EVALUATION OF THE TACTILE DETECTION RESPONSE TASK (TDRT) IN A LABORATORY TEST USING A SURROGATE DRIVING SET-UP

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ABSTRACT:

This paper presents findings of a laboratory experiment which aimed at evaluating the sensitivity and intrusiveness of Tactile Detection Response Task (TDRT) methodology. Various single task, dual task and triple task scenarios were compared. The task scenarios consisted of a surrogate of driving (tracking task) and different secondary tasks (n-back, SuRT). The results suggested that the TDRT was sensitive to load levels of a secondary task which primarily demands for cognitive resources (n-back). Sensitivity to variations of visual-manual load could not be shown (SuRT). TDRT was also sensitive to different modes of primary task which varied in terms of cognitive load (visual vs. auditory tracking task). Results indicated intrusiveness of TDRT on primary task performance and secondary task performance depending on the type of underlying task scenario.

1 INTRODUCTION

The Detection Response Task (DRT) is a novel method based on a simple stimuli-response task similar to the well-known Peripheral Detection Task (PDT) (Martens and van Winsum, 2000). Both methods measure effects of secondary task load on driver attention and are intended for evaluation of in-vehicle information and control system interfaces. The participant presses a button in response to frequent stimuli presented at a randomly varied interval of 3 to 5 seconds. PDT uses LEDs for presenting visual stimuli. However, visibility of the stimuli can vary with lighting conditions. To avoid this limitation, the TDRT has been developed which presents a vibrating (tactile) stimulus to the participant's shoulder (Engström et al., 2005).

The experiment presented in this paper was part of a set of coordinated international studies which supported the ongoing development of an ISO standard on the DRT (ISO, 2013). The standardization is in process and there are still open questions with regard to sensitivity of the new method. Although the main focus of the TDRT is to measure effects of cognitive load, other types of secondary task load such as sensory-actuator demands and/or perceptual-motor demands may also affect TDRT results. Other open questions refer to intrusiveness, as the effect of TDRT on primary task and secondary tasks have not been systematically investigated so far. The current study was designed to examine these issues by focusing on the following research questions:

- To what extent is the TDRT sensitive to different load types and load levels of both primary task and secondary task?
- How does the TDRT affect the task performance of primary task and secondary task?

2 METHOD

The experiment was performed in the HMI laboratory of BASt.

2.1 Participants

22 licensed drivers (10 female, 12 male) volunteered in participating in the study. Age of the participants ranged from 19 to 64 years (mean 41.7, SD 13.9).

2.2 Surrogate driving task

A surrogate of driving was used as primary task in the experimental set-up. Participants had to perform a continuous sensomotor tracking task using a steering wheel as input device for manually controlling the tracking deviation. The task was to minimize tracking deviation over a given winding track.

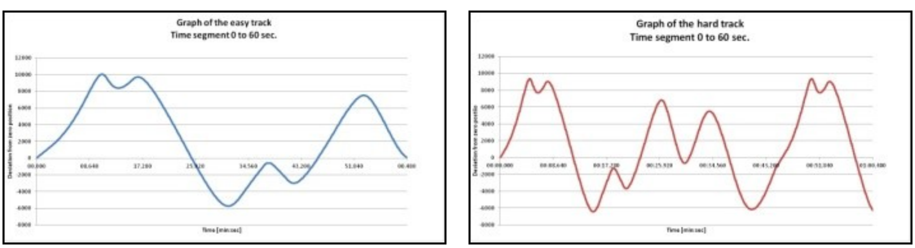

Fig. 1 Tracks used for the easy (left) and hard tracking task

Two types of tracking task with different modality of feedback to the participant were used: a) visual tracking, b) auditory tracking. Each tracking type was conducted at two difficulty levels depending on the bendiness of the track: easy = low bendiness, hard = high bendiness (Fig. 1).

Track and tracking deviation were visually presented to the participant when performing the visual tracking task. No visual feedback was presented to the participant during the auditory tracking task. In this case, the participant only received acoustic feedback indicating the extent of deviation (via tone frequency) and the direction of deviation, i.e. the side of the track where the deviation drifted to (via left/right speaker). The cognitive load imposed to the participant by the auditory tracking task, i.e. mental effort to control tracking deviation, was higher than for the visual tracking task (Gelau and Schindhelm, 2010). Thus including both modes of tracking task (visual, auditory) in the experimental set-up allowed for variation of primary task in terms of perceptual-cognitive demands, whereas the difficulty levels of tracking task (easy, hard) primarily varied the perceptual-motor demands of primary task.

2.3 Secondary tasks

Two secondary tasks were included in the study, the Surrogate Reference Task (SuRT) and the n-back Task. SuRT is a visual-manual search task, while the n-back Task imposes mainly cognitive load on the participant. Each secondary task was conducted at two load levels.

The SuRT (Mattes et al., 2007) required the participant to visually search a display for a target circle which was surrounded by a set of distractor circles. After detection of the target circle the participant responded by pressing the right or left key of a numeric keypad thus inducing a visual cursor moving to the target circle. Visual perceptual load was varied in terms of size of the distractor circles in comparison to the target circle (easy = large difference in size; hard = small difference in size) (Conti et al., 2014). The two SuRT levels additionally differed in terms of manual load. Only few keystrokes to reach the target were needed on the easy level, whereas the hard level required a higher amount of inputs. A new sub-task appeared on the screen as soon as the participant confirmed completion of the preceding sub-task.

During n-back Task (Mehler et al., 2011) a series of spoken digits were presented to the participant by a computer. In the 0-back condition (easy) the participant was required to orally repeat the last number heard. In the 1-back condition (hard) the participant had to repeat the second last digit.

2.4 TDRT

The tactile stimuli of the TDRT were presented by a small electrical vibrator which was fixed to the participant's shoulder or upper arm. A push button was attached to the participant's left index finger or thumb. The participant responded by pressing the push button against the steering wheel. TDRT stimulus was on for max. 1 second and switched off when a response was given. Time between stimuli was randomly varied between 3 and 5 seconds.

2.5 Experimental set-up

The participant's seat was centrally positioned behind the steering wheel and a LCD display. Track and tracking deviation were visually presented on the LCD display during visual tracking task. The acoustic feedback of tracking deviation during auditory tracking task was presented by two speakers, one on the left and the other on the right hand side of the LCD display. A small LCD display and a keypad were located on the right hand side of the participant. These elements were used for the operation of the SuRT task (Fig. 2).

Fig. 2 Experimental set-up for the triple task scenario which combines visual tracking task, SuRT and TDRT

2.6 Experimental design

A within-subject design was employed with primary task, secondary task and use of TDRT (with, without) as independent factors. Primary task included four levels which varied by modality (visual tracking, auditory tracking) and difficulty (easy track, hard track). Secondary task was varied by task type (SuRT, n-back, no secondary task) and difficulty (easy, hard). An incomplete factorial design was implemented which covered the research questions to be examined and resulted in various task scenarios (triple-task, dual-task, single-task scenarios).

Dependent variables where derived from TDRT measures (reaction time, hit rate), tracking task performance (root mean square deviation), SuRT (mean response time) and n-back performance (percentage of correct answers).

2.7 Procedure

Following a brief introduction, participants performed several trials for training of single-task and dual-task scenarios (tracking tasks and TDRT, but without secondary tasks). They then performed the main trials of the same task scenarios. In the second part of the experimental session dual-task and triple-task scenarios (visual tracking task, secondary tasks and TDRT) were applied. The participants again received some training on the scenarios in the beginning and then performed the main trials. The order of trials was randomized between participants.

3 RESULTS

TDRT response times

Mean hit rate was above .8 for all applied task scenarios and conformed to ISO-draft. Therefore, only mean response times are reported below.

Two-way repeated measures ANOVAs were used to identify the effects of task type (secondary: n-back, SuRT; primary: visual, auditory) and task difficulty (easy, hard) on response time. The level of α was set to .05. Partial η^2 is reported as a measure of relative effect size. Effects of primary task difficulty were analyzed with paired-samples t-Tests. Significance levels are displayed in Figure 3.

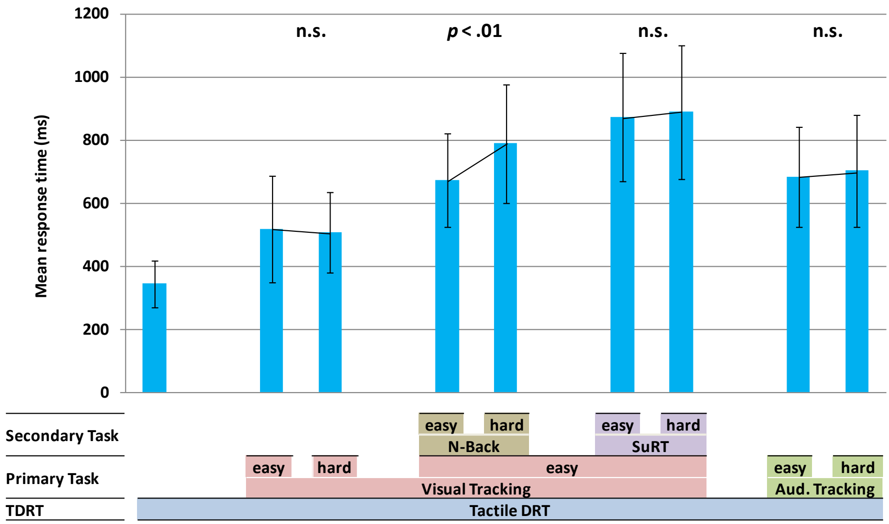

Fig. 3 TDRT response time in different task scenarios. Error bars: standard error of the mean

For the triple task conditions, the main effect of secondary task type was significant ($F(1,\ 21) = 31.1$, $p < .001$, $\eta^2 = .60$), as was the main effect of secondary task difficulty, ($F(1,\ 21) = 6.9$, $p < .05$, $\eta^2 = .25$). The interaction between these two factors was also significant, ($F(1,\ 21) = 10.1$, $p < .01$, $\eta^2 = .32$). The hard n-back task resulted in significantly increased TDRT response time compared to easy n-back task. There was no significant difference between TDRT response time for the hard and the easy SuRT. The dual-task scenarios (visual tracking + TDRT, auditory tracking + TDRT) did not display any significant differences between response times of easy and hard tracking task. However, tracking mode (visual, auditory) revealed a significant effect on TDRT response times ($F(1,\ 21) = 79.4$, $p < .001$, $\eta^2 = .79$).

Due to the violation of normal distribution, non-parametric tests (Wilcoxon signed-rank test) were applied for the remaining analysis of effects of TDRT on primary and secondary task performance. Significance levels are reported in the figures below.

Root mean square deviation of tracking task

Figure 4 shows the effects of TDRT (with/without TDRT) on tracking deviation.

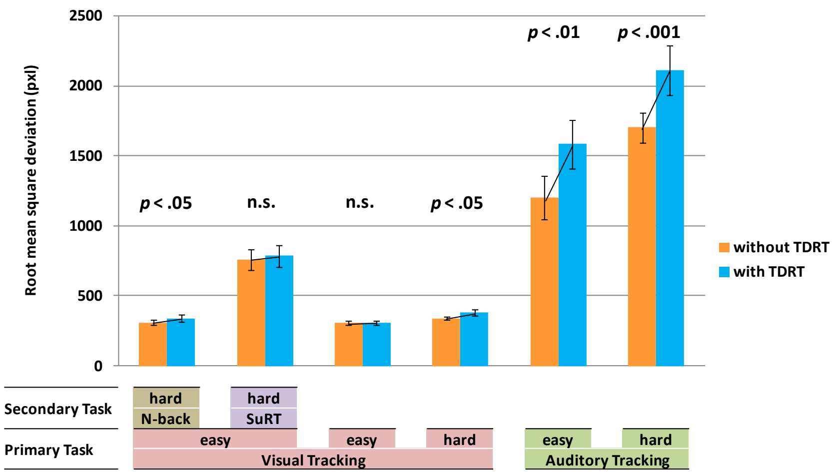

Fig. 4 Root mean square deviation of tracking task in different task scenarios. Error bars: standard error of the mean

The triple-task scenario consisting of n-back, visual tracking and TDRT resulted in a significantly higher tracking deviation compared to the task scenario without TDRT. Tracking deviation also increased when combining TDRT with SuRT and visual tracking, but no significant difference could be shown for SuRT difficulty. In case of task scenarios without secondary task, tracking deviation significantly increased when TDRT was performed concurrently with primary task, except for the scenario including easy visual tracking.

N-back performance

N-back performance (percentage of correct answers) was used as an indicator in the task scenario consisting of n-back task, visual tracking and TDRT (with/without). There was no statistically significant difference between conditions with and without TDRT.

SuRT response times

SuRT response time was used as an indicator of the task scenario which consisted of visual tracking, SuRT and TDRT (with/without). SuRT response time significantly increased when TDRT was applied (Fig. 5).

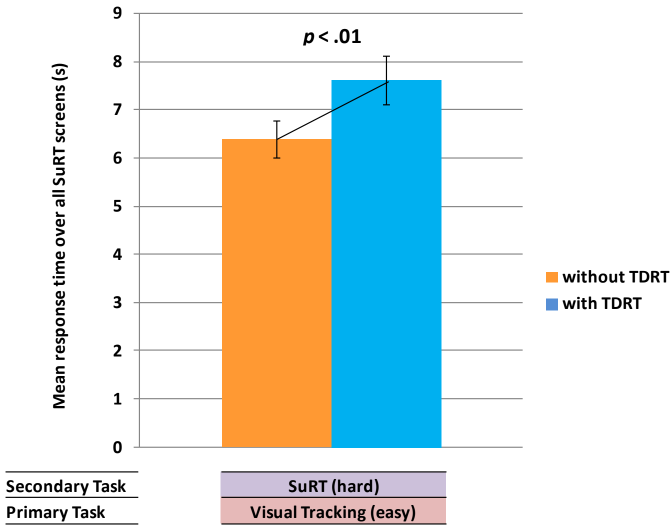

Fig. 5 SuRT response time in task conditions without TDRT vs. with TDRT. Error bars: standard error of the mean

4 CONCLUSION

Sensitivity of TDRT to different levels of cognitive load imposed to the participant was studied in task scenarios which contained n-back as a secondary task (TDRT + visual tracking + n-back). The TDRT response times for the two difficulty levels of this task were shown to be significantly different. The results suggest that TDRT is able to differentiate between different load levels of secondary tasks which primarily demand for cognitive resources.

No significant difference in TDRT response time could be shown between easy SuRT and hard SuRT (task scenario: TDRT + visual tracking + SuRT). However, there was a significant difference between the two secondary task types, SuRT and n-back. TDRT response times of triple task scenarios containing SuRT were significantly longer than those of triple task scenarios containing n-back task.

The results shown for n-back and SuRT are in line with findings from previous studies (Bruyas & Dumont, 2013; Young, Hsieh & Seaman, 2013). As both the SuRT and the TDRT demand for motor resources, a possible interference between SuRT and TDRT may be the reason why TDRT performance decreased. Further, due the possibility to self-pace the response frequency in the SuRT, the manipulation of visual-manual workload might not have worked in the intended way, i.e. there might not have been a difference in total visual load between the easy and hard condition. Future studies should address this issue by including tasks, where visual workload can not be self-regulated by the participant.

Another hypothesis of this study addressed sensitivity of TDRT to load levels of primary task in dual-task scenarios, i.e. tracking task + TDRT, but without secondary task. No significant differences between the load levels of tracking tasks in dual task scenarios could be shown in terms of TDRT response time. A difference in mental load between the two load levels of this tracking task had been shown in former studies using the Rating Scale of Mental Effort (RSME) as an indicator (Gelau and Schindhelm, 2010). The results of the current study suggest that the TDRT was not sensitive to this variation of tracking task load.

Mode of tracking task showed a large effect on TDRT response time. The TDRT response time of the auditory tracking task was longer than that of the visual tracking task. This result reflects the difference between the different task demands, as the auditory tracking task demands for more resources of working memory and uses cognitive resources more intensively than the visual tracking task. The results indicate that the TDRT is sensitive to differences in primary task demands, thus confirming findings of a driving simulator study performed by Diels (2011). However, with regard to the two load levels of auditory task which showed no significant difference, there seems to be a minimum difference in cognitive load beyond which the TDRT is not able to differentiate between load levels.

The results show some indications for intrusiveness of TDRT on primary task performance. It can be seen from Figure 4 that including TDRT to the task scenarios resulted in a decrease of tracking task performance, i.e. root mean square deviation increased. As both tracking task and TDRT are manually operated, one may assume that the decrement of primary task performance was caused by interferences between tracking task and TDRT due to the demand for motor resources. However, it seems that also mental demands of

TDRT intruded on primary task performance, especially in those cases where the cognitive demand of the underlying task scenario was high. This can be seen, when the scenario "visual tracking + n-back + TDRT (with/without)" is compared with the scenario "visual tracking + TDRT (with/without)": the task scenario visual tracking + n-back imposed higher cognitive load on the participant and showed a significant higher root mean square deviation when performed with TDRT.

The effect of TDRT on secondary task performance depended on the type of secondary task. TDRT did not intrude on n-back task performance. However, SuRT response time increased significantly with TDRT, thus indicating that TDRT intruded on SuRT performance.

Summarizing the results of this study, a recommendation of the DRT Task Force to not use TDRT for task scenarios with strong motor demands can be confirmed. The results suggest that TDRT is sensitive to effects caused by differences in cognitive load. Further experiments are recommended to confirm sensitivity for secondary tasks other than the n-back task.

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