Modifications of Driver Attention Post-distraction: A Detection Response Task Study

Oliver M. Winzer[1(✉)], Antonia S. Conti[1], Cristina Olaverri-Monreal[2], and Klaus Bengler[1]

[1] Institute of Ergonomics, Technische Universität München, Garching, Germany
{o.winzer,antonia.conti,bengler}@tum.de
[2] University of Applied Sciences Technikum Wien, Vienna, Austria
olaverri@technikum-wien.at

Abstract. Previous research showed that reaction time (RT) on driving related stimuli did not return to its performance level as per baseline immediately after periods of distraction. In this paper, a Detection Response Task (DRT) experiment is reported, implemented to investigate performance differences across different phases of driver distraction: before, during and post-distraction. Different task types were implemented (cognitive and primarily visual-manual) to venture whether these types were associated with differences in the speed at which drivers were able to respond to visual stimuli during the aforementioned phases.

Keywords: Post-distraction · Driver attention · Cognitive distraction · Head-mounted Detection Response Task · Secondary task · Dual-task

1 Introduction

Previous research has contributed to the standardization of different DRT variants (e.g., tactile, head-mounted, remote) [1]. The DRT is sensitive to online changes of attention resulting from additional task performance and measures these changes through a reaction time (RT) to a signal and a respective hit rate (HR). Prior research has used this method to detect the cognitive distraction from DRT RT and HR (e.g., [2–5]). Typically, the DRT is performed together with another task (or multiple tasks) and, therefore, previous research investigated the DRT performance while performing such tasks (e.g., [6–8]). This research is very important for designing human machine interactions. The known examples are the designing of In-Vehicle-Infotainment-Systems (IVISs) or creating standards and driving safety guidelines (e.g., Alliance of Automobile Manufacturers AAM, National Highway Traffic Safety Administration NHTSA).

However, one of the first research works that investigated the long term effect of tasks was presented in Strayer et al. [9]. They showed that RT during driving related stimuli did not return to its performance level as per baseline immediately after periods of distraction. They investigated different phone and car voice-command systems and concluded that drivers can be distracted up to 27 s after finishing a highly distracting task and up to 15 s after interacting with a moderately distracting system [9]. The

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classification of highly and moderate distracting was self-definite with a model presented in Strayer et al. [10].

Although previous DRT research concentrated on RTs and HRs during the performance of some other task, DRT performance prior to and after these tasks were performed has not yet been documented. The aim of this study was to holistically observe DRT performance prior to, during and post additional tasks performance to assess how driver attention changed across these phases. Figure 1 shows the qualitative outcomes of the DRT RT over the different phases of the experiments preformed. The behavior before and during the distraction phases can be very well estimated, because of the many previous studies (e.g., [6–8]). The phase after distraction, however, has not been yet investigated with the DRT and is of interest here. In terms of expectations, Fig. 1 shows a few possible outcomes in terms of RT prior to, during and after a phase of distraction.

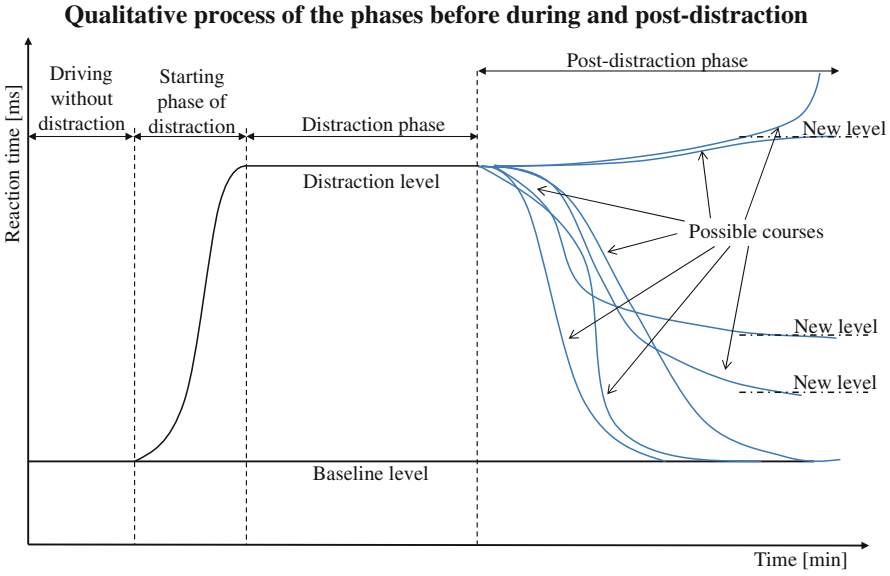

Fig. 1. Possible courses of DRT RT after finishing a secondary task

Additionally, driving performance was also measured during these phases to identify if the participants tried to compensate for the level of workload [11, 12]. According to Wickens [13], tasks that stimulate different modalities or use human resources other than that used by the main task (driving), can be combined and performed well together. If the driving task and secondary task have to share the modalities or human resources, the performance of one of these tasks will suffer. This means that the participants can neglect the driving task for a better performance in the other tasks (DRT or secondary task). Therefore, in order to check this performance tradeoff, the driving performance should be measured. To this end, an experiment was implemented where participants performed different (3) tasks (hereafter referred to as secondary tasks) while driving in

a simulated environment and at the same time responding to a visual signal (the head-mounted DRT; HDRT). To investigate performance differences across different phases of driver distraction, each task consisted of five performance phases: baseline, before, during, post and post-baseline. In the current paper, the phases with HDRT (before, during and post) are analyzed. Two cognitive tasks with a different level of load and one visual-manual task were selected. The spelling task was used as the cognitive task with a lower level of cognitive distraction. For the higher cognitive distraction, the n-back task (with the level of two) was carried out. The visual-manual task was the sorting for colored candies, designed after Bengler et al. [14].

2 Methods

2.1 Participants

Thirty-one participants (9 females, 22 males) between the ages of 22 and 56 years ($M = 28.16, SD = 7.29$), were involved in this study and each of them had a valid driver's license. Slightly more than half of the participants (17 of 31) reported that they had performed at least "sometimes" a secondary task while driving. One person reported to have color vision related deficiencies (red-green color blindness), but this participant was able to distinguish the different colors of candy wrappers and was retained for the analysis. All participants possessed a valid driver license. Seven of the 31 persons reported to drive less than 5,000 km (nearly 3,107 miles) per year and the other 24 participants reported driving more.

2.2 Apparatus

The experiment was conducted in the static driving simulator of the Chair of Ergonomics, Technical University of Munich (Fig. 2). Three of the six visual projectors displayed a 180°-degree view in the front of the BMW E64 mockup and the other three displayed the back view. Furthermore, six sound channel complete the experimental environment (Software: SILAB from WIVW GmbH, Würzburg, Germany).

Fig. 2. Setup of the static driving simulator of the Institute of Ergonomics, TUM

2.3 Tasks

Primary task: simulated driving. The primary task was a simulated driving task where participants drove on a highway with two lanes in each direction. The participants were instructed to follow a leading car on the right-hand lane with a speed of approximately 80 km/h and a distance of 50 meters. For a more approximate estimation of the instructed distance, the participants were able to orient themselves to street posts positioned at the side of the motorway, located 50 meters away from each other.

Secondary Task: Head-mounted Detection Response Task (HDRT). To measure the cognitive distraction of drivers the HDRT method was used. In the current experiment, a red LED was attached to participants' head at a distance of 12–13 cm from the left eye. The LED turned on every 3000–5000 ms and remained on for a duration of 1000 ms or until a response button was pressed. For responses to the presented signals the participants wore a button attached on their left index finger. Participants were instructed to respond as quickly and accurately as possible to the DRT. During distraction phases, participants performed all three tasks together: driving, DRT and one secondary task. The participants were instructed to drive safely at all times and to perform the other tasks (HDRT and secondary tasks) to the best of their ability.

Secondary Task: n-back, spelling and candy sorting task. Two different types of task were tested: two cognitive (with a variable level of cognitive load) and one visual-manual task. The two-cognitive tasks were the n-back [15] and a spelling task. The spelling task was intended to approximate a normal conversation, for example with someone on a hands-free cell phone, which according to Conti et al. [2] has a lower level of cognitive distraction potential than the 2-back task. The visual-manual type candy sorting task (modeled after a task reported in Bengler et al. [14]) was additionally performed.

The n-back task is a system-paced task. In the current experiment, a recorded audio file dictated four sequences of each 10 randomized numbers to the participants. The participants were instructed to repeat the numbers with a delay of two steps ($n = 2$). This means for the current experiment that per sequence a maximum of 8 numbers can repeated (in total 32 numbers). The duration for this task was approximately 2:14 min.

The spelling task was a self-paced task where participants were presented with up to 20 different words to be spelled aloud. The selected words were every day words (e.g., "Flugzeug" [German for "aircraft"]). All the participants were German native speakers. The duration for this task was 2:30 min. or until the last word was completed.

The candy sorting task was also self-paced. For this task, two containers were positioned on the front passenger seat. One of the containers was filled with four different colored candy (green, red, yellow and orange) and the other was empty. For this task, participants had to search for and move all candies of an instructed color into the empty container. After finishing the first color (red) they received a further color. Similar to the spelling task, this task was terminated after 2:30 min or until only one type of color was left.

2.4 Procedure

The session began with a demographic questionnaire and a multimedia presentation introducing and explaining the tasks to be performed in the experiment. A written handout with the instructions was also offered to each of the participants. Following this, participants acquainted themselves with the simulator and practiced all tasks. At this point they also had the chance to ask questions if anything was not clear. When participants were comfortable with the tasks and the experimenter deemed their performance acceptable, the experiment began. Throughout the experiment, each secondary task (3) was performed separately, one time each. DRT performance was measured before, during and after the secondary task was activated and driving performance was continuously recorded.

Except for the sections of the secondary tasks, all other tasks had the performance time of 1 min. As previously mentioned, the performance time of the secondary tasks are: 2-back task 2:14 min and spelling/candy sorting task 2:30 min.

2.5 Statistics and Dependent Variables

For calculating the average data (see Table 1) of the current experiment the range of data were adapted. Extreme values per participant per variable were excluded (top and bottom 2.5%) as suggested by Eckey, Kosfeld and Dreger [16]. As the same subjects were tested in the performed experiment, a 3×3 repeated measures ANOVA statistical approach was run to assess the effects of task and phase on mean DRT RTs.

The driving performance was assessed though longitudinal and lateral vehicle control. The longitudinal vehicle control was measured as the "following distance" (FD). This was rectified by the instructed safety parameter of 50 m. The standard deviation of lane position (SDLP) was used to measure the lateral vehicle control.

The quality of how the participants had performed the secondary task while driving was measured as presented in formula 1 [17]. Specifically, the quality (Q) of the 2-back task was measured as the quotient of the sum correctly responses to events (event) as a ratio to all possible numbers (task).

$$quality = event/task \tag{1}$$

3 Results

The Mauchly's test to verify the equality of the variances of the differences indicated that the assumption of sphericity for the HDRT RT had been violated, $\chi^2\,(2) = 21.413$, $p < .001$. Hence the Greenhouse-Geisser correction ($\varepsilon = .657$) was applied to reduce the error rate for the effect on RT. A significant effect of phases was found: $F\,(1.314, 39.419) = 144.518$, $p < .001$. The Bonferroni post hoc test was significant ($p < .001$) between all phases. For the other main effect of task type, was no significant effect identified.

Table 1. Average and standard deviation for measured data (N = 31)

Tasks	Phases		RT	HR	SDLP	FD*	Q
			[ms]	[%]	[m]	[m]	[%]
2-Back	Driving (D)	M	–	–	0.260	7.221	–
		SD	–	–	0.079	14.397	–
	D + HDRT	M	330.487	98.491	0.253	7.575	–
		SD	70.660	3.604	0.098	13.605	–
	D + HDRT + Task	M	600.074	84.381	0.224	3.732	91.810
		SD	161.635	12.364	0.070	13.705	8.855
	D + HDRT	M	362.473	98.338	0.235	1.143	–
		SD	70.390	3.163	0.101	12.923	–
	Driving	M	–	–	0.270	4.415	–
		SD	–	–	0.103	13.235	–
Spelling	Driving	M	–	–	0.264	5.384	–
		SD	–	–	0.098	12.348	–
	D + HDRT	M	319.097	99.109	0.252	7.695	–
		SD	66.0768	2.268	0.105	11.802	–
	D + HDRT + Task	M	537.162	92.545	0.222	4.741	89.739
		SD	144.328	7.830	0.095	13.765	9.307
	D + HDRT	M	344.011	99.379	0.250	3.676	–
		SD	70.536	1.862	0.092	11.648	–
	D	M	–	–	0.253	2.148	–
		SD	–	–	0.112	11.763	–
Sorting Candy	Driving	M	–	–	0.234	3.204	–
		SD	–	–	0.088	9.953	-
	D + HDRT	M	321.120	99.109	0.239	7.988	–
		SD	62.120	2.268	0.080	11.683	-
	D + HDRT + Task	M	559.7116	90.118	0.566	5.795	84.858
		SD	136.062	10.991	0.200	18.823	10.466
	D + HDRT	M	390.398	97.057	0.275	11.260	–
		SD	104.015	4.526	0.114	15.663	–
	Driving	M	–	–	0.236	6.926	–
		SD	–-	–	0.097	13.651	–

HDRT = Head-mounted Detection Response.
HR = Hit rate.
SDLP = Standard Deviation Lane Position.
Following Distance: *FD** = *FD*–50 m.
Q = Quality of secondary tasks.

Table 1 shows the means and standard deviations of the five measured performance phases for 31 participants. To comply with the recommendation of the ISO 17488:2016 [1] valid RTs are only possible within the range between 100–2500 ms. Outside of this range they were declared as a cheat (between 0 and 100 ms) or a miss (over 2500 ms) [1]. The raw data show no cheats. Another indicator for cheating is the button-down rate, which shows

how often the response button has been pressed in relation to the number of stimuli presented. For example, it is possible that a participant pushed the button constantly. The analysis of this measurement indicates that there was no observable attempt to cheat. The highest button down rate of one participant was 137% the average was between 100% and 108% depending on the phases, which is acceptable. The ISO 17488:2016 [1] includes an another condition for valid RTs: the average of HR must be over the level of 80% per phases to measure a valid RT. This requirement was met in all phases.

No participant had a lower average safety distance (longitudinal vehicle control) then 50 meters in average. The highest corrected average distance was measured in the post-distraction phases of the sorting candy task. The phases of during the sorting candy task had the greatest standard deviation. While the phases of post-distraction of the 2-back task the lowest FD* was measured. During the visual-manual task the worst mean value of SDLP was recorded. The quality of the three secondary tasks were measured: sorting candy task 85%, spelling task 87,9% and 2-back task 92%.

The following three Figs. (3, 4 and 5) show the detailed performed RT of each presented signal on average. Each chart also presents the mean RT of the three phases (before, during and post-distraction) per secondary task. In the diagrams, it can be seen that during secondary task performance, the mean RT of the counters varies more than before and post-distraction. Furthermore, for the candy sorting and spelling task the first three signals are clearly over the average of the respective part.

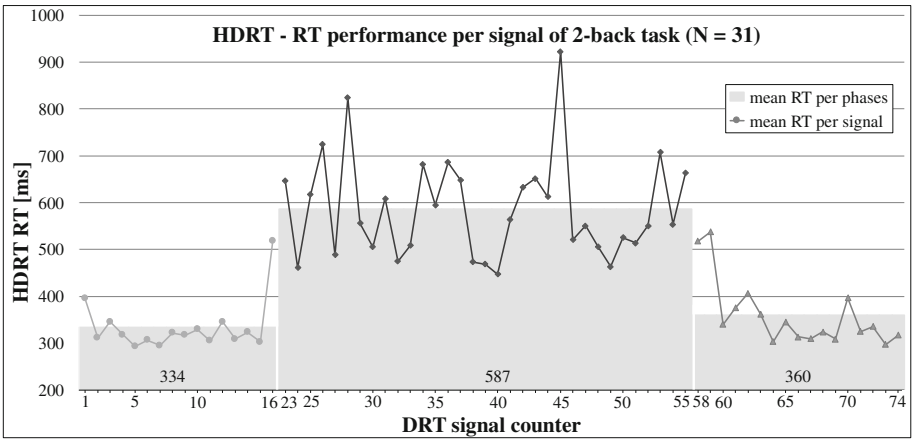

Fig. 3. Reaction time performance of HDRT per signal and phases (before [left], during [middle] and post [right]) 2-back task (N = 31). Number of signals per person varied slightly due to the signal being presented at a random interval between 3000–5000 ms.

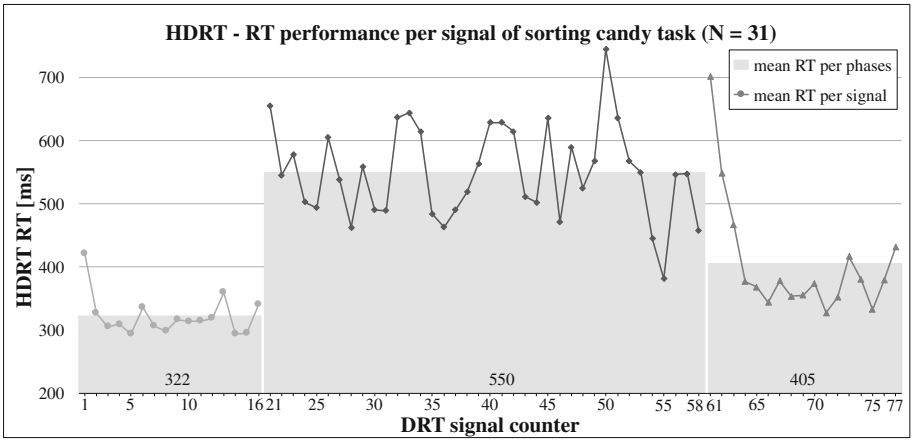

Fig. 4. Reaction time performance of HDRT per signal and phases (before [left], during [middle] and post [right]) sorting candy task (N = 31). Number of signals per person varied slightly due to the signal being presented at a random interval between 3000–5000 ms.

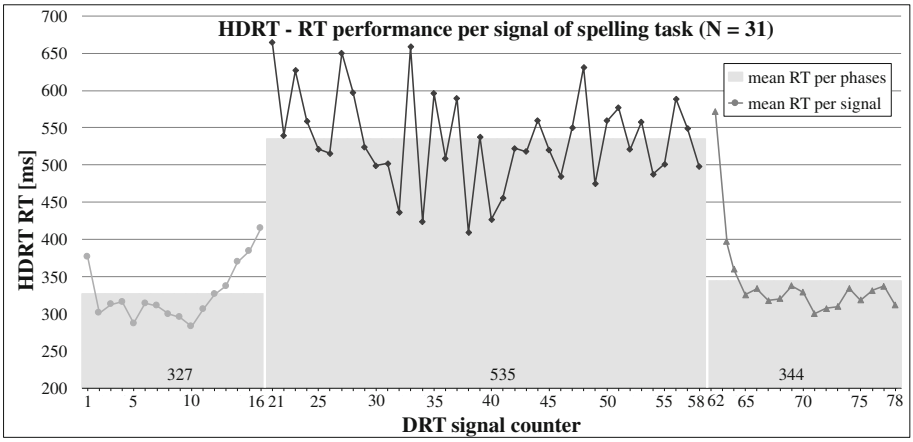

Fig. 5. Reaction time performance of HDRT per signal and phases (before [left], during [middle] and post [right]) spelling task (N = 31). Number of signals per person varied slightly due to the signal being presented at a random interval between 3000–5000 ms.

Figure 6 shows the total HDRT performance evaluation of the current investigation. Both the mean HDRT RT and HR are depicted. Independently of the distractions tasks, all averages RTs of post-distraction phases are higher than their associated baseline. It can also be seen, that during the distraction phases the mean RT is higher and the HR is lower than before.

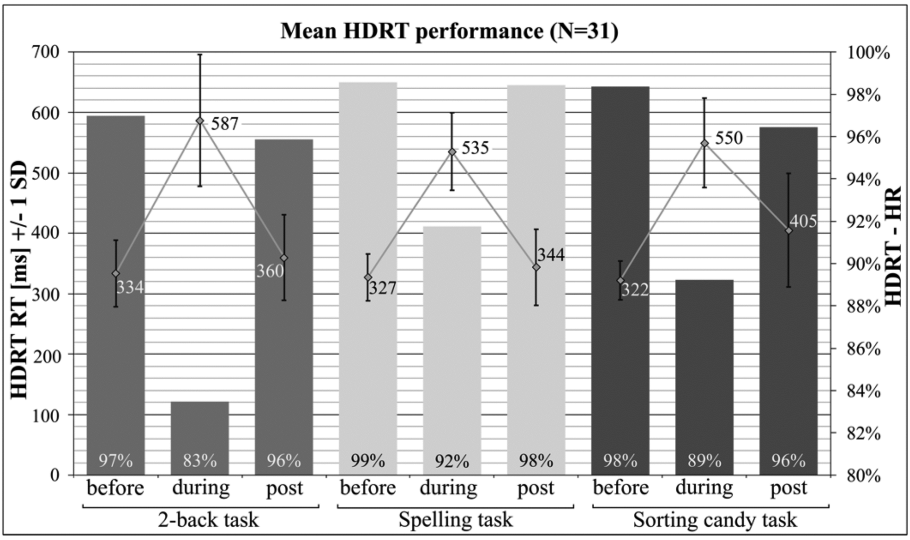

Fig. 6. Mean HDRT RT (±1 SD) and HR Performance overview (N = 31)

4 Discussion

The aim of the current investigation was to measure changes in driver attention post-distraction. Mainly the measured HDRT RT and HR may be used for a conclusion about the cognitive distraction (e.g., [1–4]). Additionally, a lateral and longitudinal parameter of vehicle control were defined (FD and SDLP) to ensure that the participants drove safe and no compensation effects are present. For this reason, the quality of secondary task was also assessed. With these five factors, it should be possible to estimate the post-distraction behavior.

The current study supports previous findings [9] where task performance required additional time to return to its baseline level after a period of distraction. In line with previous research, the findings of mean HDRT RTs and standard deviations before and during the distraction phases are similar to Conti et al. [2]. Comparing the measured mean RTs before the 2-back task there was a difference between 20 up to 30 ms; during the 2-back task there was a difference of nearly 40 ms to Conti et al. [2]. Therefore, it can be assumed that the presented results of during distraction phases are comparable to previous findings. The analysis of the quality of secondary task performance indicated that all participants performed the secondary tasks well and no participant tried to neglect in one of the tasks. This means that no participant tried to cheat by neglecting the secondary task for a better performance in DRT or driving.

The total overview of HDRT mean performance (see Fig. 6) shows that there are differences in RTs and HRs both before and after distractions. The Bonferroni post hoc test identified that there are significant differences of the RTs between all phases, but especially the difference between before and post-distraction are interesting. This means that the participants did not have the same average RT in a period of 1 min after a

distraction than before. Furthermore, this performance difference is independent of the kind of secondary task. The lateral vehicle control is thus recognizable that during the visual-manual task the SDLP is almost twice as high like the other phases (see Table 1). For the FD, it is striking that highest average value is achieved in the phase post-distraction of sorting candy. Regarding the high FD at the post-distraction phases of sorting candy (see Table 1) is no clear reason indicated. Perhaps the participants used this phases to improve their decremented lateral control during the task. Another possibility could be that the participants started to relax after the task and so they neglect longitudinal control.

Looking at the three detailed Figs. (3, 4 and 5) shows a similar image. In all three cases the best mean performance was recorded in the phases before the distraction. During each distraction, the mean RTs between the signal counters strongly fluctuated. Perhaps this indicates a higher level of cognitive distraction comparable to the higher standard deviation in phases during secondary task performance. The parts of the Figs. (3, 4 and 5) regarding the post-distraction phases show that over the time of 60 s the mean reaction time is higher than before. Especially, the visual-manual task (see Fig. 4) is critical. In this case, we can see that the RT of all signal counter (nr. 61 to 77) are higher than the mean of the phases before distraction (322 ms). Furthermore, the first RT of post-distraction (nr. 61) is over and the second one (nr. 62) is on the average level of during distraction (550 ms). This results suggest that visual-manual tasks have a longer influence on the RT and thus also on the distraction like the cognitive tasks. In comparison to the two cognitive tasks, the mean RTs per signal in the post-distraction phase for the visual-manual task do not return to the overall mean RT level recorded in the pre-distraction phase. The 2-back task has a higher fluctuation in the post-distraction phase than the spelling task. Hence, from the higher overall mean HDRT RTs on post-distraction phases comparing to phases before, can be deduced that a modification of driver attention post-distraction has occurred.

5 Conclusion

The current study used the HDRT method static driving simulator to investigate the effect of task and phase on DRT performance. Thirty-one participants performed three different secondary tasks (two cognitive [n-back and spelling] and one visual-manual [candy sorting]) while also performing a simulated driving task and the HDRT. HDRT performance was measured during three phases: prior, during and after distraction. The results show that mean HDRT RTs were significantly affected by task phase. This indicates that the participants did not have the same mean RT before and after a period of distraction despite which secondary task was performed. In terms of real-world relevance, the reported data suggests that secondary tasks may affect the driver even after a task/distraction phase has been completed.

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