially in short-term take-over situations. In order to understand how take-over performance is impacted by different NDRTs, this paper summarizes and compares available results according to the NDRT's impact on the sensoric, motoric and cognitive transition. In addition, aspects of arousal and motivation are considered. Due to the heterogeneity of the empirical work and the available data practically relevant effects can only be attested for NDRTs that cause severe discrepancies between the current driver state and the requirements of the take-over task, such as sensoric and motoric unavailability. The paper concludes by discussing methodological issues and recommending the development of standardized methods for the future.**

Keywords*— Conditional Automated Driving, Non-Driving Related Tasks, take-over performance, take-over time, driver state transition

I. Introduction

Various forms of automated driving already are or will be introduced to the consumer market within the next decade. Several vehicle manufacturers (e.g. Tesla, Mercedes-Benz and BMW) and technology companies such as Alphabet or Apple are working on different types and levels of driving automation systems. Following the taxonomy of the SAE [1], in level 2 systems the drivers are required to continuously monitor the traffic environment and the automated driving system for instant intervention in case of system malfunctions or system limits. Level 3 systems allow drivers to engage in NDRTs but hereby require the driver to intervene when being requested. Only SAE level 4 and 5 systems are designed to not require the driver as a fallback option. It is also possible that hybrid systems will vary in their degree of automation according to their operational design domain or road conditions, for example, requiring the driver to monitor in urban regions but not on highways.

As long as a human driver is still needed to intervene occasionally (level 3) or to monitor permanently (level 2), he or she will still play a crucial role to ensure the safety of those automated driving functions. Control transitions from automated to manual driving have thus attracted great research interest. Many empirical studies (see [2] for a recent review) focused on time and quality aspects of the take-over performance following a request to intervene (RtI). Since many results point towards critical safety issues the development of driving automation systems should therefore take into account the limitations of human performance to ensure controllability and thereby road safety especially at control transitions.

Different influencing factors on the drivers' take-over performance in CAD were already examined, e.g. looking at the influence of the traffic environment [3] or drivers' trust in automation [4] on take-over performance. The biggest change from SAE level 2 to SAE level 3, however, is that drivers can now engage in NDRTs.

It can be assumed that in automated driving the human driver will not be continuously monitoring the driving environment or the system performance [5] but rather engage in NDRTs. The duration of the conditionally automated driving period as well as the engagement in NDRTs will affect the state of the driver [6]. In the event of a take-over situation, a task switch, the so-called *driver state transition process*, from the NDRT towards the driving task must be accomplished [7]. During the driver state transition process the driver is expected to achieve a target state which enables the driver to successfully handle the take-over situation.

The driver availability model [6] distinguishes between different drivers' state aspects relevant for the transition process:

- the sensory state transition describes what the driver can currently perceive with his sensory systems and the kind of information that is required in a specific take-over situation (e.g. direction of view, acoustic receptivity).

- the motoric state transition describes the drivers' posture (sitting upright facing the road, or having a twisted body position) or the availability of the drivers' hands (one or two hands occupied) with respect to the required driver action.

- the cognitive state transition relates to the drivers' reconfiguration of mental task sets or response rules [8]. NDRTs may be cognitively demanding and maintenance of sufficient situation awareness may be limited - especially for demanding take-over environments.

- Arousal and motivational factors: the transition processes may be modulated by passive task related fatigue ([9]; [10] & [11]) or by motivational factors, such as a reduced willingness to instantly interrupt the NDRT.

II. Overview of Studies Examining the Influence of NDRTs on Take-Over Performance in Conditional Automated Driving

This chapter aims to summarize the results of published studies about the influence of different NDRTs on take-over performance. Following the theoretical concept of driver availability [6] NDRTs are considered to specifically influence aspects of the current driver state and the required transition process on various levels.

The literature review includes studies that investigate at least one NDRT versus a control condition and compare take-over performance by statistical measures. This analysis can either use timing aspects (e.g. reaction time between RtI and significant driver intervention) or quality aspects of the drivers' input (e.g. maximum accelerations or minimal time-to-collision) [12]. Participants in the control condition should either be instructed to not perform any NDRT, supervise the system or to drive manually whereas participants of a NDRT condition had to deal with a specific NDRT for the entire ride until the take-over occurred. It has to be mentioned that reported reaction times between the different experiments may not be directly comparable due to different test environments (e.g. driving simulator experiments or on-road experiments), different reported reaction times (e.g. hands-on time vs. steering intervention time, gaze-reaction times) and different statistical parameters describing the distribution of individual response times (e.g. median vs. average values). Also simplified designs of the automated driving systems are often implemented for human factors research which do not allow to directly transfer human performance results to series production systems.

Finally, the design of the respective take-over scenario plays a crucial role for the take-over process and measurable performance parameters. According to [13] take-over scenarios can be described in different dimensions like urgency (available time-budget for the drivers' intervention), predictability (lead time for the intervention), criticality (possible amount of damage) and the complexity of the required driver intervention (depending on required drivers' intervention and the traffic environment).

A. *NDRTs affecting the sensory transition*

In order to trigger the driver state transition the user must first be able to notice the RtI signal and get an initial image of the driving situation. For example, in an experiment it could be shown that unimodal visual RtIs may not be detected reliably by users especially when distracted by another visual task [14]. The results indicate that late detection performance led to a dramatic shift in the 95% percentile of reaction times (5.6 vs 20.1 s). Similar effects may occur if acoustic warnings are not detected by users, e.g. by wearing headphones. Although this "sensory unavailability" has not been looked at in empirical studies, the associated problem seems obvious. Therefore, a unimodal RtI that only addresses the auditory, visual or haptic sensory channel should not be used, whereas a redundant, multi-modal warning signal is recommended [14].

Concerning the impact of visual distraction on take-over performance, several studies have been conducted:

Marberger compared a visual manual task (playing Tetris on an installed tablet) with the task of listening to an audiobook. They found significant delays (on average 2 s) with respect to a 'first gaze on road' measure in uncritical take-over situations. However, concerning later steps in the transition process like touching the steering wheel or deactivating the automation feature no significant differences were found between the conditions [15].

The authors of another experiment investigated the impact of several visually demanding NDRTs presented in the vehicle's center display and also implemented a baseline without a task. No significant effects on time-based metrics (eyes on road, hands on steering wheel, system deactivation) were found. However, take-over quality regarding lateral control was impaired for a video and news reading task compared to a control group without a task [16].

Also Gold addressed this issue. He concluded that the SuRT task caused increased response times and lower minimal TTCs compared to a 2-Back task condition. In his doctoral thesis he modeled different take-over performance measures based on data of a series of driving simulator studies [3]. Among others, visual distraction and the NDRT were used as predictors of the take-over performance. Visual distraction did not show a significant influence in any of the models and therefore seemed to have a minor influence compared to the other predictors [17].

Petermann-Stock compared take-over times in transition situations of rather low urgency when dealing with a visual demanding quiz-task vs. a comparable auditory quiz-task. Participants who had to read the questions before answering them (=visual demanding) needed a longer period of time for taking-over. However, the difference did not reach statistical significance [18].

A similar tendency was also found by Wandtner. Descriptively inspected, NDRTs with a visual component were associated with delayed take-over times compared to an auditory task and a baseline. This difference was particularly pronounced when encountering a highly critical take-over situation for the first time (broken down car with TTC = 6 s), where situation assessment might have been most challenging for the drivers [19].

In summary, NDRTs that demand visual resources can cause impaired take-over performance. Metrics related to the quality of the drivers' intervention seem to be more affected than measures of reaction times. Since some studies did not find any significant effects of visual distraction this particular sensory state seems to contribute rather little to the prediction of take-over performance. Visual attention towards central displays installed close to the vehicle's windshield seem to allow fast gaze switches between the NDRT and the road environment maintaining the drivers' awareness of the traffic surroundings on a high level. Such devices can be considered favorable for carrying out NDRTs during CAD.

B. *NDRTs affecting the motoric transition*

NDRTs that affect the physical availability and hence the motoric transition were examined in driving simulator studies as well as in on-road experiments. The here reported studies cover three types of motoric impairment caused by the NDRT: unfavorable body posture (turning away of the entire body), occupation of the drivers' hands by an object, or tasks that require manual interaction but do not permanently occupy the drivers' hands.

1) *Unfavorable body posture*

In a study reported by Marberger and colleagues, participants experienced CAD on-road in a real car by means of a Wizard-of-Oz approach. The test participants had to deal with different NDRTs while being driven by a "highway pilot". One of these tasks was a visually and manually demanding search task (finding a predefined shape in a closed bag placed on the backseat). When requested to take-over vehicle control, most participants had to get into an adequate driving position first, before resuming control of the vehicle. Results clearly show that take-over times were significantly higher due to this particular motoric transition. The mean take-over time resulted in M = 5.1 s compared to a mean of around M = 3-3.6 s in conditions where subjects did not turn their body backwards [15].

It can be assumed that an inadequate body posture extends the time demand for a safe control transition, however, the number of studies that examined exactly this factor is too low to make a general statement.

2) *Manual interaction with hand-held devices*

In a study conducted by Zeeb, participants either had to read a scientific article on an installed tablet or on a hand-held device. A significant increase in reaction times for the hand-held condition was reported (M = 2.8 s vs. M = 2.25 s for a take-over situation requiring a lateral maneuver and M = 3.1 s vs. M = 2.9 s for a take-over situation requiring a brake maneuver) as well as deteriorating effects of high manual load on the quality of lateral vehicle control [20].

Marberger examined the effects of playing Tetris on a mounted touchscreen compared to reading a hand-held print magazine (standard size) in non-critical traffic scenarios on real roads. Results suggest that a hand-held task delays the deactivation of the automated system significantly (M = 5.0 s in the reading-task group compared to M = 3.5 s in the Tetris-task group) [15]. The assumption for this is that both tasks have a similar cognitive demand and that the difference can be attributed to occupancy of the hands.

Similarly, Eriksson & Stanton looked at the distribution of control transition times in non-critical driving (simulator) scenarios and compared the effects of a reading task (requiring holding a printed magazine) with a reference condition (no NDRT). They report a significant shift of median values from M = 4.6 s to M = 6.1 s due to the additional visual-manual task [2].

In a study reported by Wandtner, stimulus and response modalities of a NDRT were systematically manipulated while keeping the task itself as constant as possible. For a highly critical take-over scenario (broken down car on ego-lane requiring a braking maneuver), a visual-manual texting task resulted in impaired take-over performance, in particular when the task was performed on a hand-held tablet computer. Hands-on times for the hand-held NDRT were significantly longer compared to the same task performed on a mounted device (texting on hand-held device: M = 1.78 s vs. texting on mounted device: M = 1.33 s). However, the increase in the overall take-over time did not reach statistical significance. Furthermore, quality aspects of the take-over reaction were shown to be deteriorated in the hand-held condition [19].

In another driving simulator study, the authors compared different NDRTs in a well-trained take-over scenario that required a lane-change within a time-budget of approx. 8 s [17]. Among other tasks, a manual-task (dealing with a shape-sorter ball stored in a bag) was performed by the test participants. When requested to intervene the hands had to first be pulled out of the bag for the steering maneuver. As a result, take-over times were delayed by approximately 0.7 s compared to a cognitive task and a baseline condition. The effects of manual load on take-over time disappeared when the drivers had to stop in front of a broken vehicle instead of conducting a lane-change. In accordance to the reviewed studies, also Diederichs [21] reported delayed reaction times for participants engaging in hand-held NDRTs.

Overall, results suggest that timing aspects of the take-over reaction may be affected by hand-held NDRTs compared to mounted NDRTs. The effect of impaired reaction times seems to be larger in take-over situations with lower urgency. Furthermore, it seems that hand-held NDRTs especially increase hands-on or steering intervention times and do not necessarily affect the first brake reaction time. This may be due to the fact that non-occupied hands are especially important for interventions at the steering wheel, whereas the brake reaction is not directly affected by a hand-held device.

3) *Manual interaction with installed devices*

This section focusses on manual tasks with installed devices (e.g. OEM equipped touchscreens or mobile devices mounted on the center stack) in a vehicle or driving simulator. Since the drivers' hands are not occupied by something that has to be put away before taking over this is expected to be generally advantageous for the take-over performance.

In an experiment carried out by Petermann-Stock participants had to deal with a quiz game [18]. The authors manipulated the demand induced by the game. In the "low demand" setting, only cognitive and auditory resources were addressed whereas in the "high demand" setting additional visual and motoric resources had to be used. In the "high demand" group participants needed on average 1.3 s longer for the take-over compared to the "low demand". The take-over scenario was characterized by rather low criticality and urgency.

In an experiment conducted by Diederichs, a vehicle-integrated reading task (presented in the instrument cluster, scrolling via steering wheel buttons) was compared with a baseline of supervised automation and found a non-significant increase of $M = 0.1$ s in take-over time [21].

Also Zeeb conducted research in this area. She found no difference in take-over time for an e-mail writing task (performed on an installed touch screen in the center console) compared to a control group without any task. There were also no differences in terms of take-over quality [16].

The findings indicate that visual-manual interactions with installed devices may increase take-over time. However, the results are heterogeneous and effects rather small. Compared to the other motoric factors "unfavorable body posture" and "manual interaction with hand-held devices" manual interaction with (reasonably) installed devices does not seem to be a significant critical factor for predicting take-over performance.

C. NDRTs affecting the cognitive transition

In order to successfully take-over vehicle control also the cognitive transition needs to be taken into account. The cognitive processes in a take-over situation may include the generation of sufficient situation awareness as well as sub-processes for action planning and preparation. Therefore, NDRTs that fully capture the humans' cognitive resources are considered to deteriorate take-over performance. A number of studies looked at the impact of cognitive demand caused through task difficulty.

Gold analyzed the effects of a verbal 20 question task in comparison to a no task condition. Participants had to take over vehicle control in situations with different complexity (traffic density was varied between the situations) and a time-budget of 7 s. The assessment of the horizontal gaze dispersion showed clear evidence of the increased cognitive demand of the 20 question task. Nevertheless, there were no significant effects on timing and quality measures [3].

In contrast, in another experiment, the authors found faster brake reactions in a critical take-over situation when participants were engaged in a phone call compared to a baseline group with no NDRT. The observed reaction times are not described in detail but merely presented as a graphic in their report. Therefore, the mean values are not mentioned in this review [22].

In another experiment conducted by Gold a visual-manual (SuRT) and a demanding auditory-cognitive (2-back-task) task were analyzed. On average, the visual demanding task lead to significant higher reaction times (approx. 0.5 s) compared to the auditory demanding task [17].

In another study, two versions of a visual-manual (hand-held) task were implemented (low vs. high workload) and compared to a low demanding auditory baseline task. In the visual-manual task with low cognitive load specific sentences had to be simply transcribed, using the virtual keyboard of a tablet computer. By contrast, in the version "high cognitive load" the words of the sentences had to be alphabetized by the drivers (e.g. "drive" → "deirv") which induces increased cognitive workload [24]. There was a marginally significant effect for take-over time. Descriptively inspected, the slowest response was found for the cognitive demanding visual-manual task, followed by the low demanding visual-manual task. The results were obtained for a critical take-over situation (broken down car on ego-lane requiring a braking maneuver), regardless of time-budget (6 vs. 8 s) [23].

Radlmayr compared the cognitively demanding 2-Back task and a visually demanding SuRT to a baseline condition for several critical take-over scenarios in a driving simulator study. With respect to take-over time no significant differences were found between the NDRT conditions. Although the frequency of collisions was higher in the SuRT condition the authors conclude that a cognitively demanding NDRT can have similar deteriorating effects on take-over performance compared with mainly visual-manual tasks [25].

Across all reviewed studies, the effect of cognitive workload on take-over performance are not homogeneous. Depending on the circumstances of the individual studies cognitively loading NDRTs may either capture the drivers' attention and hence hinder the build-up of situation awareness or they may increase the general alertness of the user and hence facilitate quick response after a RtI.

D. NDRTs affecting the arousal level of the driver

Due to the changed role of the driver from an active driver to a fallback-ready operator conditionally automated driving may lead to monotony and insufficient arousal levels of the drivers. Experts expect that, although active driving related fatigue may be reduced, passive task related fatigue may be increased by vehicle automation [9]; [10]. In studies that focused on the energetic state of the driver, NDRTs were used to either induce fatigue or to prevent drivers from fatigue.

In a study conducted by Jarosch the impact of different levels of activation on take-over performance was examined for a critical take-over situation in a dynamic driving simulator [26]. Either an activating quiz-task or a fatiguing monotonous monitoring task was used to manipulate the energetic state of the participants. After a CAD period of 25 minutes no effects of drivers' activation could be found on take-over times or on parameters concerning the drivers' input. In a second experiment the same tasks were used to affect the drivers' state. In this experiment the time of the uninterrupted (e.g. by TOR´s) automated driving period (and hence the time to engage in the both tasks) was increased to 50 minutes. Results show that drivers who had to accomplish the monotonous monitoring task showed poorer reaction times after the RtI. The eyes-on road time was delayed by 0.33 s ($M = 1.18$ s in the monotonous task condition vs. $M = 0.85$ s in the activating task condition) and the first braking reaction was delayed by 0.62 s ($M = 2.33$ s vs. $M = 1.71$ s). Participants from this group were also more likely to collide with the obstacle ($n = 4$ in the monotonous task condition vs. $n = 2$ in the activating task condition) [27].

Schömig examined effects of an activating quiz task vs. a no task condition vs. a manually driving condition. The automation period and the quiz task engagement lasted for 15 minutes. Results showed that in the no task and in the manual driving condition the drowsiness level clearly increased during automated driving. For participants that experienced the quiz task, drowsiness stayed on a low level and remained constant during the test phase. Although no effect of the experimental condition was found on the take-over quality, the results nevertheless implicate that an interesting and motivating secondary task has the potential to keep the drivers' alertness on a (desired) high level [28].

E. Motivational Aspects of NDRTs

NDRTs that strongly motivate the driver to stay engaged may cause drivers to delay a required response to a RtI. There are a few studies that looked into this hypothesis.

In a study by Wandtner, participants performed system-paced texting tasks on a mounted tablet during CAD. In order to induce conditions of high motivation, a monetary incentive for every finished task was used. Take-over situations (sharp bend with a time-budget of 8 s) occurred when drivers were right before the end of the task and only few more characters had to be entered to complete it. Drivers showed a strong tendency to persist in the tasks under these conditions. On average, drivers continued approximately 70 % of all tasks and took over with only one hand on the steering wheel. For the circumstances of the post transition phase (low criticality with no surrounding traffic) lateral control performance of the vehicle was negatively affected by this behavior [29].

Lockouts might be a useful approach to support drivers' NDRT disengagement in take-over situations. When the NDRT is locked out (i.e. blacked out screen) simultaneously with the RtI, reaction times can be improved together with the perceived safety [19]. Accordingly, NDRTs that are integrated with the automated driving system are considered favorable.

Apart from the task-related motivation to stay engaged in NDRTs also the person-specific attitude towards automation and NDRTs in general (e.g. individual level of trust) should be considered as it can significantly determine how the individual user deals with the demands of a NDRT in the context of a particular driving situation. Zeeb, for instance, found that self-chosen NDRTs during CAD reduced take-over times in a critical situation compared to obligatory NDRTs of the same type (2.4 s vs. 3 s) [30].

In addition, in another study drivers were aware of task-specific impairments and self-regulated NDRT disengagement accordingly. Visual-manual NDRTs with high subjective workload were canceled most strictly when there was a RtI. Individual self-regulation of arousal and workload seems to help maintain a suitable driver state [19].

So far, the available studies point towards an impact of motivational aspects – either due to the characteristics of the NDRT itself or due to the characteristics of the user.

III. SUMMARY

Taking over control from a CAD vehicle does imply several cognitive and physical steps, including RtI stimulus perception, information processing, restoring physical driver readiness and finally execution of the take-over action with stabilization of manual vehicle control. It is expected that those steps, which obviously depend on cognitive resources and the physical availability of the driver are influenced by the execution of different NDRTs. We therefore summarized results from different human factors experiments where participants had to take over control from a CAD vehicle engaged in different NDRTs.

Generally, the hypothesized effects of NDRTs on the driver state transition and the resulting take-over performance could be verified, although the size of effects differs strongly between studies, sometimes failing to find clear and systematic differences between experimental conditions. Apparently, the most critical issue is when a NDRT is preventing the perception of the RtI, potentially causing severe delays or complete omissions of a take-over. However, this problem is less related to characteristics of NDRTs but to a flawed automated driving system design. Another significant issue seems to apply for NDRTs which cause the driver to stay in (extreme) “out of driving” postures. A more frequent critical issue is related to hand-held devices, which need to be put away before manual intervention at car controls can effectively happen. Most of the studies see at least a small increase of reaction time measures when a task is conducted with a hand-held device. The magnitude of effects increases if the situations are less critical and therefore allow for more variance of the drivers’ reactions. With a higher number of critical situations and lower time-budgets, these effects decrease. Although impacts of NDRTs on visual and cognitive load or arousal level can often be verified the resulting effects on take-over performance cannot be reliably shown by different authors.

Overall, the findings of the present review match well with a meta-analysis of 93 studies investigating SAE automation level 2 or above [31]. The authors found strong increases in the mean take-over time for NDRTs performed on a hand-held device. Results were ambiguous for the tasks without hand-held devices, overall suggesting that engagement in visual or auditory task can also yield small increases in the mean take-over time.

Figure 1 graphically illustrates different response times from selected studies according to the NDRT induced impact on the transition process. In addition, different phases of the transition process are considered (first response/motor readiness/intervention). It can easily be seen that the size of the impact depends on the driver state induced by the NDRT, but also on methodological issues like testing environment and scenario design. The results reported by Marberger, for instance, differs significantly from the other studies as the take-over behavior was investigated in less critical and less urgent traffic situations in real traffic [15].

IV. DISCUSSION AND OUTLOOK

Overall, the effects of NDRTs on the take-over performance were less pronounced than one might expect and seem to be largely dependent on various methodological aspects. Since many studies differ in the way the investigated system and the test scenario was designed, it is difficult to pool individual results for a general conclusion. Gold for instance described how situational parameters interact with effects of the NDRT and thus have a significant impact on the take-over performance [13]. Schittenhelm came to comparable results [32]. Additionally he showed the significance of basic situational design parameters and used definition of take-over performance in the observed performance. Factors like urgency, predictability, criticality and complexity of the take-over scenario do not only determine the resulting time-budget for taking over control, they also affect the demanding requirements of the take-over process and which behavioral strategies is the most expedient solution in order to deal with the situation. For instance, in highly critical and urgent take-over scenarios subtle differences of the required driver state transition may not be detectable in terms of increased response time since all drivers are urged to react within the available sparse time-budget. Up to a specific limit, humans may be capable of accelerating the control transition, however, beyond this limit the quality of control will be sacrificed [33]

Occasionally hypotheses on negative effects of NDRTs on take-over performance were not only unconfirmed, but even the opposite effect was shown by the obtained data. In

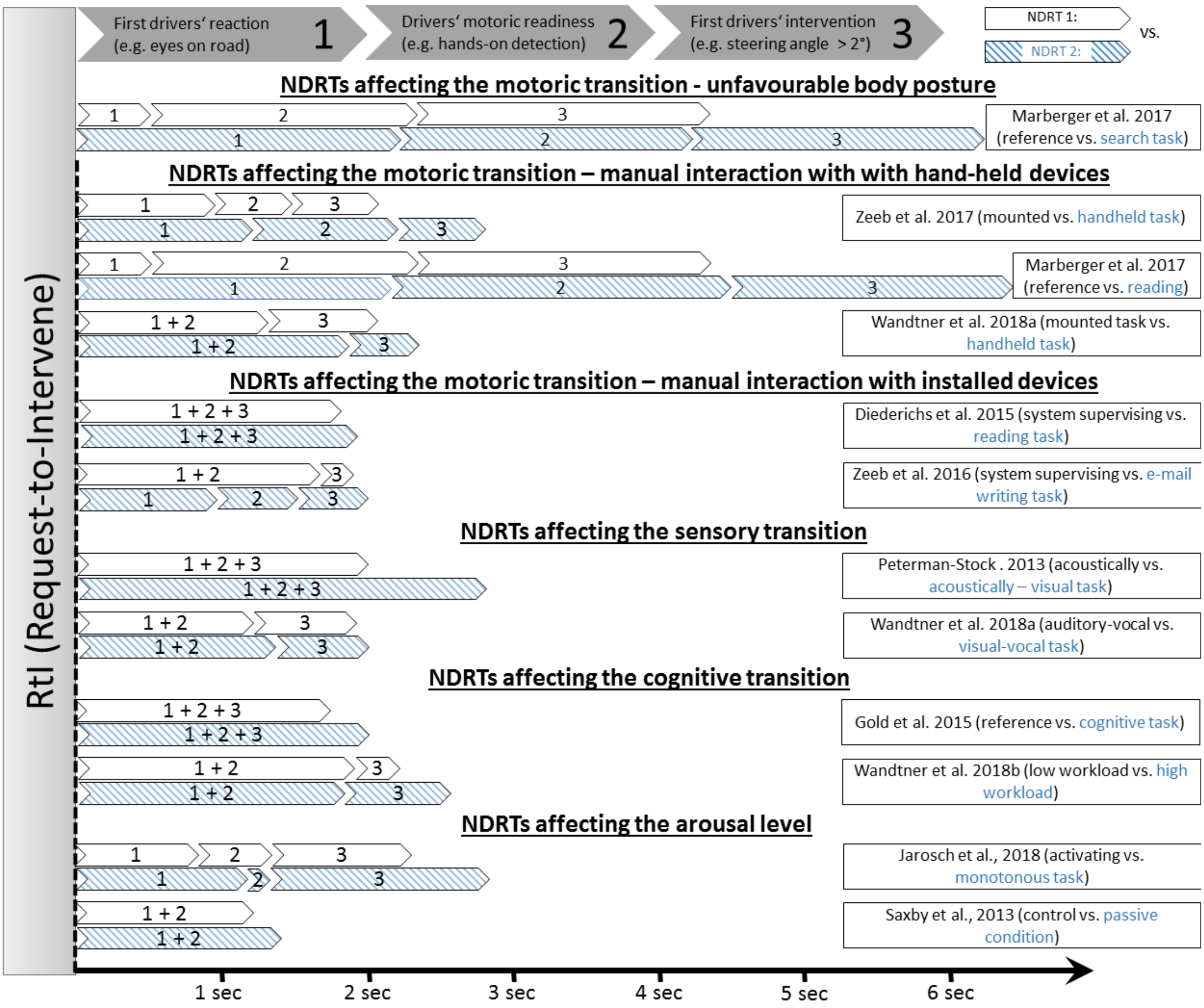

Figure 1: Overview of response times for different types of NDRTs from selected experiments (control vs. NDRT condition)

these cases NDRTs might have had multiple effects on the drivers' ability to take-over. Such, drivers' might be able to intuitively recognize a high demand of the NDRT and might (over-) compensate this unfavorable state by increased effort and resources, e.g. by reflexive and not least quick brake responses that counteract an increase of reaction times. Furthermore, NDRTs could also lead to a state of high mental activation and prevent a performance decrement due to underload or hypo-vigilance.

Another methodological issue is related to the test environment itself. The majority of studies was conducted in driving simulators (of different types and quality). Gold compared take-over times produced in a dynamic driving simulator with those shown from a corresponding validation study on a real test track [34] and found similar response times for a critical take-over scenario. Eriksson, however, showed significantly faster reactions in real traffic for uncritical take-over situations [35].

In this paper we have summarized and interpreted a selection of studies in order to understand the impact of NDRTs on the driver state and finally on the take-over process. First judgements about the relative impact of the resulting driver states have been made, but it seems to be a permanent challenge to provide a comprehensive overview of the entire process between human factors, environmental conditions and automation system design. This is partly due to methodological issues that prevent comparing different studies or creating strongly needed meta-analyses (see [31]). Therefore, the development of standardized methods is highly recommended for the future in order to guide the selection and instruction of test subjects, the design of the automated driving system and the characteristics of the take-over scenario. In addition, clear guidance should be given to researchers as to which take-over performance measures should be used and which statistical parameters have to be reported. Against this background, joint research within the human factors community would be greatly facilitated allowing researchers to derive more detailed and sustainable conclusions.

V. Limitations

Take-over performance assessment usually includes timing and quality aspects of the drivers' input. As in some of the reviewed experiments only reaction times were presented, this paper focuses on effects on timing aspects after a RtI only. Another limiting factor is that person-specific aspects concerning the engagement in different NDRTs and the trust in such automated systems was not considered in most of the studies. This can significantly determine how the individual user engages in different tasks during automated driving.

Also great care must be taken when transferring conclusions from a particular study to another context, e.g. looking at different system designs or scenario types. Many of the implemented automated driving systems in the reviewed studies will not match with the specific features a series-production system may come with (e.g. optimized design of the RtI, independent safety systems to assist in take-overs or system-initiated minimal risk manoeuvers). It is legitimate to simplify system designs for human factors research, but it is vital to validate a specific (new) system by dedicated studies for all relevant scenarios.

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